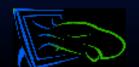


Fuel Cell Vehicle Systems Analysis

Tony Markel, Keith Wipke, Kristina Haraldsson, Ken Kelly, Andreas Vlahinos National Renewable Energy Laboratory

May 20, 2003

DOE Hydrogen and Fuel Cell 2003 Annual Merit Review Berkeley, California





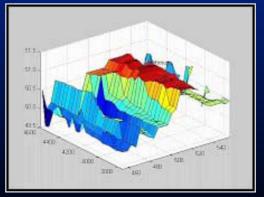


Outline

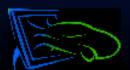
- **Objectives**
- **Approach**
- Timeline of Highlights
- Accomplishments
- **Addressing Reviewer Comments**
- **Industry Interactions**
- **Future Plans**
- **Summary**

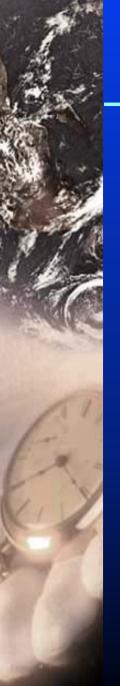






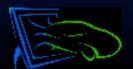






Objectives

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





Approach

 Develop and link to existing component and vehicle models to enhance systems analysis capabilities

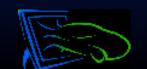
Work with industry to apply robust
 design techniques, optimization tools,
 and CAE tools to overcome technical barriers



 Study benefits of fuel cell system and vehicle design scenarios and transfer to industry



 Assess impact of various technical team targets at component level







Highlights and Milestones

techniques to fuel cell components

Planned Completed

* = milestone

6/02	Presented FC response time study results at FutureCar Congress
10/02	Presented fuel cell system model evaluation study at 202 nd Electrochemical Society Meeting
10/02	Incorporated two detailed fuel cell system models into ADVISOR vehicle simulation program
11/02	Presented the Technical Targets Tool to DOE
3/03	Developed FEA models of fuel cell components and successfully demonstrated the application of robust design techniques
4/03	Presented results of 4 fuel cell system studies at ASME/RIT Fuel Cell Technology Conference
6/03	Results of gasoline reformer warm-up fuel economy impacts study to be presented at 2003 Future Transportation Technology Conference
7/03*	Expand database of fuel cell components
9/03*	Summarize the influence of key fuel cell program technical targets on fuel consumption reduction
9/03	Complete initial applications on reformer, end-plate design,
	stack pressure profile and high-temperature stack design
9/03*	Publish technical report on methodology for applying robust design



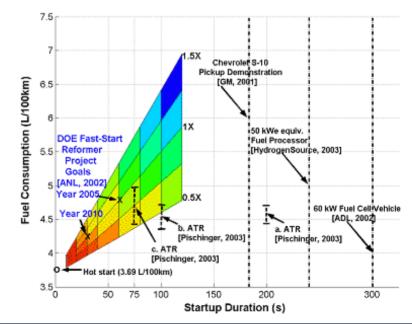
Accomplishments

Analyzed Fuel Economy Impacts of Gasoline Reformer Warm-up

- A. Allow warm-up period before FTP starts
- B. Design reformer and fuel cell system to provide minimum power requirements for FTP cycle with no energy storage
- C. Hybridize to balance out drive cycle requirements with achieving reasonable/efficient reformer startup time



Warmup Time (s)	(kW)	Cum. Raw Energy [Usable] (Wh)	Window (%)	Pack Total Energy (Wh)
30 s	13.5	15	20	75
60 s	13.5	45	20	225
195 s	25.7	158	20	790
10 min	25.7	658	20	3290
Toyota Prius	25	1	~5	1781
Honda Insight	6	1	~10	936
Honda Civic	n/a		n/a	864



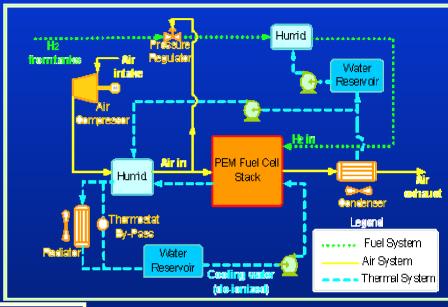
 Drive cycle traction power and energy demands satisfied with relatively small battery

