Fuel Cell Vehicle Systems Analysis

2004 DOE Hydrogen, Fuel Cells & Infrastructure Technologies Program Review

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This presentation does not contain any proprietary or confidential information

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 (both current status and future goal evaluation)
- Highlight potential system level solutions to technical barriers

Budget and Safety

- Budget
  - FY04 funding: **$200 K total**

- Safety
  - All work conducted under this project is simulation and analysis. Standard office safety protocols followed.

Technical Barriers and Targets

- Technical Barriers:
  - Fuel Cells
    - D. Fuel Cell Power System Benchmarking
    - R. Thermal and Water Management

- Technical Targets:
  - Specific technical targets related to fuel cell vehicle systems modeling do not exist
  - The modeling activity integrates the component level technical targets and development activities to quantify the potential cumulative impacts of the DOE programs

10/03	Project Timeline	9/04

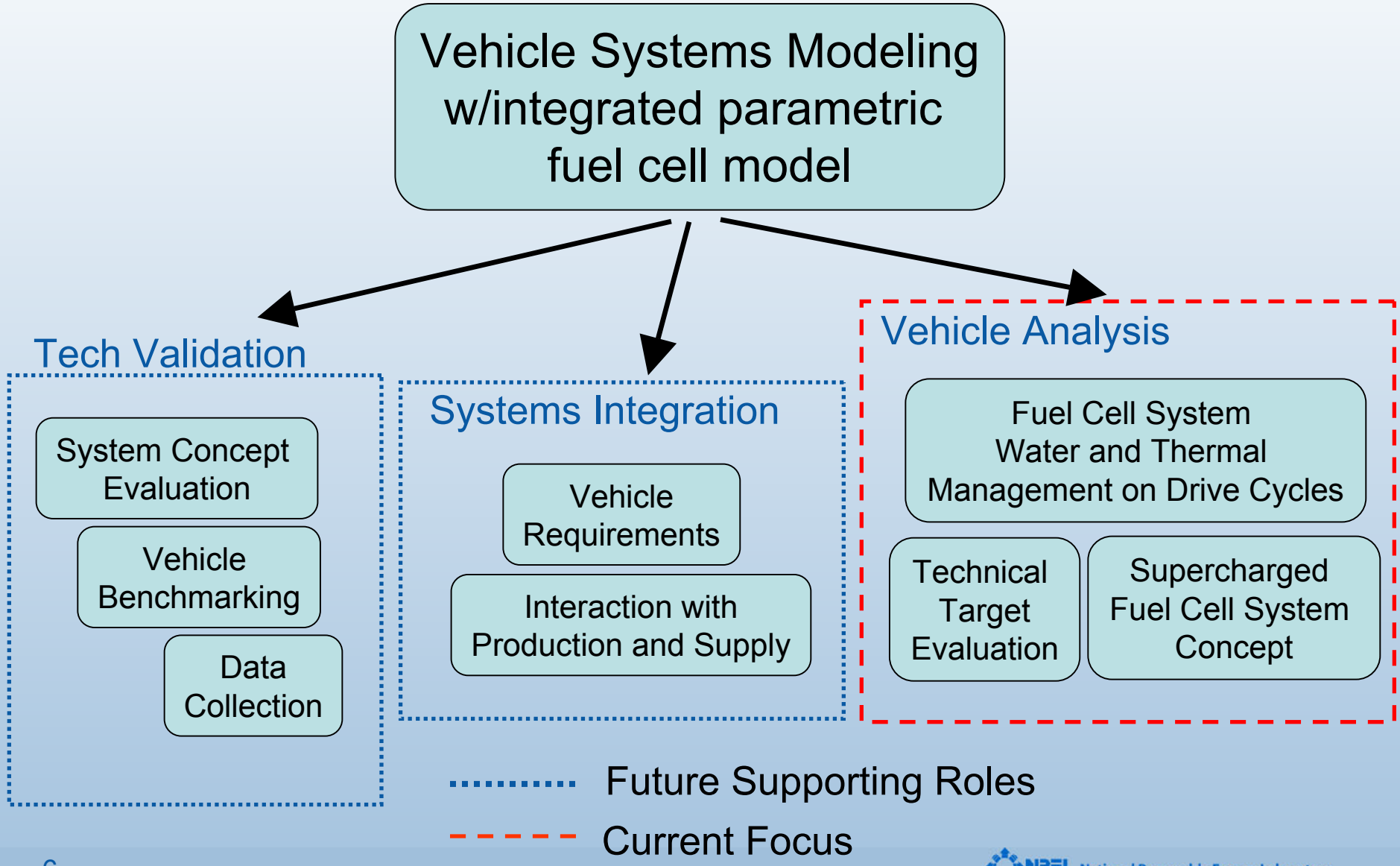
1 2 3

Milestones

1. Complete Preliminary Water and Thermal Management Analysis (2/04)
2. Complete Technical Targets Tool Enhancement and Analysis (6/04)
3. Simulate Supercharged Fuel Cell Power System In Hybrid Vehicle (7/04)

