Enabling High Efficiency Ethanol Engines (VSSP 12)

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U.S. DEPARTMENT OF ENERGY

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Overview

Collaboration between ORNL and Delphi Automotive Systems to make use of advanced powertrain components and controls to achieve and demonstrate significant improvements in engine efficiency which take advantage of the unique properties of ethanol and ethanol-gasoline blends..

Duration

- FY 2008 – 2010

Barriers

- Efficiency/combustion
- Engine management

Budget (from Vehicle Systems)

- FY 2008 $150k
- FY 2009 $150k
- FY 2010 $150k (anticipated)

Interactions / Collaborations

- CRADA with Delphi
- Leveraged with DOE Fuels Technologies program
- Regular updates at VSATT meetings

Objective

- **To explore the potential of ethanol-based fuels for improvements in drive-cycle efficiency and emissions based on simulation and experiments.**
- **Activity makes use of state-of-the-art engine technology through industry partnership in support of VTP R&D priorities**
  - » Engine fuel efficiency
  - » Alternative fuels
  - » System optimization & control
  - » Efficiency impact of environmental compliance
- **Funding 30% Vehicle Systems ($150k/year), 70% Fuels Technologies ($350k/year)**

Milestones

FY 2008 Milestone – *Complete*

- **Establish a baseline vehicle model, to create a common set of vehicle parameters from which to build a multitude of powertrain configurations (September 30, 2008).**

FY 2009 Milestone – *In Progress*

- **Establish and evaluate initial baseline engine map in each powertrain, both conventional and hybrid, over the identified driving cycles. The initial baseline ethanol engine map will be developed using a direct-injection multi-cylinder ethanol engine with variable valve actuation (September 30, 2009).**

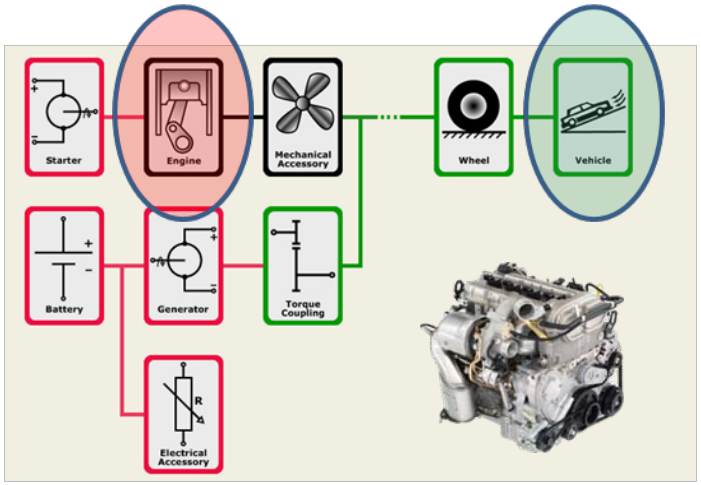
Approach

Overall approach includes the following tasks:

- Variable compression ratio (VCR) engine experiments to bound ethanol potential.
- Development & baseline of engine management systems.
- Multi-cylinder engine experiments to explore efficiency opportunities.
- Drive-cycle estimations of efficiency & emissions with PSAT for advanced powertrain configurations.

VSATT specific approach includes:

- Development of representative vehicle models.
- Development of advanced powertrain & component models in collaboration with Delphi.
- Simulation of conventional & advanced powertrains over relevant drive cycles.



Combustion → Engine System → Vehicle System

Summary of Technical Accomplishments

- **Multi-cylinder engine cell for evaluating ethanol efficiency potential and enabling technologies is near completion.**
- **Ethanol engine build and controls are complete with expected delivery of engine to ORNL in April 2009.**
- **Saab Bio-Power engine maps validated for gasoline & ethanol fuels.**
- **Development of parallel HEV & PHEV vehicle models are underway for use with Saab data.**
- **Aforementioned models being used to simulate conventional and advanced powertrains over relevant drive cycles.**

Advanced engine/controls develop and build is *on track …*

Engine modifications performed at Delphi Rochester Technical Center with engine scheduled to be delivered to ORNL in April 2009.

