IV.H.2 Fuel Cell Vehicle Systems Analysis

Tony Markel (Primary Contact), Keith Wipke, Kristina Haraldsson
National Renewable Energy Laboratory
1617 Cole Blvd.
Golden, CO 80401
Phone: (303) 275-4478; Fax: (202) 586-9811; E-mail: Tony_Markel@nrel.gov

DOE Technology Development Manager: Nancy Garland
Phone: (202) 586-5673; Fax: (202) 586-9811; E-mail: Nancy.Garland@ee.doe.gov

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 HFCIT development efforts at the vehicle level (both current status and future goal evaluation).
- Highlight potential system-level solutions to technical barriers.

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 Research, Development and Demonstration Plan:

- D. Fuel Cell Power System Benchmarking
- R. Thermal and Water Management

Approach

- Integrate existing fuel cell component and vehicle models and develop to enhance systems analysis capabilities.
- Models are used to:
  - Address thermal and water management issues using real driving profiles and a range of environmental conditions.
  - Assess impact of technical team targets at component and system level.
  - Quantify the benefits of innovative fuel cell system concepts to address cost and volume challenges.

Accomplishments

- Completed the development of a detailed parametric fuel cell system model in Simulink that is fully integrated with ADVISOR™*.
- Completed enhancements to the Technical Targets Tool, including expanded reference vehicle database, refined focus on maximizing national petroleum consumption reduction, and incorporation of a predictive penetration model.
- Presented an innovative supercharged fuel cell system concept that will potentially reduce the cost and increase the specific power and power density of current fuel cell system technology.
- Analyzed the potential for thermal and water management challenges in fuel cell vehicle design under typical driving conditions and a range of ambient conditions.

*ADVISOR is a trademark of the Midwest Research Institute.

- Fuel consumption increases by 14% when driving at 3000 m vs. 0 m elevation.
- Matching the range of ambient conditions with the range of operating conditions leads to fuel cell balance of plant (BOP) component sizing requirements.

Future Directions

- Perform fuel cell hybrid vehicle system optimization – work with FreedomCAR fuel cell, energy storage, hydrogen storage, and vehicle systems technical teams to develop pathways toward efficient and sustainable vehicles.
- Using Technical Targets Tool, assess how well fuel cell hybrid vehicle technology will compete against conventional and combustion engine hybrid vehicles for future market share.
- Apply robust design techniques to derive potential fuel cell vehicle system design scenarios that address thermal and water management challenges over a range of environmental conditions.

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. Recent efforts build upon and expand the capabilities of this activity. We developed, integrated, and applied a fully parametric fuel cell system model into ADVISOR that provides the ability to gain a better understanding of the water and thermal management challenges that might be encountered during fuel cell vehicle operation over typical drive cycles and a range of environmental conditions. Additionally, the Technical Targets Tool, introduced last year, was significantly enhanced and was used to assess the program technical targets. 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. Future studies will try to find ways to resolve the water and thermal management issues during vehicle operation. Finally, we are working to develop collaborative relationships with industrial partners to ensure that the modeling predictions are accurate and provide valuable insights into resolving critical technical barriers.

Approach

It has been our approach to develop and link to existing component and vehicle models to enhance our systems analysis capabilities. We work with industry to share and apply robust design techniques, optimization tools, and Computer Aided Engineering (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 has been an 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 level.

Results

We have developed and integrated a fully parametric fuel cell system model into ADVISOR. This model originated through our collaboration with Virginia Tech and is based on its contributions to the FutureTruck competition. The model includes a predictive polarization model of the fuel cell and complete models for the balance of plant. It allows us to model systems with variable pressure operating strategies and performs thermal and water balance analyses on the system. The model was applied to

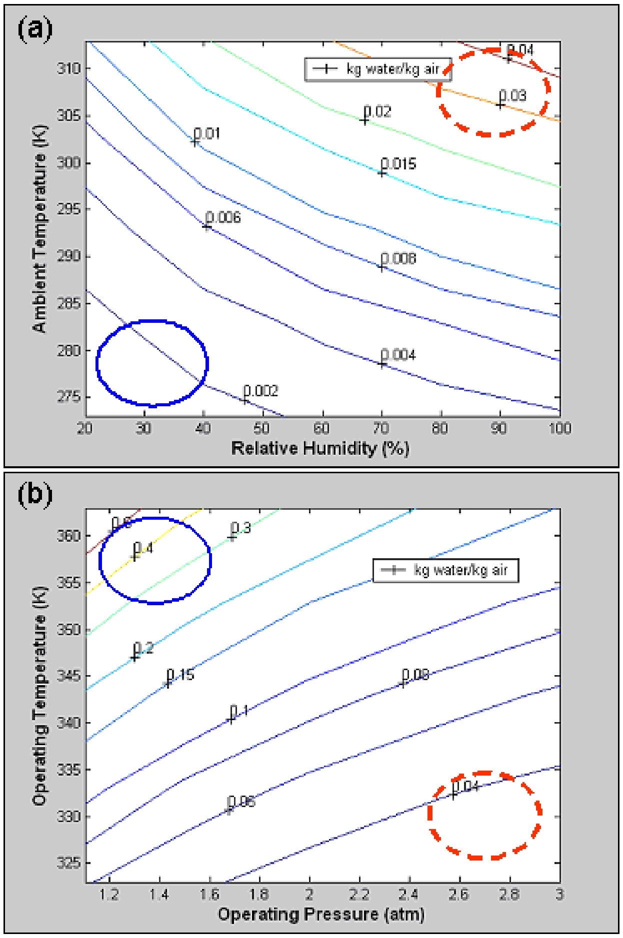

Figure 1. Matching Water Availability and Requirements a) water available in ambient air, b) cathode humidification requirements (80% RH)

assess the impacts of environmental conditions on fuel cell hybrid vehicle performance over typical drive cycles. The results indicated a 14% increase in fuel consumption when elevation increased from 0 m to 3000 m. Additionally, water balance analysis indicated that considering the range of ambient conditions and the range of operating conditions is critical. Under the worst scenario (cold and dry environment; high temperature and low pressure operation), the air will contain less than 1% of the water needed for operation so that a substantial water recovery system will be required (see solid circles in Figure 1). The dashed circles in Figure 1 represent the best combination of conditions, where we might have ~80% of the water needs met by water in the ambient air.