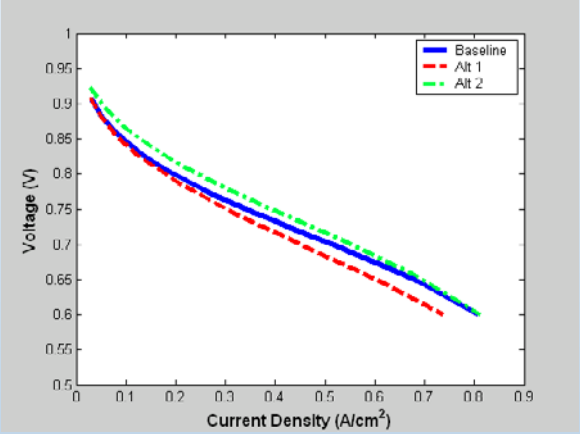
NREL has provided Fuel Cell Vehicle Systems Analysis support to OHFCIT annually since 2000.

Overall Approach



Vehicle Systems Modeling in ADVISOR 2003 with Integrated Parametric Fuel Cell Model

- Original work initiated with Virginia Tech
  - Benchmarked based on Honeywell/GE fuel cell integration into 2002 FutureTruck entry
- Focus on thermal system modeling
- Parametric polarization curve

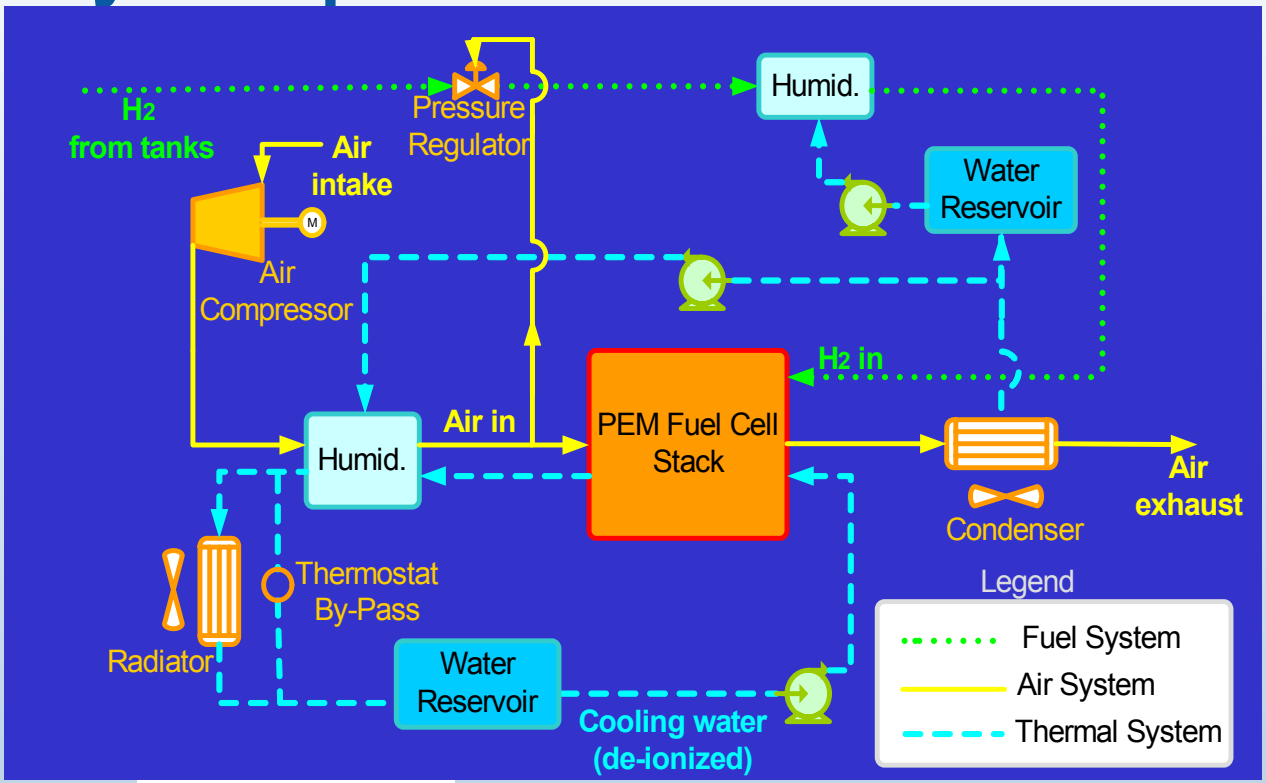


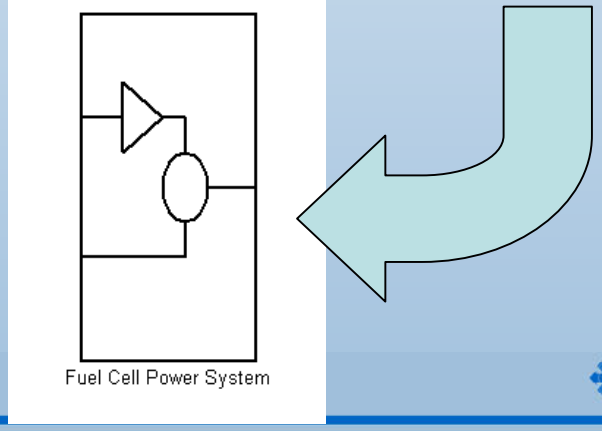
- Primary applications
  - Understand impacts of cycle dynamics on fuel cell operation
  - Quantify water and thermal management requirements under a variety of driving conditions
  - Assess opportunities for system optimization