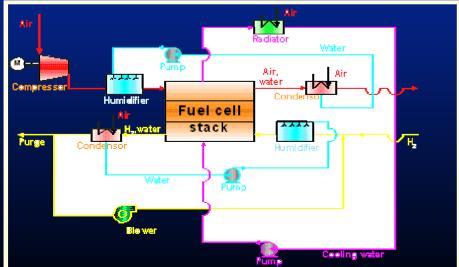
 Fuel economy penalty significant if duration is long or fuel rate is high



Accomplishments Two Detailed Fuel Cell System Models in ADVISOR







the Virginia Tech Model

the KTH Model

AccomplishmentsRange of Model Complexity in ADVISOR

More Detail

*** User-defined model ***

- · configurable subsystem structure
- ability to link to fuel cell models in other tools (e.g. Saber, Simplorer,...)

KTH Model

- Springer et. al. fuel cell model
- thermodynamic library
- balance of plant components
- water transport in MEA

VT Model

- parametric polarization curve
- system thermal model
- balance of plant components
- variable operating pressure

Less Detail

Simple Polarization Curve

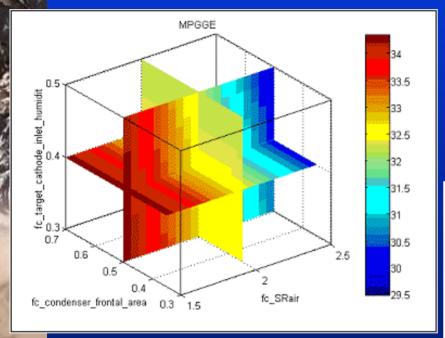
- defined current and voltage
- simplified balance of plant

Net Power vs. Efficiency

- single curve
- scalability



Accomplishments Water Balance Sensitivities Assessed



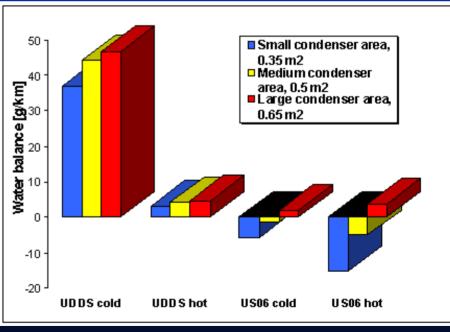
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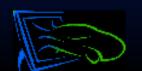
sensitive to cold/hot start

US06:

sensitive to condenser size

- Assessed water balance sensitivity in vehicle environment (drive cycles)
- Impact of condenser size and startup conditions quantified

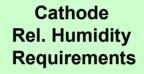


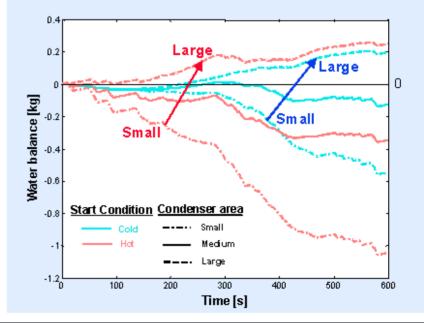




Accomplishments Water Balance Variability on the US06 Drive Cycle 0.6 0.5 0.4 Low RH Water balance [kg] 0.2 Medium RH High RH -0.1 100 200 300 400 500 600 Time [s] Condenser Area **Better WB at low temperature operation**

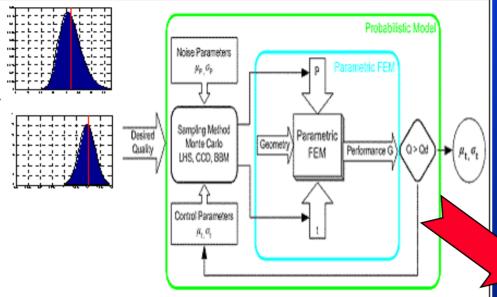
Positive WB at low relative humidity requirements







Accomplishments Robust Designs of Fuel Cell Components

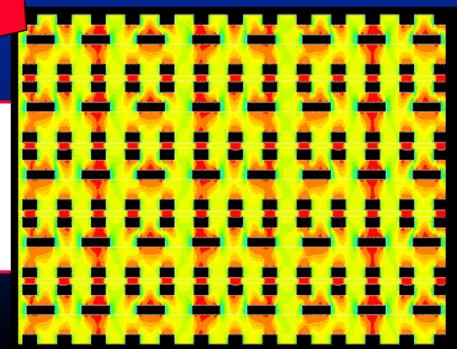


Collaborative effort with industry to apply <u>robust design</u> techniques to fuel cell components:

