Advanced Technology Vehicle Lab Benchmarking – Level 1

2014 U.S. DOE Vehicle Technologies Program
Annual Merit Review and Peer Evaluation Meeting

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Argonne National Laboratory

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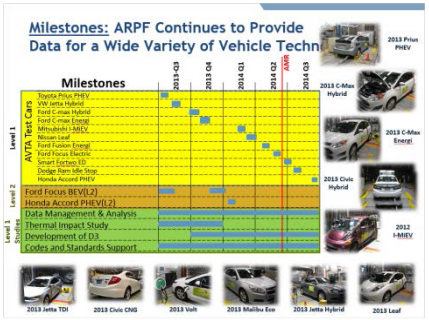
This presentation does not contain any proprietary, confidential, or otherwise restricted information.

U.S. Department of Energy
Energy Efficiency and Renewable Energy
Bringing you a prosperous future where energy is clean, abundant, reliable, and affordable

Overview

- **Timeline**
  - Benchmarking at ANL started in 1998
  - FY13 & FY14 Completed Testing:
    - 10 vehicles tested in FY13, 4 in FY14
    - Thermal impact study
    - Conventional vehicle study
  - FY14 and FY15 Test Vehicles
    - See Milestone on slide 6



- **Budget**
  - FY2013 $1,300k
  - FY2014 $1,480k
  - Other Leveraged DOE Projects (separate funding): Codes and Standards test support, Thermal Impact Evaluations

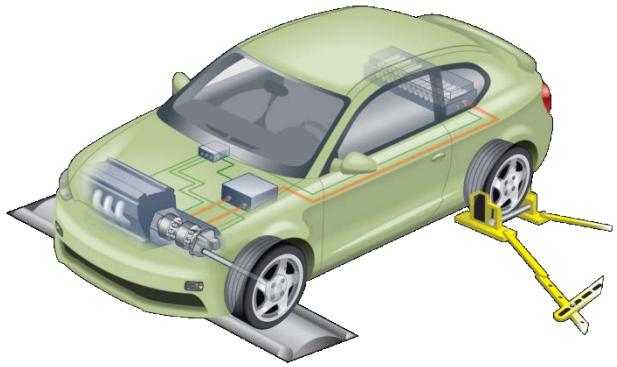
- **DOE VSST barriers addressed:**
  - Computational Models, Design and Simulation Methodologies (C)
    - Model development and validation
  - Lack of Standardized Testing Protocols (D)
    - Validating BEV and PHEV test procedures
    - Support of SAE committee (J2951 Drive Metrics, J2907/2908 Powertrain rating, J2263 Coast Down, etc…)
  - Constant Advances in Technology (F)
    - Public data generation from benchmarking recent mass-produced BEVs and PHEVs.
    - Advances in HEVs and Alt Fueled Vehicles compared to previous models

- **Partners:**
  - AVTA (Advanced Vehicle Testing Activity): DOE, INL, ANL, Intertek
  - DOE, National Laboratories, USDrive, OEMs, Suppliers, Vehicle Competitions

Relevance: Objectives of the Advanced Powertrain Research Facility (APRF)

Benchmark Objective

"Provide to DOE and Partners the Best Advanced Vehicle Test Data and Analysis"



Codes and Standards Objective

"Assist in codes and standards development with public and independent research and data"

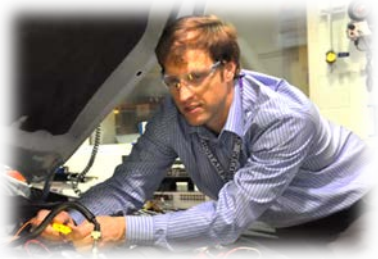
Laboratory Testing Mission

Enable petroleum displacement through technology assessment & data dissemination

- Establish the state-of-the-art automotive technology baseline for powertrain systems and components through test data generation and analysis
- Provide independent and public data for evaluation of emerging technology
- Generate data to support model creation and validation, standards development, and DOE target setting

Focus for FY14

- Establish technology benchmarks for HEV, PHEV, BEV, Conventional and Alternative Fuel Vehicles.
- Development of data management and analysis tools for quicker data distribution
- Evaluation of thermal effects on energy consumption and powertrain behavior



Relevance: Advanced Technology Benchmark- Matching Technology to Targets

- Vehicle Research: Dynamometer Testing
  - Vehicle system testing
    - Energy consumption (fuel + electricity)
    - Emissions
    - Performance
    - Vehicle operation and powertrain strategy
  - 'In-situ' component and system testing
    - Component performance, efficiency and operation over drive cycles
    - Component mapping
  - Technology assessment and goal setting

Vehicle Technologies Office Plan

- Hybrid and Vehicle Systems
- Energy Storage
- Advanced Power Electronics
- Materials Technology
- Advanced Combustion Engines
- Fuels and Lubricants

VSST Challenges and barriers

A. Risk Aversion
B. Cost.
C. Infrastructure.
D. Lack of standardized test protocols.
E. Computational models, design and simulation methodologies.
F. Constant advances in technology.