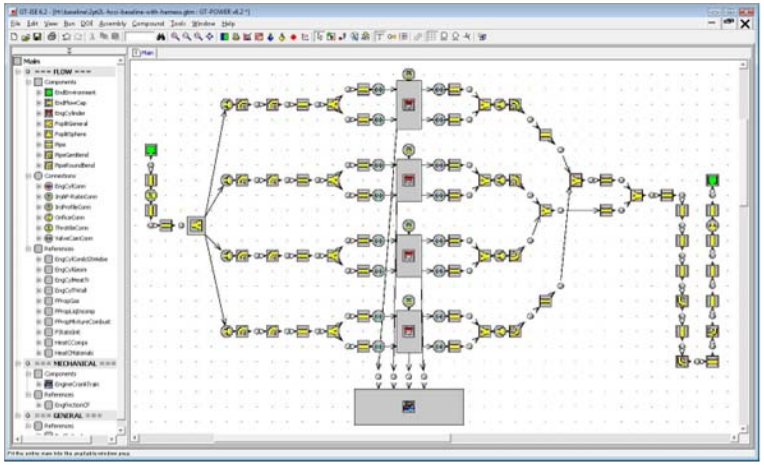
2.0-L ECOTEC SIDI-turbo with Delphi ethanol compatible components, pressure based control system, and flexible micro-processor based control system

Direct injection fuel system

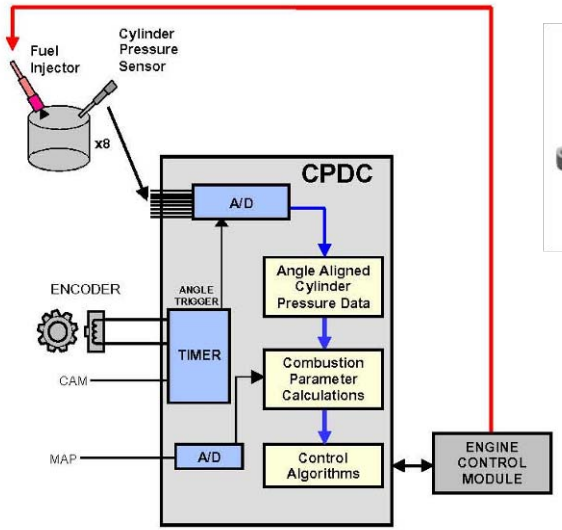
Production viable flexible intake & exhaust valve control system

Engine operational and evaluation of advanced components is complete

- **Extensive GT Power and multi-dimensional combustion modeling to guide not only engine configuration but also initial calibration.**
- **Initial experiments are on-going at Delphi to finalize selection and installation of valve train configuration, piston geometry, etc.**
- **Shakedown experiments include evaluation of DRIVVEN control system and Delphi cylinder pressure development controller (CPDC).**