Structure

Primary Component Models

- Cell polarization model (tunable)
- Air compressor
- Thermal
  - Stack
  - Humidifier
  - Condenser
  - Radiator
  - Reservoir
- System controller





Programmed in Simulink™

Parametric Flexibility

Inputs

- Polarization model coefficients
- Pressure, stoichiometry, and humidity operating strategies
- Air compressor operating maps
- Coolant pump characteristics
- Radiator and condenser characteristics
- Stack thermal properties
- …

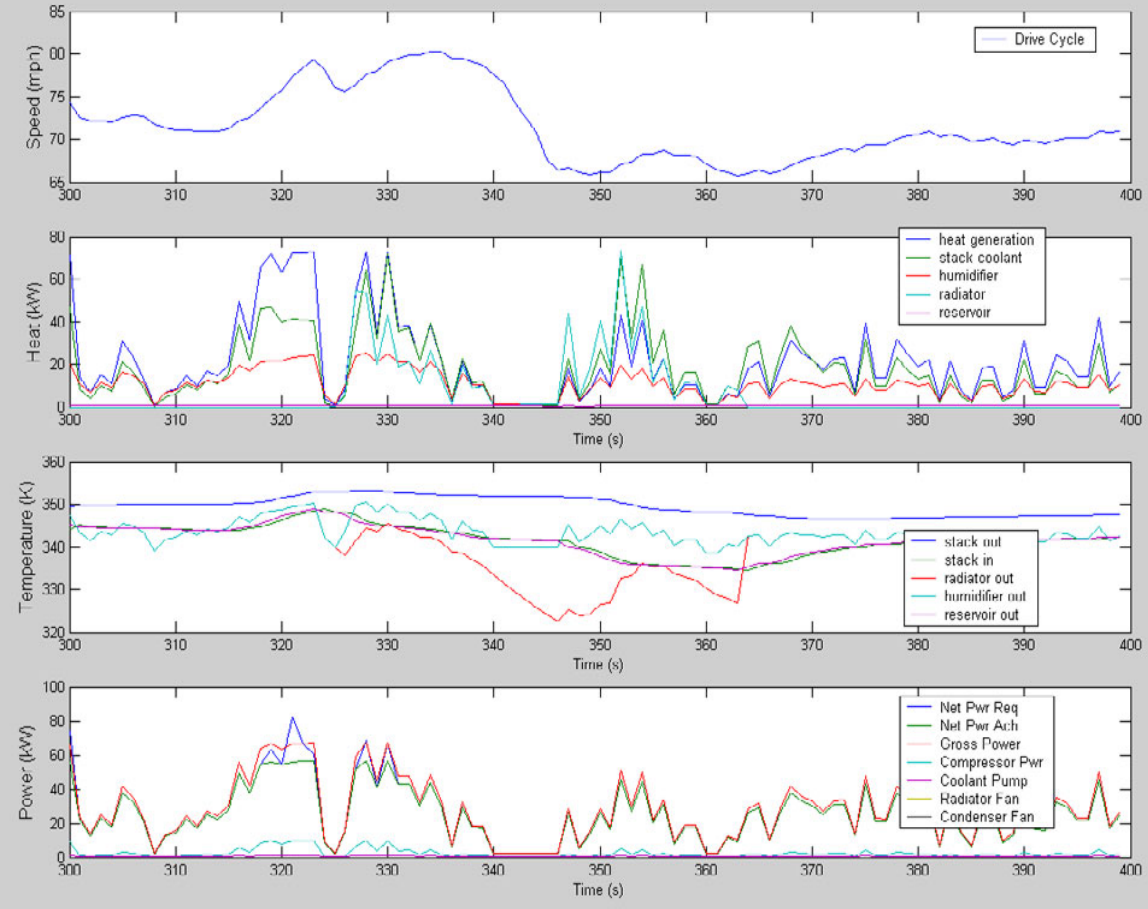
Outputs

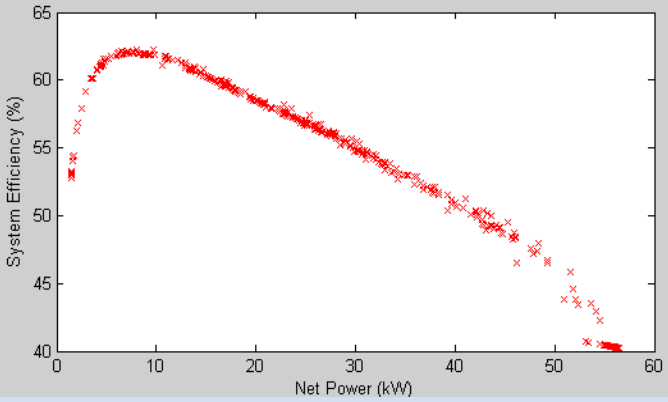
- Cell current density and voltage
- Component temperatures
- Parasitic power consumption of components
- Net system power output
- State of water balance
- Heat production and rejection breakdown by component
- Fluid flow rates throughout the system
- …

