Advanced Vehicle Technology Analysis and Evaluation Team

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DOE Hydrogen, Fuel Cells, and Infrastructure Technologies Program

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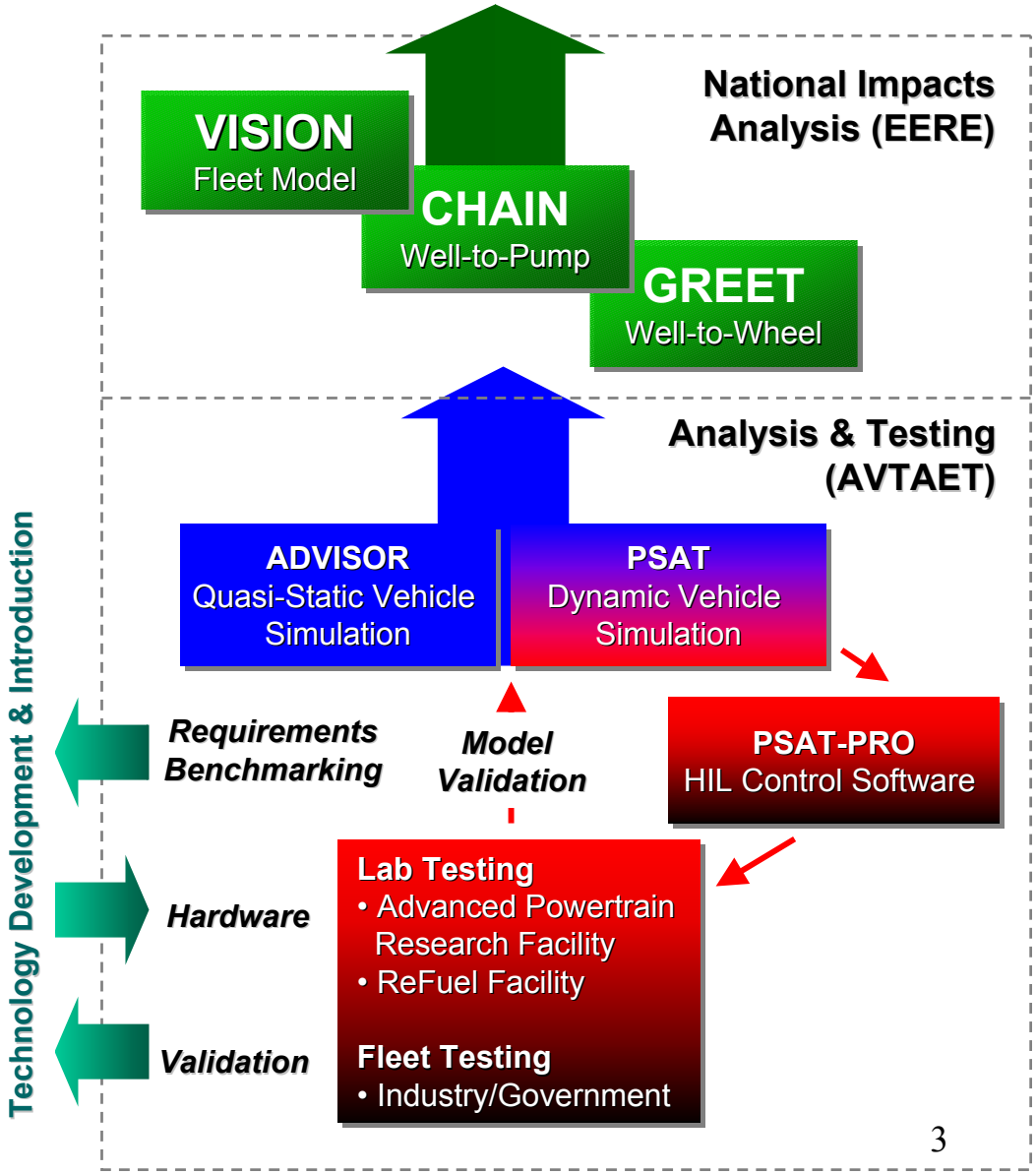
Charter

- AVTAET's mission is to develop and apply the tools and skills necessary to:
  - Identify technology development needs and requirements to support OFCVT goals and
  - Collect, analyze, and disseminate unbiased information on advanced transportation technology components, systems, and vehicles that potentially support OFCVT goals.
- Goal of analytical groups at ANL, NREL and ORNL
  - Develop and apply modeling and simulation tools to help DOE, manufacturers and suppliers design and develop clean, energy efficient components and systems for automotive applications.
- Funded through OFCVT by Interior Appropriations Committee

History

- Development of vehicle systems analysis tools and FC models at the labs began 5-10 years ago
- The ability to test with H2 to validate models was developed within the last 3 years
- Analysis and testing were integrated in the last 2 years to insure traceability from analysis through development and introduction
- Focus on PSAT development due to dynamic/HIL capability