Relevance: Purpose and Destination of Vehicle Testing and Analysis

"Knowing how good you are requires an accurate picture of how good everybody else is"

Data and Analysis

D^3 Dynamometer Downloadable Database
www.transportation.anl.gov/D3/
Limited Public data sets

US Drive Tech Team Support
Full data sets

Supporting DOE

Independent technology evaluation
Baseline for technical targets and goal setting

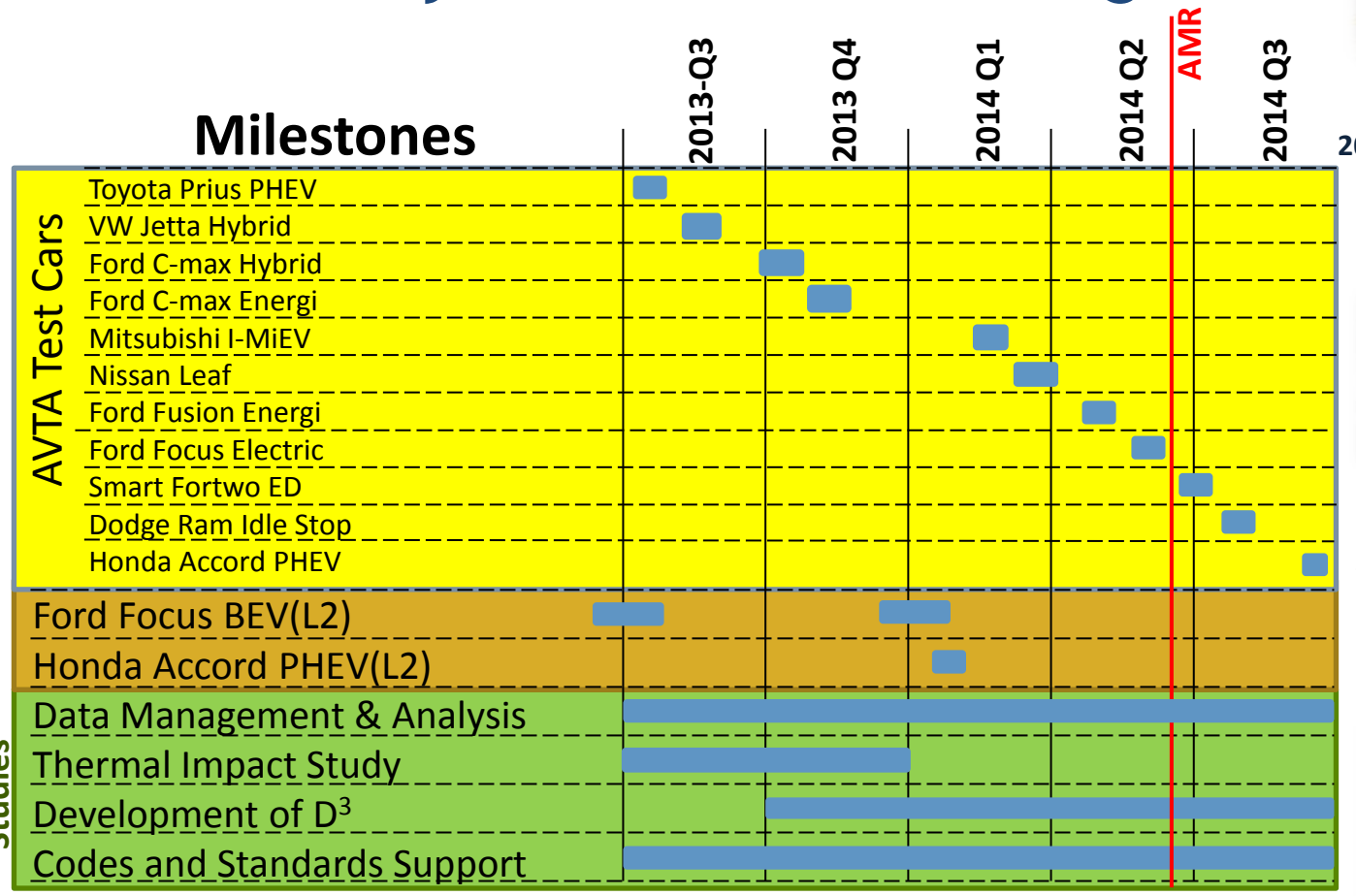
- *Vehicle efficiencies and energy use: average over drive cycles at different temperatures*
- *Component behaviors from a vehicle system perspective*
- *Charging profiles, battery capacities, battery characterizations*