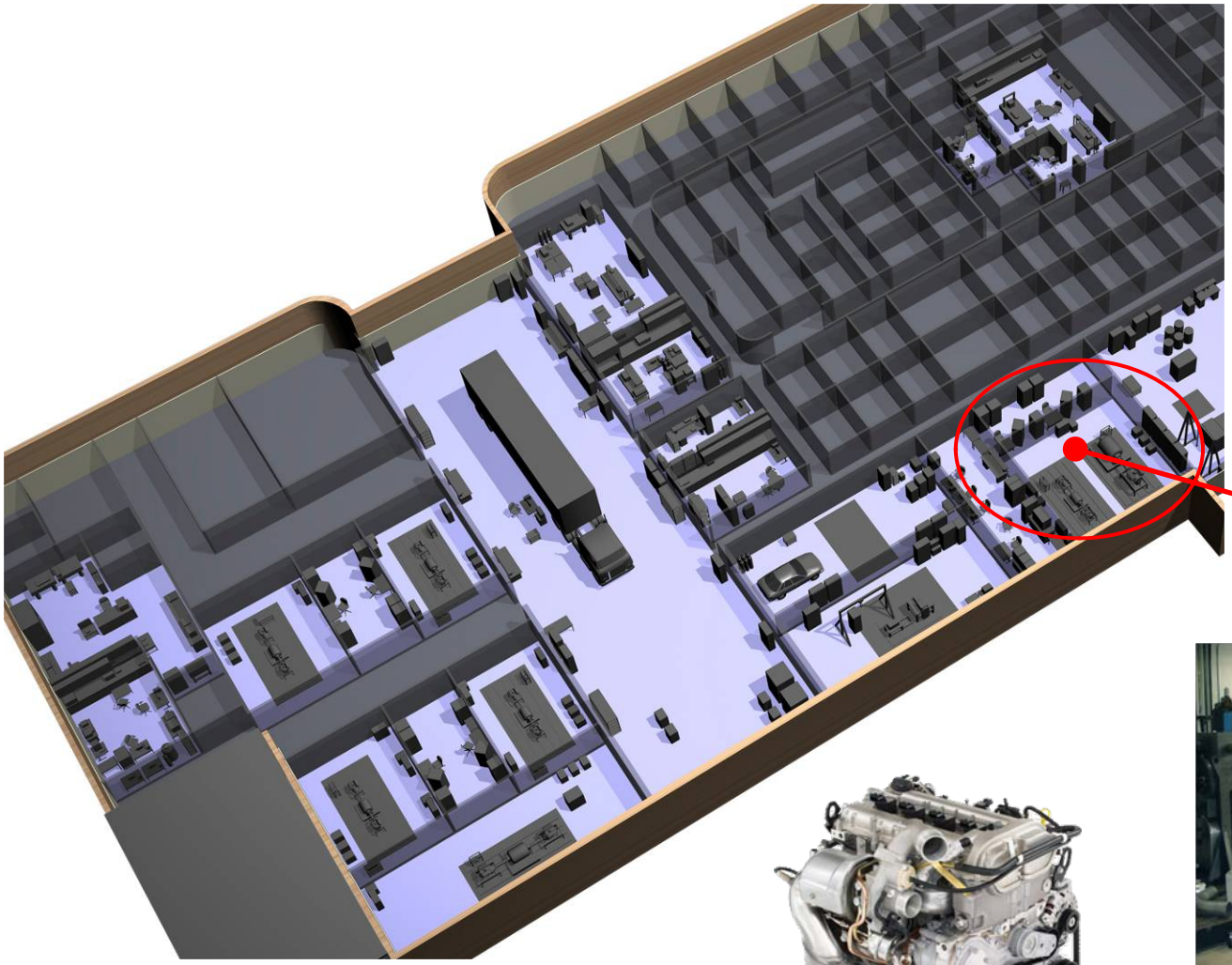


GT Power model of Delphi engine



CPDC Controller (SAE 2007-01-0774)

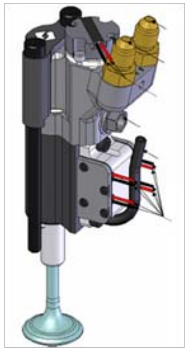
New engine laboratory constructed at ORNL for this CRADA



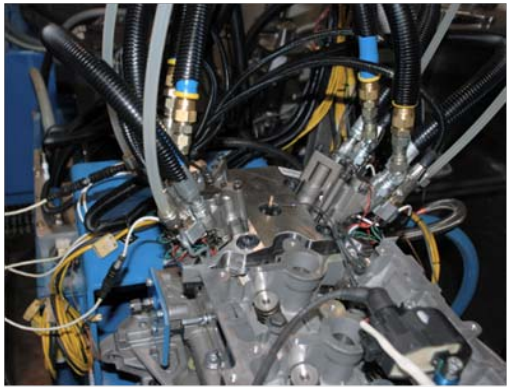
New cell infrastructure is complete and ready for engine delivery.

Single-cylinder experiments for fundamental investigation of compression ratio and intake/exhaust valve phasing on ethanol potential

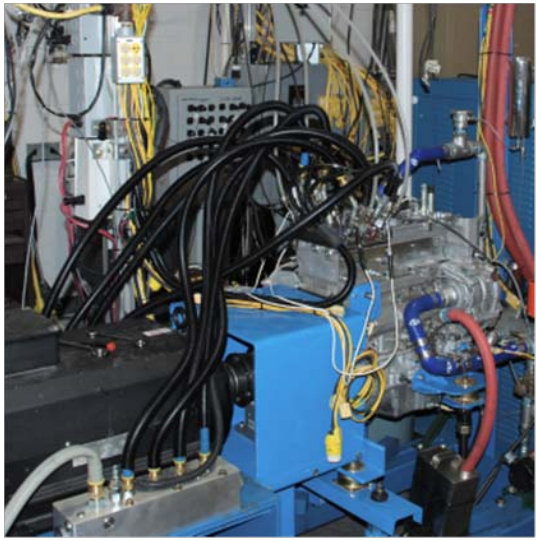
- **Single-cylinder engine based on 2.0-L Ecotec engine with flexible micro-processor based controller.**
- **Hydraulic valve actuation which allows for full flexibility of valve phasing and lift.**
- **Custom pistons for step changes in engine *geometric* compression ratio.**
- **GT-Power model of 2.2-L Ecotec engine as well as head flow and injector data supplied by Delphi to ORNL.**