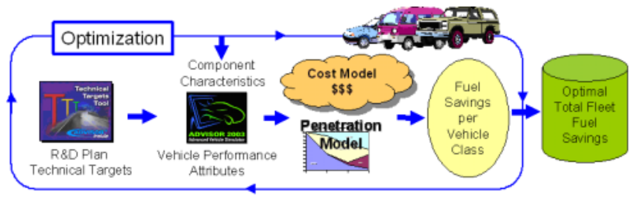

Figure 2. Technical Targets Tool Approach Focused on Maximizing National Fleet Fuel Savings

The first version of the Technical Targets Tool was introduced last year. This year major enhancements to the tool were completed. These enhancements include an expanded reference vehicle database, a new optimization approach focused on reducing national oil consumption over time (see Figure 2), and a routine for determining expected vehicle market share based on vehicle attributes (e.g. acceleration, cargo volume, fuel economy, cost, etc.). The tool was used to highlight the importance of achieving all of the hydrogen program technical targets. In one study, only when the all of 2010 volumetric technical targets for the fuel cell system and hydrogen storage system were achieved did the powertrain volume not exceed the available packaging space. Future results will assess how well fuel cell hybrid vehicles will compete (based on the technical targets) against the other available vehicle technologies including gasoline and hydrogen combustion engine hybrid electric vehicles.

The implementation of a detailed parametric fuel cell model in ADVISOR also supports our exploration of innovative systems concepts. We collected component data and performed systems analysis under typical driving conditions to assess the potential for fuel cell supercharging. Essentially, boosting the power output of the system for short durations as needed during the driving profile. As a result, significant system cost, volume and mass savings can be obtained. In Figure 3, the light colored bars are the 2005 technical targets. In comparison, the dark bars represent a supercharged system using 2005 technology. The supercharged system concept gets closer to achieving the 2010 targets (red dashed line). Several system integration issues still need to be resolved and will be addressed in follow-on activities next year.

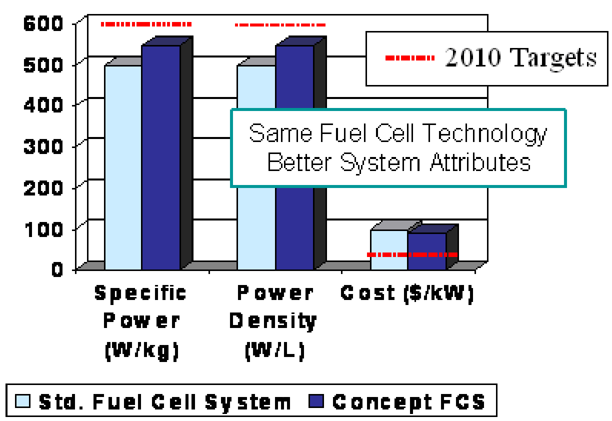

Figure 3. Supercharged Fuel Cell System Closes the Gap between 2005 and 2010 Targets

Conclusions

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

- Analysis of water and thermal management over typical drive cycles under a range of environmental conditions highlighted the influence of system attributes on fuel economy and component operation. Activities next year will expand in this area to consider robust design techniques to make the system as a whole more efficient and effective.
- Achieving both the fuel cell and hydrogen storage 2010 targets are necessary to satisfy small and mid-size cars packaging requirements
- A supercharged fuel cell system has the potential to move fuel cells one step closer to reality. Future effort will focus on involving industry partners in resolving any potential barriers to system implementation in a vehicle scenario.
- An enhanced version of the Technical Targets Tool was used to predict impacts on national fuel consumption resulting from DOE research program efforts applied across multiple vehicle platforms. The results highlighted the importance of meeting both the hydrogen storage and fuel cell system technical targets to provide feasible vehicle scenarios.

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.

FY 2004 Publications/Presentations

1. Markel, Tony; Wipke, Keith; Haraldsson, Kristina. "Fuel Cell Vehicle Systems Analysis." Presented at *Hydrogen, Fuel Cells and Infrastructure Technologies Annual Program Review.* Philidelphia, PA. May 25, 2004.

2. Markel, Tony; Haraldsson, Kristina; Wipke, Keith. "Thermal Management Characteristics For A Fuel Cell Hybrid Vehicle Under Realistic Driving Demands." Presented at *Fuel Cell Seminar.* Nov. 4, 2003.

3. Haraldsson, Kristina; Markel, Tony; Wipke, Keith. "Ambient Conditions and Altitude Effects on PEMFC Hybrid Vehicle Performance." Presented at *20th Electric Vehicle Symposium*. Nov. 18, 2003.

4. Markel, Tony; Zolot, Matthew; Pesaran, Ahmad. "Energy Storage System Requirements for Hybrid Fuel Cell Vehicles." Presented at *4th International Advanced Automotive Battery Conference.* San Francisco, CA. June 1-4, 2003.