- Parametric FEA modeling
- Probabilistic design and optimization techniques integrated with FEA
- Topology optimization for reduced mass and improved pressure profiles

Solutions to real-world technical issues:

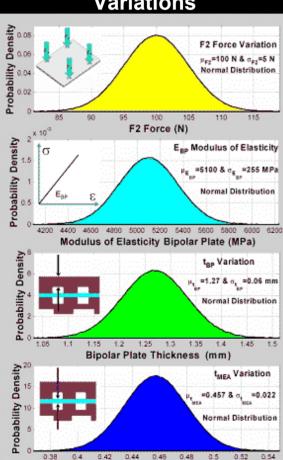
- improved thermal mechanical fatigue of ATR
- analyzed thermal efficiency of ATR
- improved pressure distribution within stack
- quantified sensitivity of design factors to nonuniform MEA pressure distribution



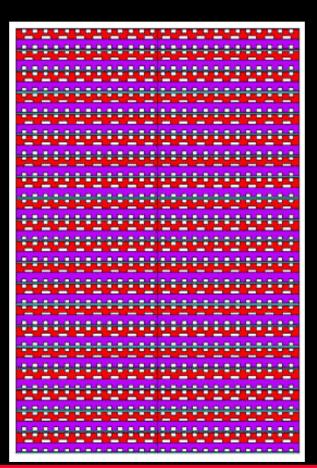


AccomplishmentsRobust Designs of Fuel Cell Components

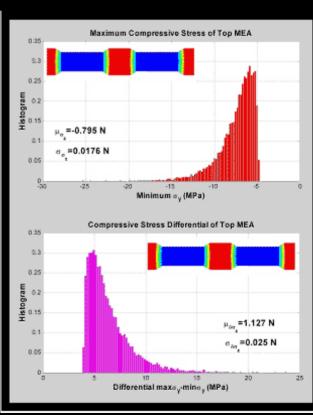
Statistical Distribution of Material and Manufacturing Variations



Parametric FEA Model of Fuel Cell Stack

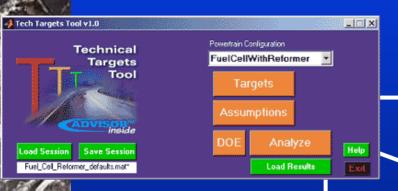


Statistical Distribution of Output Performance Measures



Published methodology for assessing the "Effect of Material and Manufacturing Variations on MEA pressure Distribution" (co-authored with Plug Power)

Accomplishments Technical Targets Tool Developed



Target Values

Individual Targets

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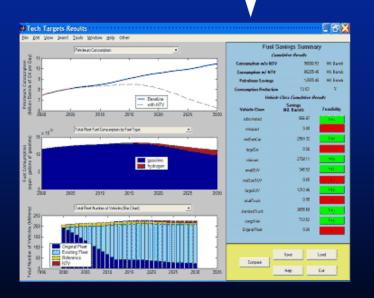
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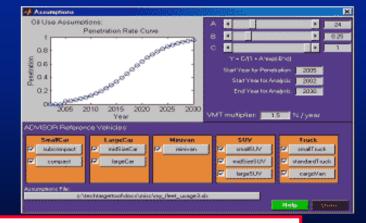
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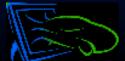
Engel C