Past Projects

- Development of map-based and engineering models of Direct H2 PEMFC systems for vehicle simulation
- Development of map-based H2 ICE models
- FCV, hybrid FCV, and H2 ICEV fuel economy studies
- Subsystem/component requirements analysis
  - H2 and electrochemical energy storage for FCVs
  - Compressor-expander module
- FCV water and thermal management studies
- Total energy cycle analyses (WTW)
- Emulated FCV hardware-in-the-loop (HIL) study
  - Propulsion system requirements focusing on the impact of FC response on energy storage

Skill Set – People

- Lab teams/contributors (see back-up)
  - ANL lead: Don Hillebrand
  - NREL lead: Tony Markel
  - ORNL lead: Ron Graves

Skill Set – Models

ADVISOR
Static Vehicle Simulation

PSAT
Dynamic Vehicle Simulation

- Conventional, hybrid and electric vehicles
- Fuel consumption and performance attributes
- MATLAB/Simulink environment

- ADvanced Vehicle SimulatOR (NREL/AVL)
- Backward model: energy management and component interactions
- Fuel cell models
  - Net power vs. efficiency
  - Polarization curve
  - Parametric polarization

- Powertrain Systems Analysis Toolkit (ANL)
- Forward model: control strategy and transient component behavior
- Supports HIL/RCP
- Fuel cell models
  - Net power vs. fuel consumption
  - Engineering

PSAT-PRO
HIL Control Software

Lab Testing
- Advanced Powertrain Research Facility
- ReFuel Facility

Fleet Testing
- Industry/Government

ADVISOR FC Models

- Direct H2 PEMFC efficiency
- Net power model based on PEMFC data
  - System represented as a black box; eff = f(power)
- Parametric polarization curve
  - Tunable cell polarization
  - Balance of plant components (water and thermal focus)
- Fully parametric model
  - Predictive cell polarization model; sub models for balance of plant components; focus on thermal and water management

PSAT FC Models

- Direct H2 PEMFC efficiency
- Net power model based on PEMFC test data
  - Net power versus fuel consumption
  - Max power and efficiency scaled linearly
- GCTool-eng (engineering model based on GCTool)
  - Appropriate detail for PSAT vehicle simulation over driving cycles while maintaining transient capability
  - Solves conservation equations for energy, mass, species and momentum
  - Written in C; used in SIMULINK as an S-function
  - Limitations:
    - Optimistic fuel cell assumptions (lack of validation data)
    - Not scalable – requires fuel cell to be redesigned for different maximum output power levels (60-160 kW to date)

H2 ICE Models

- Efficiency (fuel consumption) maps based on passenger car/light truck engine test data
- Written in SIMULINK
- Max power and efficiency scaled linearly

Skill Set – Capabilities Summary

TYPE OF ANALYSIS	RESIDENT CAPABILITY?	STUDIES SPECIFIC TO H_2?	MODELS SPECIFIC TO H_2?
Resource Analysis	No	No	No
Technoeconomic Analysis	Yes	Yes	Yes
Environmental Analysis	Yes	Yes	Yes
Delivery Analysis	No	No	No
Infrastructure Development Analysis	No	No	No
Energy Market Analysis	No	No	No

Recent Hydrogen Studies

- Impact of compressor-expander idle speed on FreedomCAR H2 storage targets for FCVs*
- Optimum degree of hybridization for FCV (impact of regeneration, ESS technology, power and target SOC)*
- Well-to-wheels fuel economy and GHG emissions*
- Emulated FCV HIL project (impact of FC response on ESS)*
- Gasoline reformer start-up fuel economy impacts
- Energy storage requirements for FCVs*
- Impacts of relative humidity on state of water in FC system*
- FCV performance for current and future stack and H2 storage capabilities

* results shared with FreedomCAR

Future Studies

- Parametric well-to-wheels study with optimistic upper bound and pessimistic lower bound
- Impact of ultra-capacitors on FC component sizing and control strategy
- Expected hybrid FCV fuel economy improvement factor considering diesel Atkinson and hydrogen Atkinson cycle engines
- Bellman optimized control strategy for hybrid FCVs
- Comparative analysis of HEV technologies including H2 ICEs
- Optimum degree of hybridization for H2 ICEVs – simulation and HIL testing
- Hydraulic hybrid H2 ICE propulsion for heavy duty applications
- Vehicle level thermal and water management

Future Direction

- Increase coordination with industry partners on analytical standards
  - PSAT and ChallengeX
  - Interaction with OEM and supplier models
- Increase coordination of technology validation and model enhancement
- Increase interaction between lab analytical groups/capabilities

Analysis Issues

- Coordination and validation of fuel cell component and system models (avoid duplication, contradiction and misconceptions)
- Cost modeling to industry standards