Sturman hydraulically actuated valve

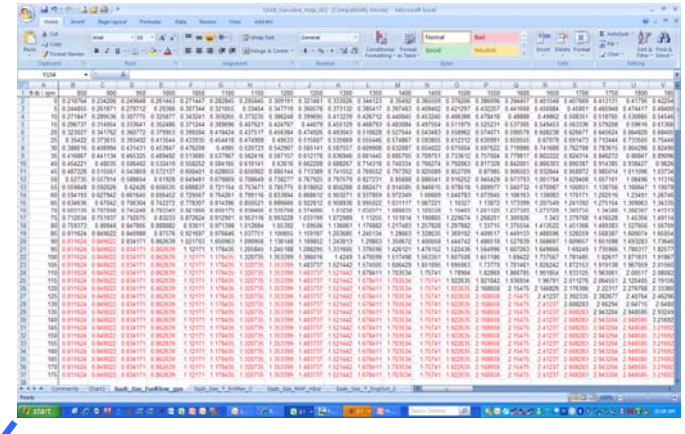


Sturman VVA system and engine installation

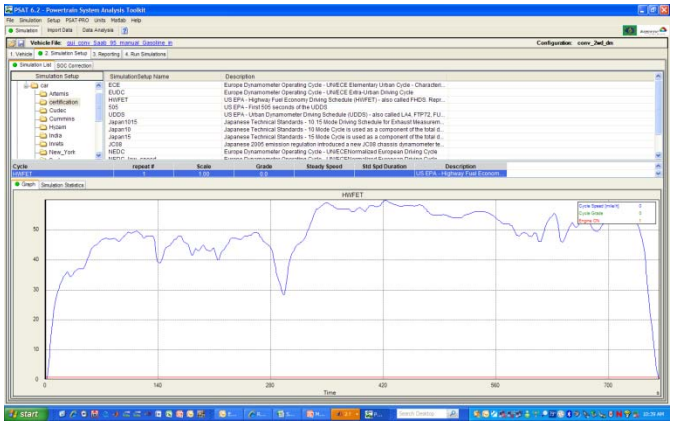


Saab Bio-Power vehicle serves as basis for initial vehicle model development

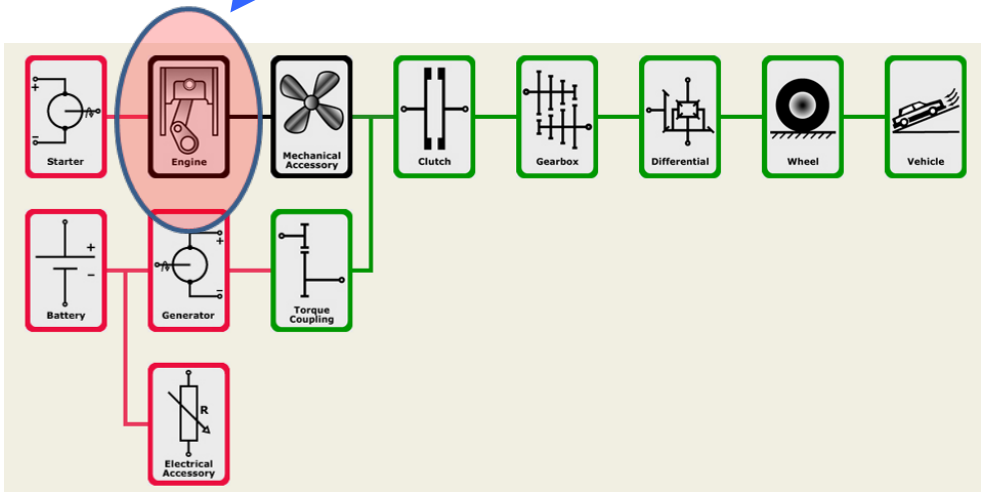
- **Saab Bio-Power is factory optimized for E85 and is gasoline compatible.**
- **Vehicle mapped with chassis dynamometer and data refined and reformatted into PSAT architecture.**
- **Complete vehicle modeled in the PSAT environment with results compared to experimental data for model validation.**