Model Parameters

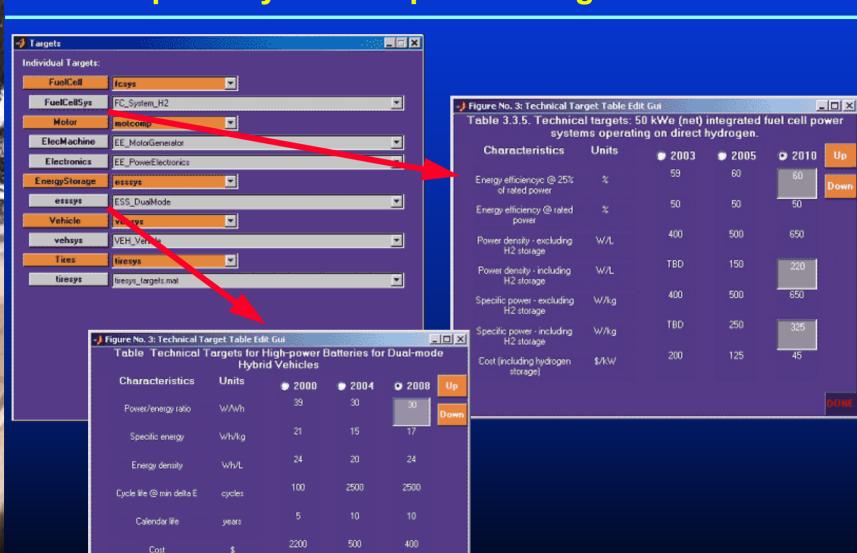




Quantifies potential impact of DOE programs.

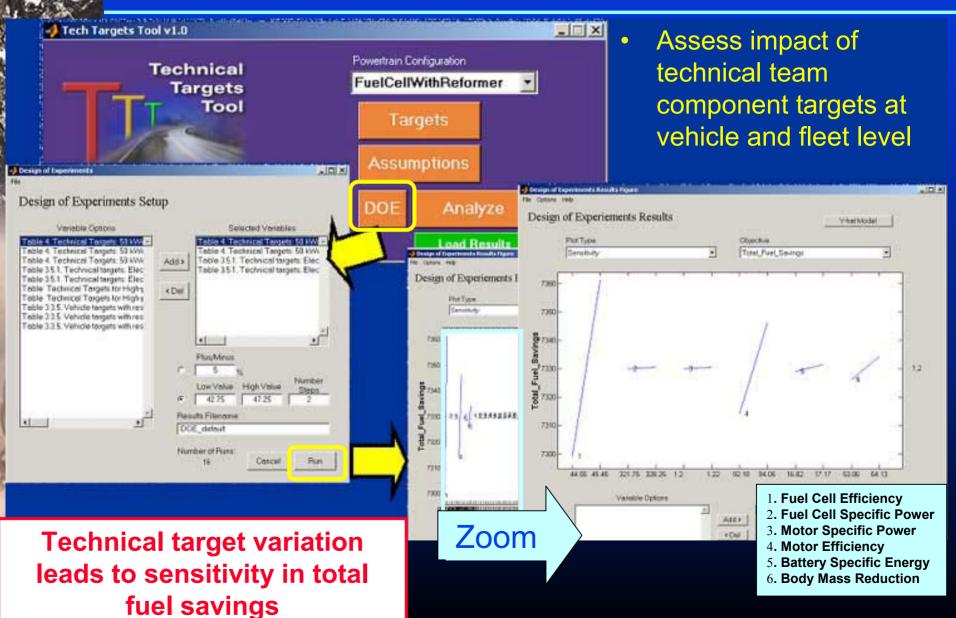


Accomplishments T³ - A Repository for Component Targets





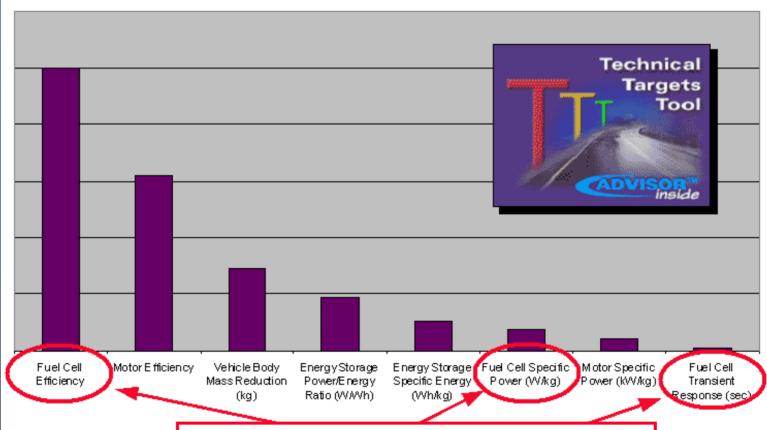
Accomplishments Fuel Cell Targets Analyzed Using Technical Targets Tool