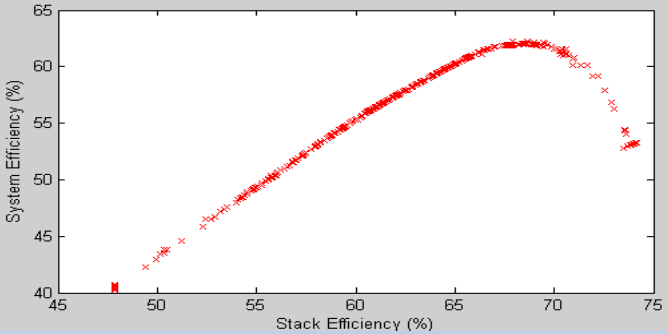
Parametric Fuel Cell Model
Detailed Results over Real Driving Profiles

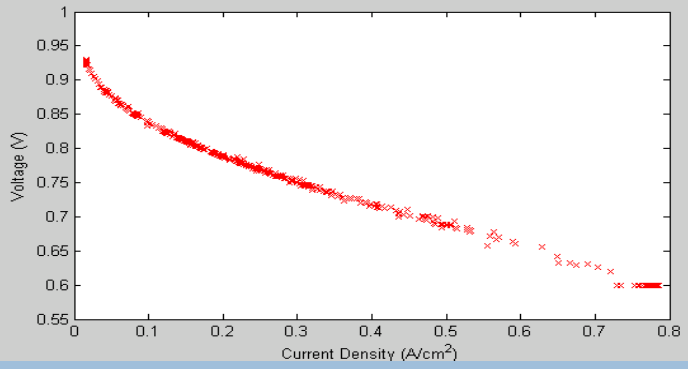
Predicted dynamic fuel cell system and component operation

Portion of US06 Drive Cycle





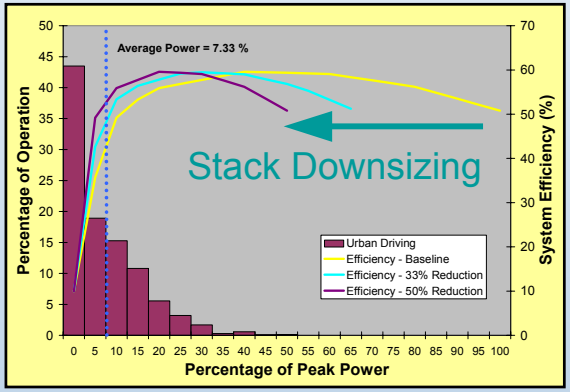




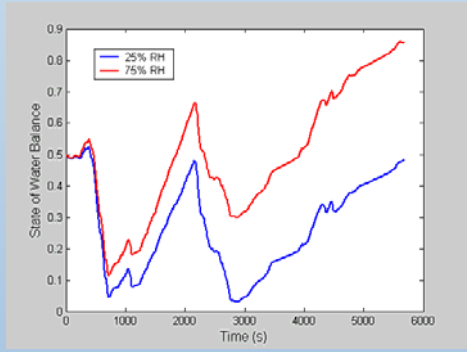
Application of Vehicle Systems Modeling
Three Project Focus Areas