Saab engine map



PSAT drive-cycle simulation

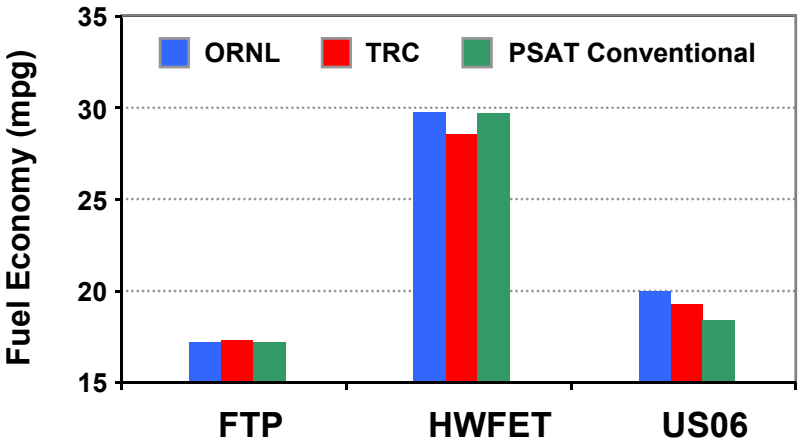


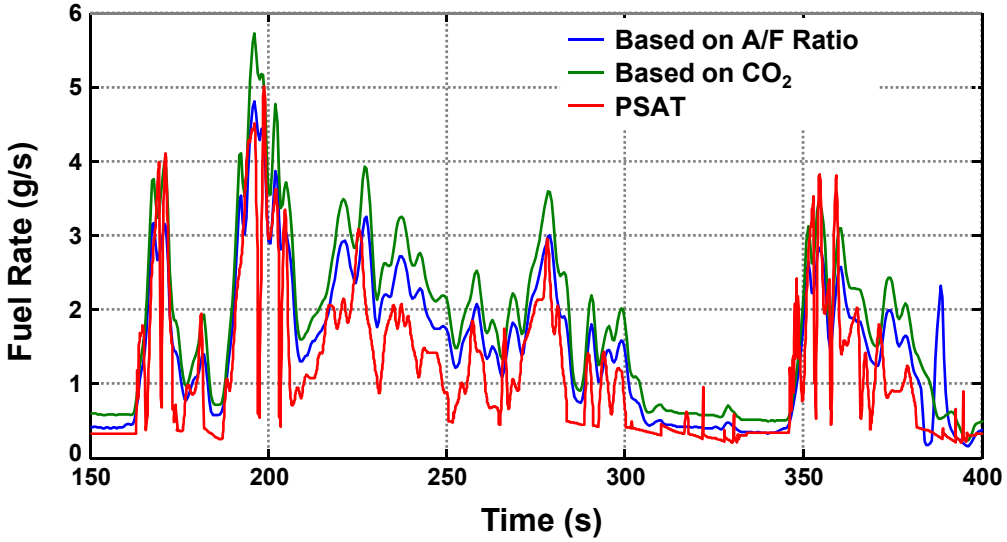
PSAT model

Validation of base vehicle model complete

- **Drive cycle predictions for Saab Bio-Power vehicle verified using second-by-second FTP data from ORNL chassis experiments.**
- **Second-by-second FTP data allowed for proper adjusting of PSAT shift parameters.**