Accomplishments T³ and DOE Highlight Relative Sensitivity of Fuel Economy

Relative Technical Target Sensitivity to Fuel Savings

Targets Varied from -1% to +1% of Nominal Target Value Based on Optimizing for Fuel Economy and Specifying the Penetration Rate









High Visibility of NREL's Vehicle Systems **Analysis Activity Through Publications**

Prediction the Fuel Economy Impact of "Cold-Start" for Reformed Gasoline Fuel Cell Vehicles

> Keith B. Wipke, Anthony Markel, Kristina Harakisson National Renewable English Laboratory

> > Patrick Davis

CONTRACTOR SANCTOR

First International Conference on First Cell Science, Engineering and Technology April 2 1-23, 2003, Rochester, New York, USA

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Fuel Cell Science, Engineering and Technology April 21-29, 2009, Rooteader, New York, USA

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EFFECT OF MATERIAL AND MANUFACTURING VARIATIONS. ON MINNEANE ELECTRODE ASSEMBLY PRESSURE DESTRIBUTION

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ARCTRACT

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AN ENGINEERING SYSTEM FOR AUTOMATED DESIGN AND OPTIMIZATION OF FUEL CELL POWERED VEHICLES

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¹ Volumente LLC, Ann Ather, NE 4211), UEA; annel relie (problemente se

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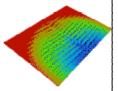
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AN ANALYSIS OF WATER MANAGEMENT FOR A PEM FUEL CELL SYSTEM IN AUTOMOTIVE DRIVE CYCLES

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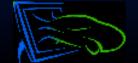
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Addressing Reviewer Comments

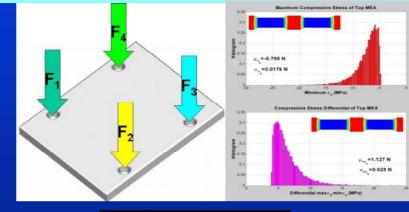
- System cost estimates should be included in analyses
 - System costs estimated within Technical Targets Tool and recent Energy Storage System Requirements study
- Computer models should be used to evaluate fuel cell program technical targets
 - Technical Targets Tool developed and applied
- Need to accommodate fuel cell and subsystem design trade-offs
 - 2 parametric detailed fuel cell system models integrated with ADVISOR vehicle simulation tool
- Review of assumptions by industry
 - working with fuel cell, hydrogen, energy storage, and vehicle systems technical teams
 - collection of peer reviewed papers published



Recent Collaborative Projects with Industry

Plug Power:

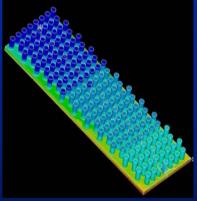
- ATR thermal analysis
- Analysis of MEA pressure profiles
- End plate topology optimization
- Robust high temp. stack design

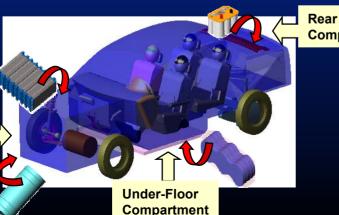


Ballard Power Systems:

 Thermal management of fuel cell power electronics







Rear Compartment



VulcanWorks/Nuvera:

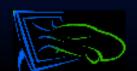
 Design and optimization of fuel cell vehicle packaging solutions

Front Compartment



Plans and Future Milestones

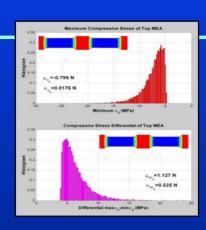
- Fuel cell hybrid vehicle system optimization working with fuel cell, energy storage, vehicle systems teams on energy storage targets for fuel cell vehicles (9/03)
- Technical Targets Tool study on sensitivity of fuel cell technical targets applied to multiple vehicle platforms (9/03)
- Complete water and thermal management analysis for fuel cell vehicles under real driving conditions (11/03)
- Validation of fuel cell models with industry partners (2/04)
- Robust design process transferred to industry to address fuel cell stack cost and durability technical barriers (9/04)





Summary

 Vehicle systems tools coupled with optimization and robust design methods are being applied to address cost and durability technical barriers





 Technical Targets Tool introduced and applied to understand sensitivity of fuel consumption to the fuel cell program technical targets

 Enhanced fuel cell system models incorporated into vehicle model to analyze thermal and water management technical barriers