- Technical targets analysis

- Supercharged fuel cell system evaluation



- Vehicle thermal and water management



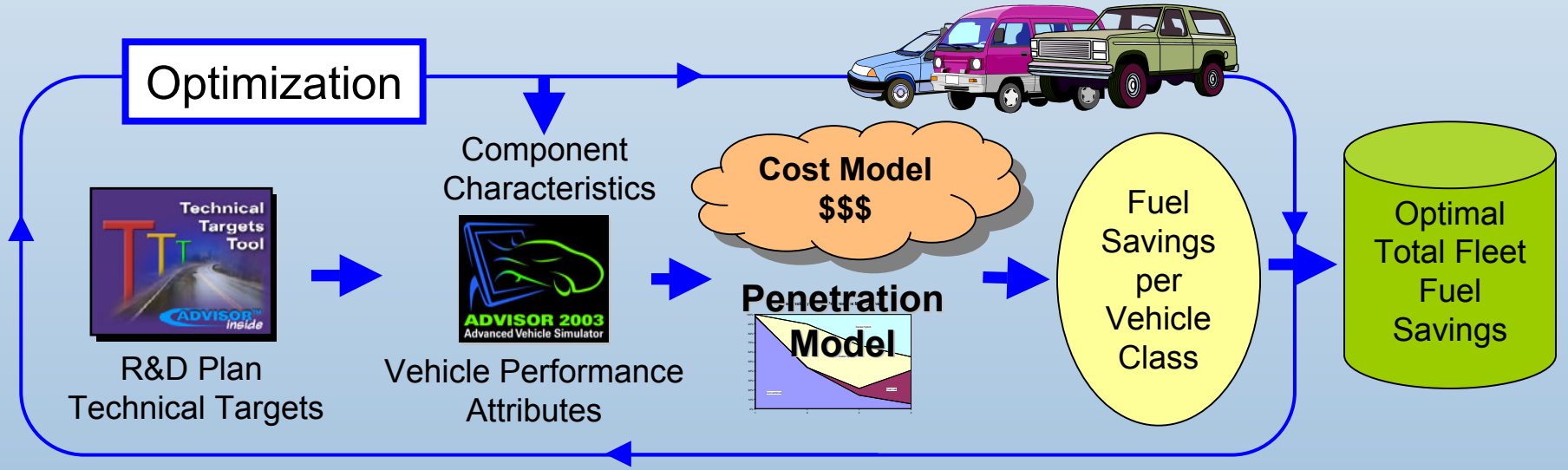
Technical Targets Analysis

Targets Analysis History

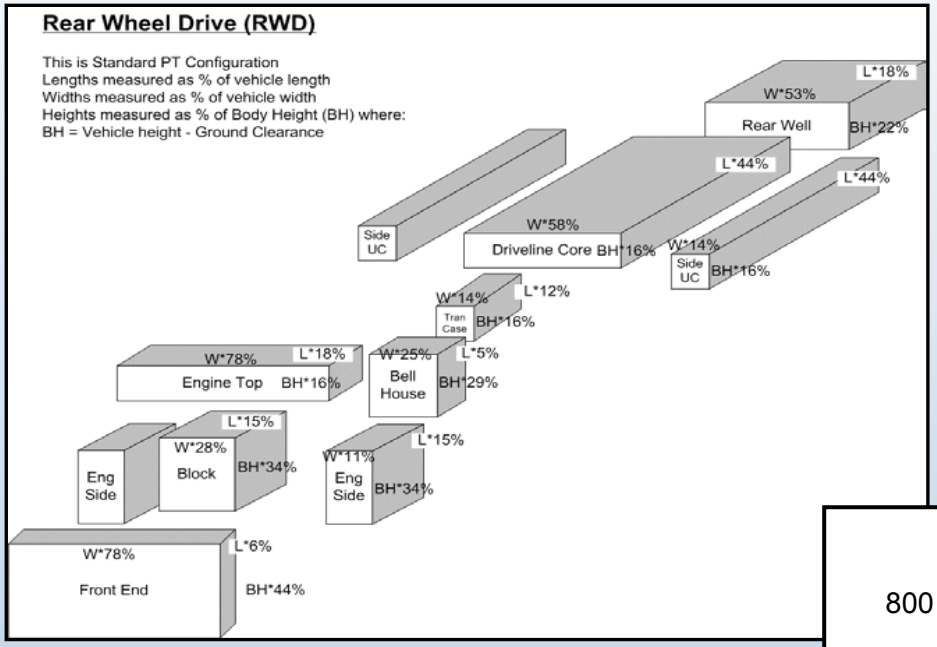
- NREL has provided DOE with high quality technical targets analysis using ADVISOR for the past 5 years

Fuel Cell Targets Study Description

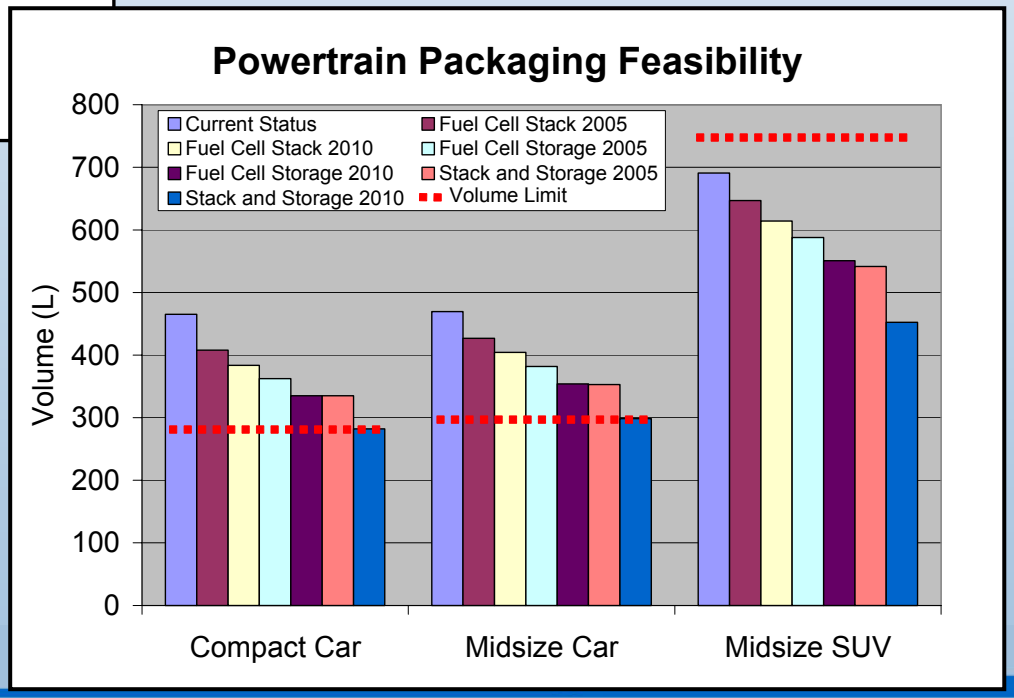
- Compared potential performance of vehicles achieving targets for:
  - current status for fuel cell stack and hydrogen storage (baseline)
  - fuel cell stack (year 2005 and year 2010)
  - hydrogen storage (year 2005 and year 2010)
  - a combination of fuel cell stack and hydrogen storage targets (year 2005 and year 2010)