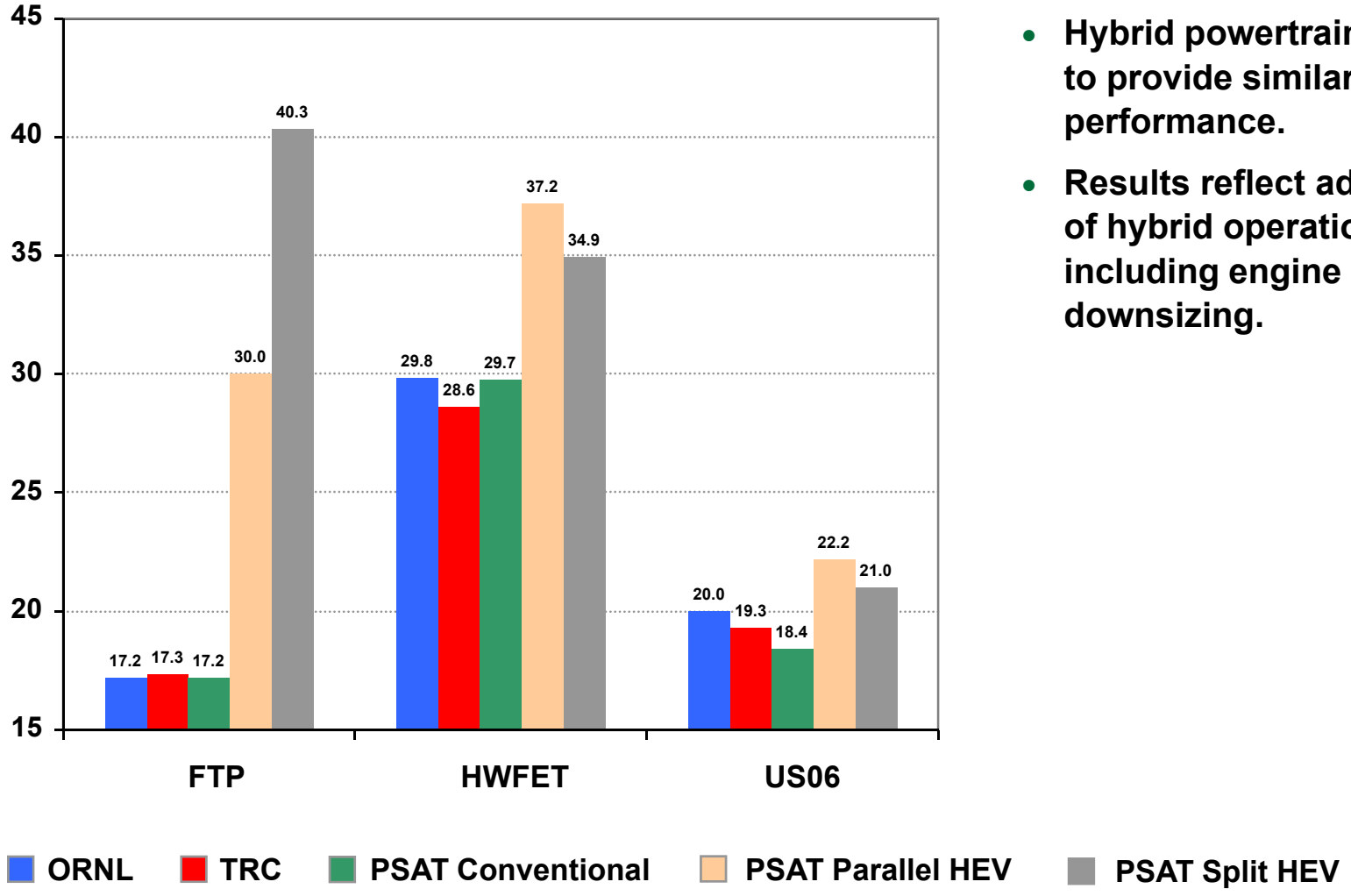
Model validation example for Saab Bio-Power fuel economy on E-85





Model validation example, fuel rate comparison for test and simulation

Simulation of parallel and split HEV based on Saab vehicle



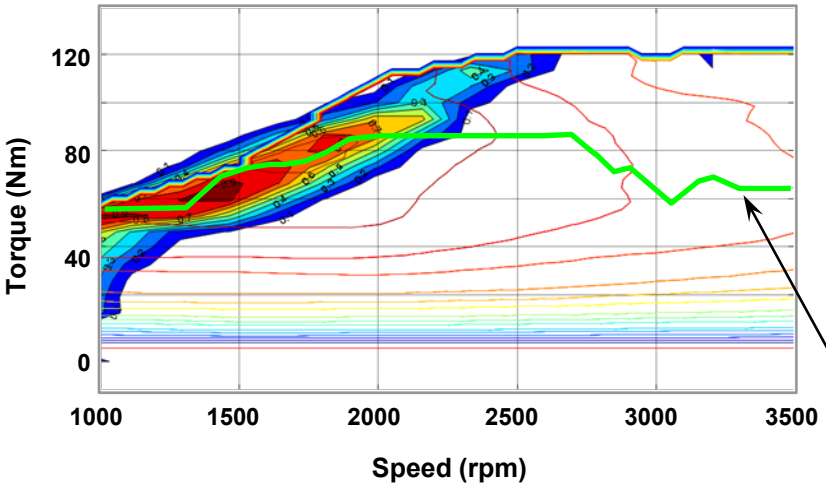
- Hybrid powertrains scaled to provide similar performance.
- Results reflect advantages of hybrid operation, including engine downsizing.