Technology challenge
→ Innovation opportunity
Heating , Thermal management, Accessory loads,….

Codes and Standards
Data for procedures development and validation

Modeling Support
Component mapping
Thermal analysis
Climate control system
Data for validation

Milestones: ARPF- Providing Data for a Wide Variety of Vehicle Technologies




2013 Prius PHEV


2013 C-Max Hybrid


2013 C-Max Energi


2013 Civic Hybrid


2012 I-MiEV


2013 Jetta TDI


2013 Civic CNG


2013 Volt


2013 Malibu Eco


2013 Jetta Hybrid


2013 Leaf

Approach: Well-Established and Proficient Testing Methods Adjusted to Individual Technologies

The vehicle benchmark activity has been refined during the past decade, which has resulted in:

- Advanced and unique facilities and instrumentation
- Continuous improvement of testing procedures
- Standardization of test plans including instrumentation and drive cycles which are adjusted for individual vehicles
- Significant knowledge of advanced vehicles and testing methods

APRF expertise in testing

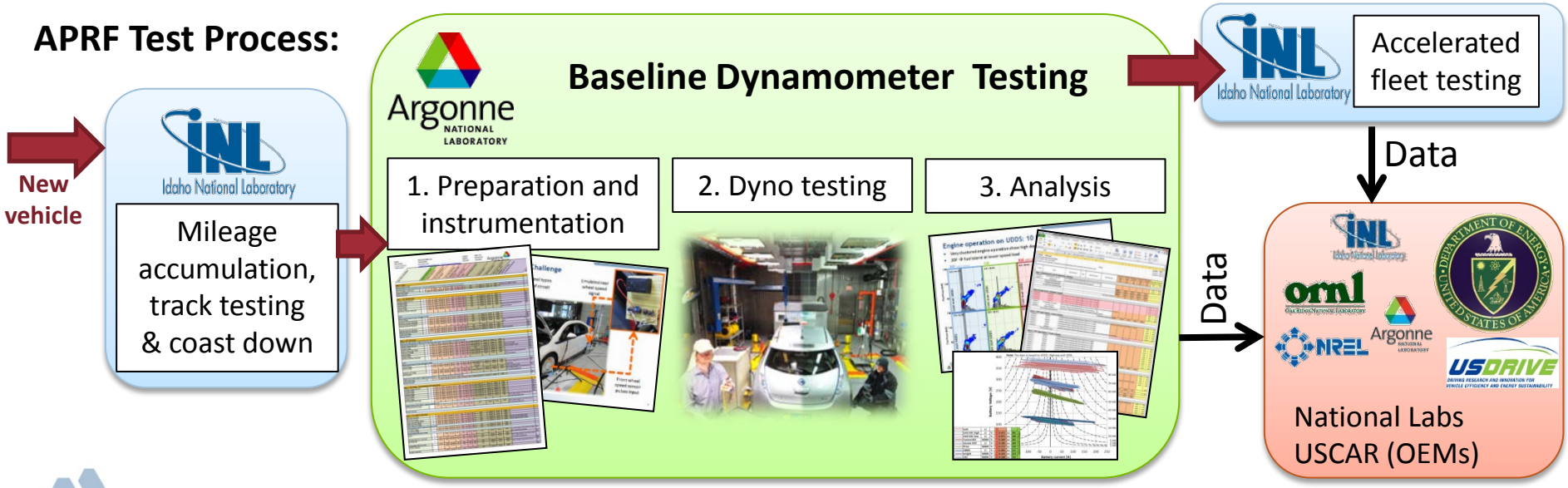
Powertrains

- Conventional
- Hybrid Electric (HEV)
- Plug-in HEV (PHEV)
- Battery Electric (BEV or EV)
- Fuel Cell Vehicle