Sample Results: Volume Constraints



- 11 sub-volumes defined
  - Engine
  - Transmission
  - Driveline
  - Rear well
  - Other undercarriage
- Packaging factors applied



- Hydrogen storage targets provide largest decrease in volume
- Hydrogen storage and fuel cell stack targets necessary to satisfy constraints

Supercharged Fuel Cell Power System

Supercharged Fuel Cell Power System Research

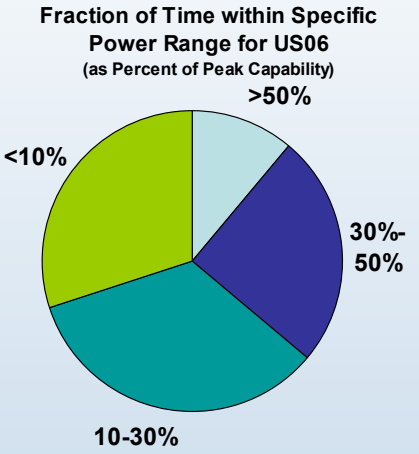
Objectives

Quantify feasibility and benefits of fuel cell system oxygen supercharging

- Increase specific output
- Downsize fuel cell stack
- Address system cost, mass, and volume barriers from vehicle systems perspective

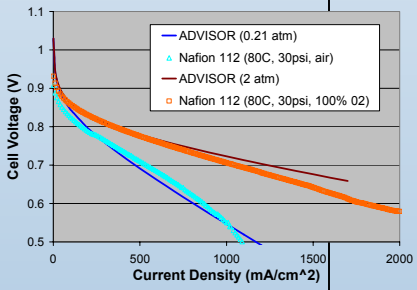
Rationale

- Reduce impact of limiting factors in stack and system
- Peak traction power demand case is only small fraction of typical operation
- Flexible system to match transient power demands



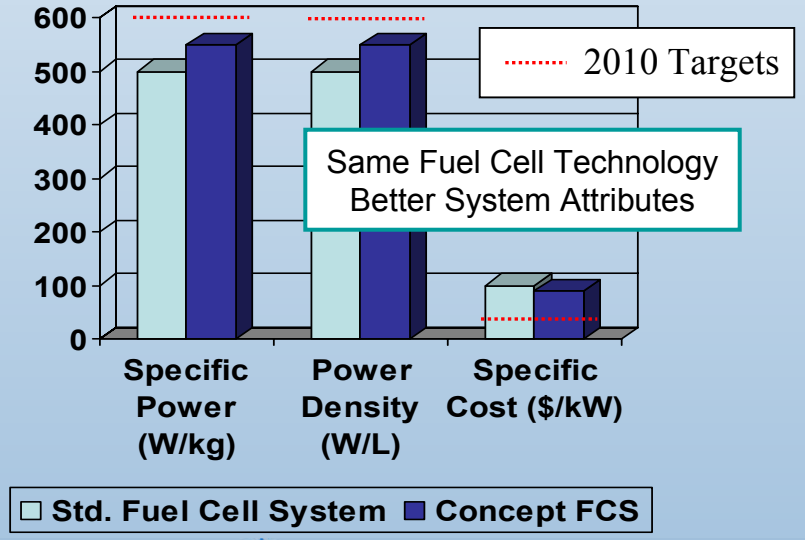
Approach

- Develop representative fuel cell system models for use in vehicle analysis
- Cell tests used to validate model predictions
- Compare performance predictions of fuel cell only and fuel cell hybrid vehicle scenarios
- Optimize component sizing and control for maximum benefit