Simulated engine operational characteristics using Saab BioPower maps

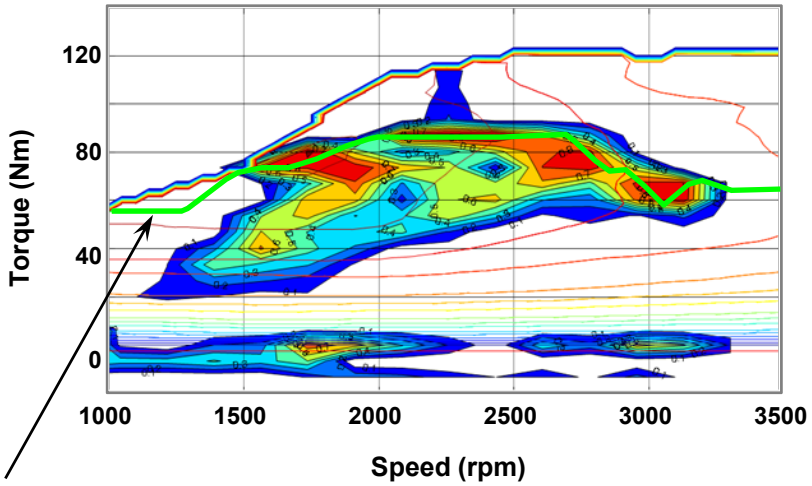
- **Power split** not speed constrained, lower speed/higher load operation
- **Power split** architecture provides greater flexibility for operating the engine in its most efficient regions

- **Parallel** spends more time operating off max efficiency curve at higher speeds

Power Split



Parallel



Maximum efficiency line based on torque

Delphi is providing updated motor models for simulations

- **Original PSAT motor model has requirement that motoring and generating share same efficiency map.**
- **Delphi modification provides for the input of separate maps for motoring and generating.**
  - » Map development based on data from Power Electronics Group at ORNL.
- **Continued PSAT modeling of advanced powertrain systems will make use of Delphi power electronics and traction drive modeling.**

Path Forward

- **Perform fundamental investigation of ethanol efficiency potential on single cylinder engine with combination of valve actuation flexibility, custom pistons, and engine modeling.**
- **Install and exercise advanced ethanol engine at ORNL to generate baseline and ethanol-specific maps for use with PSAT.**
- **Simulate conventional and advanced powertrains using Saab Bio-Power data (gasoline and ethanol) in split and parallel HEV models for relevant drive cycles.**
- **Simulate conventional and advanced powertrains using data from advanced ethanol engine and iterate between simulation and experiment to optimize operation for specific powertrain and operation.**

Summary or *take away points*

- **Objective / Background**
  - To explore potential of ethanol-based fuels for improvements in drive-cycle efficiency and emissions based on simulation and experiment.
  - Activity has joint sponsorship by Vehicle Systems and Fuel Technologies programs and makes use of state-of-the-art engine technology through industry partnership in support of VTP R&D priorities.
- **Technology Path & Demonstration**
  - Multi-cylinder engine with advanced ethanol-compatible components and controls has been developed for use in this activity.
  - Single-cylinder experiments for fundamental investigation of ethanol potential for improved efficiency.
  - Base vehicle model has been developed and evaluated with conventional and advanced powertrains, and will be used in combination with multi-cylinder engine results for further understanding of ethanol potential with advanced powertrains.
- **Technology Transfer**
  - Aspects of this activity are regularly communicated either directly or indirectly to DOE, industry, and others through government working groups, technical meetings, and one-on-one interactions.
- **Longer Term**
  - *Transient* issues are becoming more and more important. Need for more emphasis on the development, integration, and evaluation of advanced transportation technologies to better understand synergies and/or operational issues for optimal efficiency AND lowest emissions with conventional and advanced powertrains.