ADVISOR 2003
Advanced Vehicle Simulator

Supercharged Fuel Cell System Closes the Gap Between 2005 and 2010 Targets



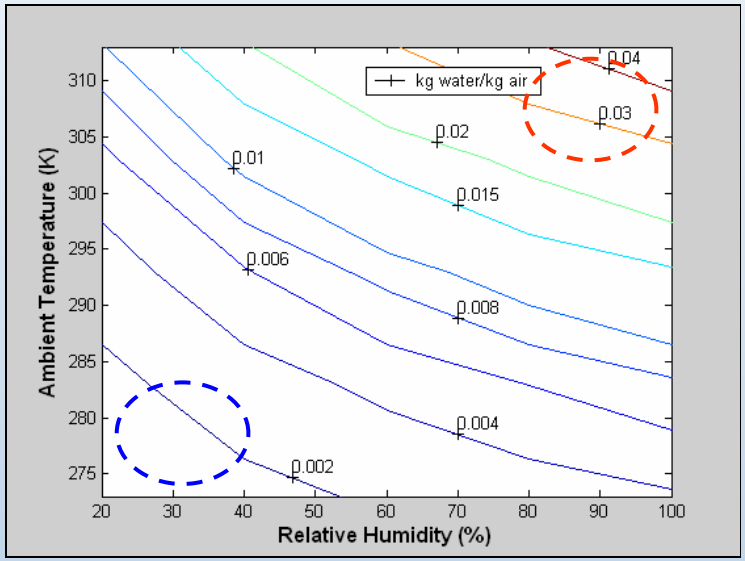
Thermal and Water Management

Fuel Cell Vehicle Thermal and Water Management

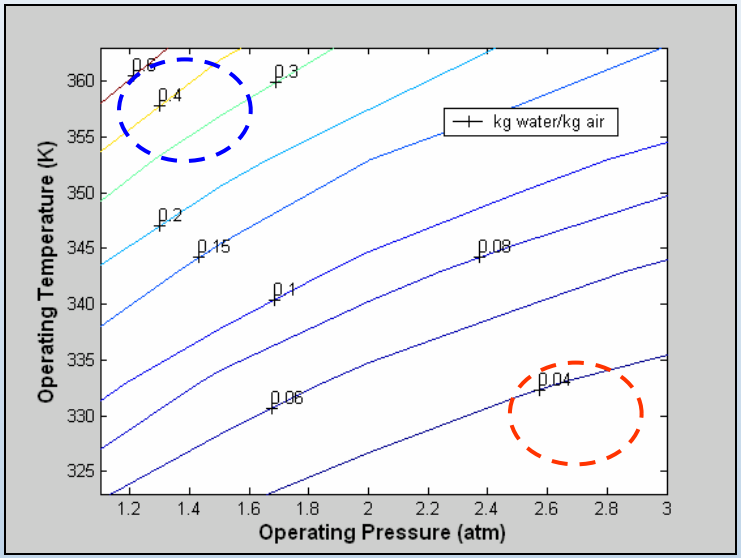
- Model revisions
  - Variable air density with respect to altitude
  - Scaling factors for components
- Assessing impacts of altitude and relative humidity on fuel consumption, heat rejection, and water balance
- Impacts most significant in high power drive cycles (i.e. US06)
  - 14% increase in fuel consumption from 0m to 3000m elevation
- Preliminary results published at EVS-20 and Fuel Cell Seminar

Water supply and demand affected by operating point and environment

Water available in ambient air



Water required for cathode humidification (80% RH)

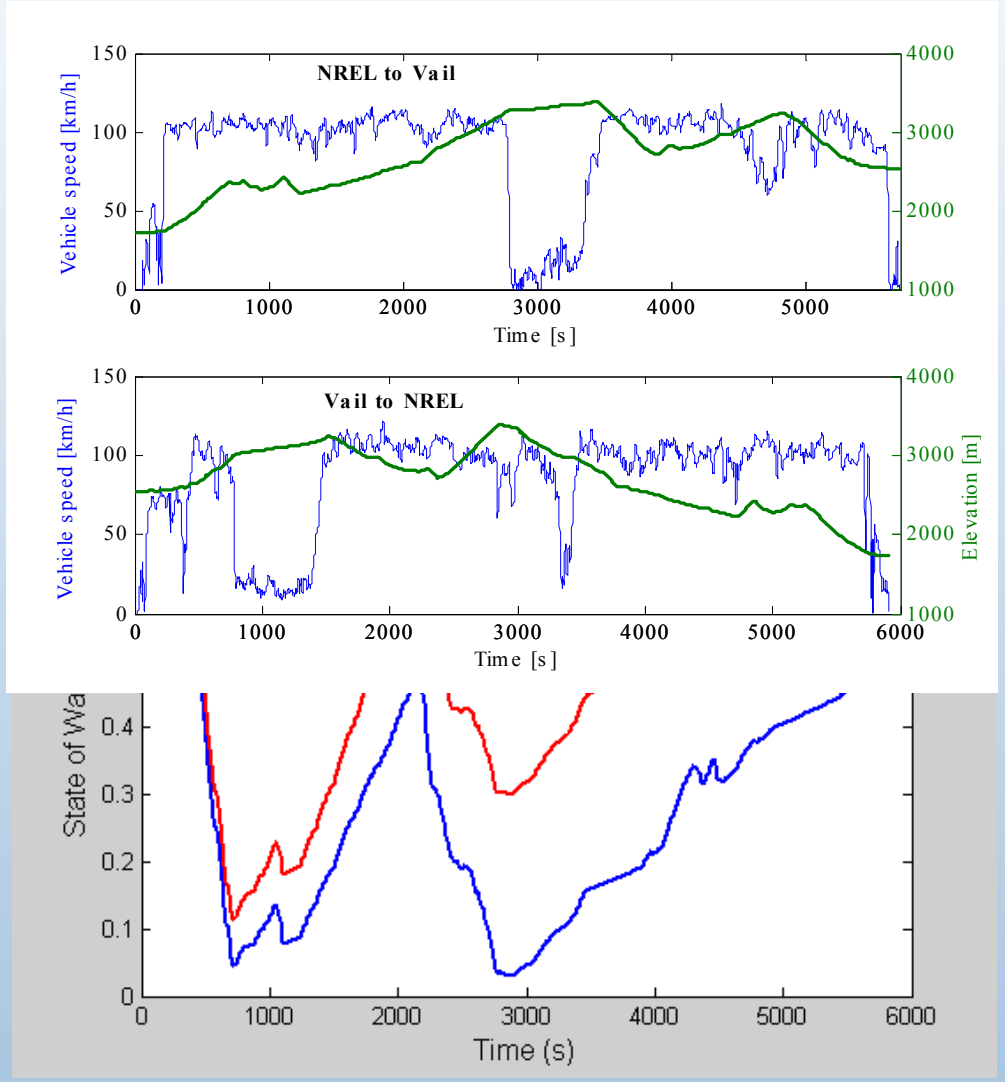


Case 1
Hot and Humid Environment
Low Temp and High Pressure
→ Ambient supply provides >80% of demand

Case 2
Cold and Dry Environment
High Temp and Low Pressure
→ Ambient supply provides <1% of demand

Impacts of Relative Humidity on State of Water NREL to Vail Drive Cycle

- Condenser fan used to maintain balance of water in a reservoir
- Variation in ambient conditions only minor impact on fuel economy (fan power)
- Results can be used to tune component sizes and control



Next Steps

Fuel Cell Hybrid Vehicles with Robust Operation

- Need to size component appropriately for a variety of ambient conditions
- Fuel cell humidification requirements difficult to satisfy in dry climates
- Rejecting low grade waste heat challenging in hot climates

Denver, Colorado
Moderate Temp, Dry, and Moderate Elevation

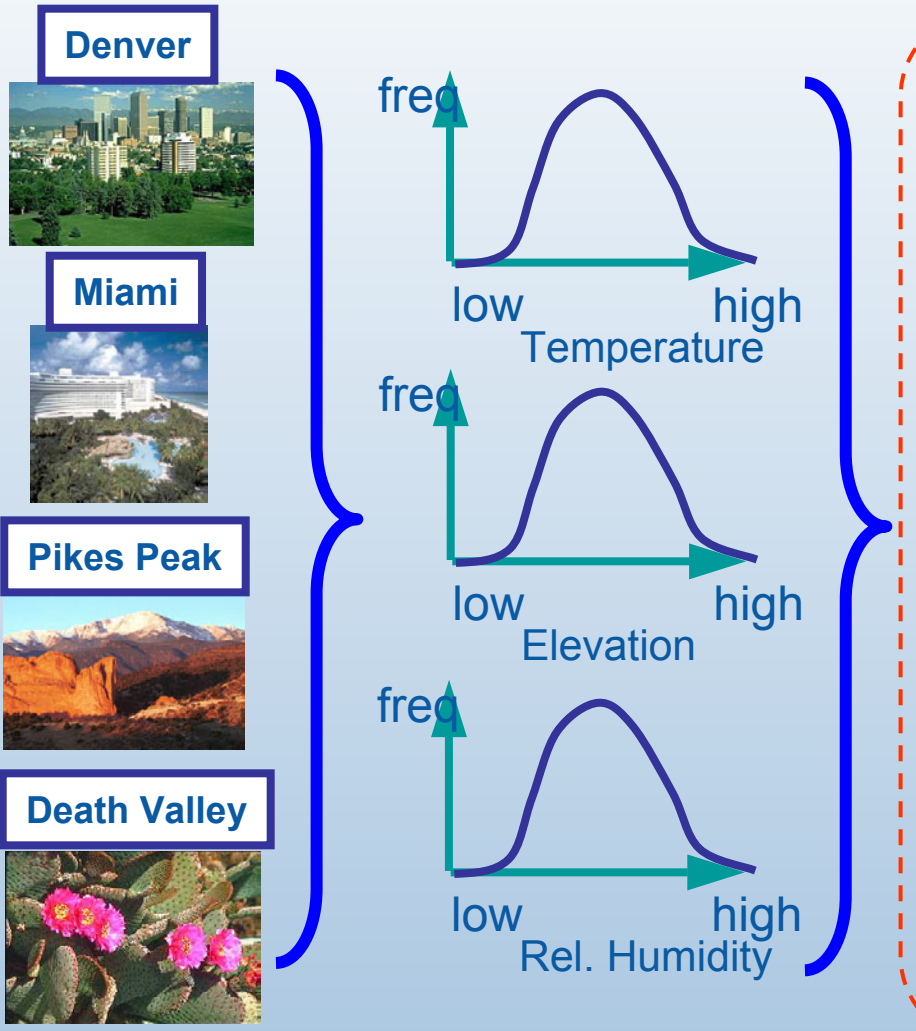
Miami, Florida
Hot, Humid, and Low Elevation

Pikes Peak, Colorado
Cold, Dry, and High Elevation

Death Valley, California
Hot, Dry, and Low Elevation

Future Work

Implementation of Robust Design Algorithm



Responses to Previous Year Reviewer's Comments

- Prefer to see greater involvement of OEM's and tech teams
  - Systems analysis is core to OEM's; collaboration challenging
  - Participate in and share results primarily with Systems Analysis Tech Team
- Focus on general systems issues and less on specific component design issues
  - Water and thermal management analysis with respect to ambient conditions introduced as general topic

Acknowledgements

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  - Aaron Brooker
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