Alternative fuels

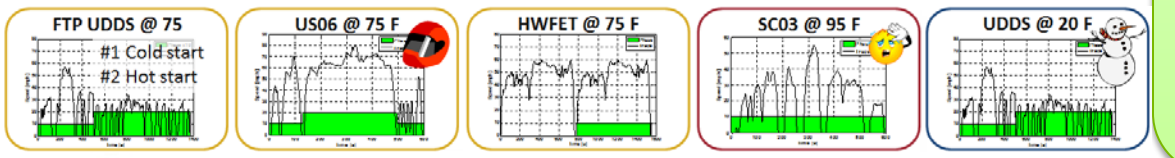
- Hydrogen, Natural Gas
- Ethanol, Butanol
- Diesel (Bio, Fisher-Tropsch)

APRF Test Process:



Approach: Purpose Built Research Laboratory for Automotive Benchmark Activities

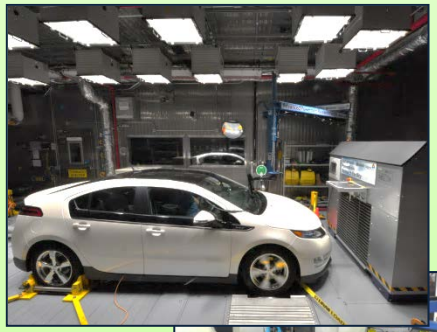
- Level 1 testing: Basic and comprehensive instrumentation
  - Level 1 = non-intrusive instrumentation
  - Vehicle characterization (fuel and energy consumption, emissions, performance)
  - Vehicle operation and strategy
  - Component specific instrumentation for analysis and modeling (speed, temp, and other technology specific removable instrumentation)
- Drive cycles and test conditions
  - Standard drive cycles, technology specific cycles, performance tests, vehicle and component mapping cycles
  - Thermal test conditions: 20°F, 72°F and 95°F with 850 W/m^2 radiant solar energy "5-Cycle"
  - Additional testing at 0°F and 40 °F as desired



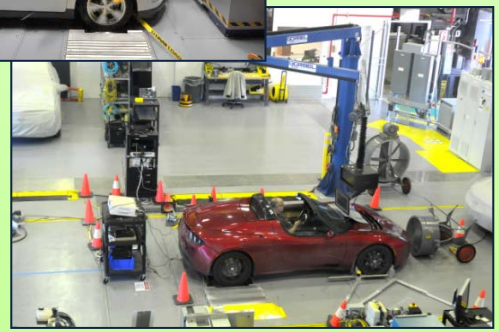
Advanced Powertrain Research Facility

The right tools for the task:

- *Two chassis dynamometer cells*
- *Custom DAQ, flexible, module-driven, used in both cells*
- *Thermal chamber which is 5-Cycle compliant (+)*



4WD chassis dyno with thermal chamber

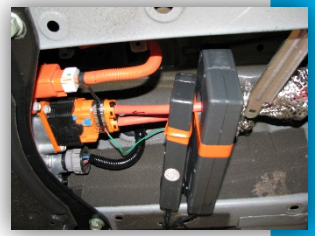


2WD chassis dyno

Accomplishments: Revised Instrumentation, Testing, and Data Management

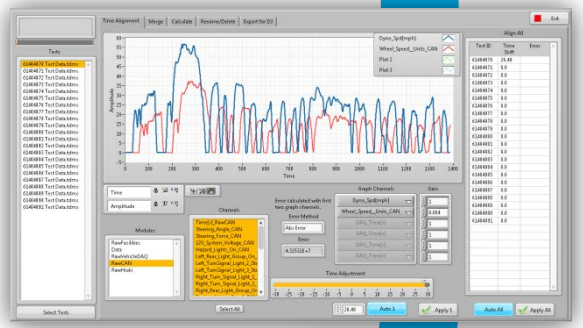
Non-Invasive Vehicle Instrumentation

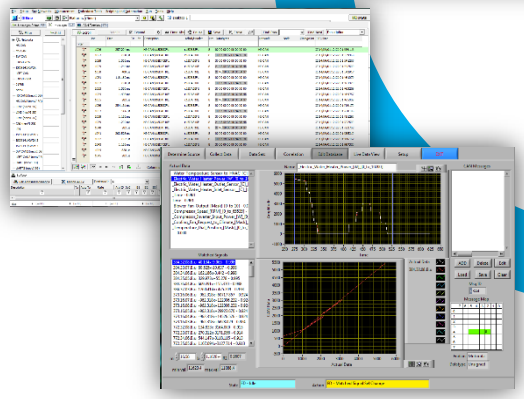




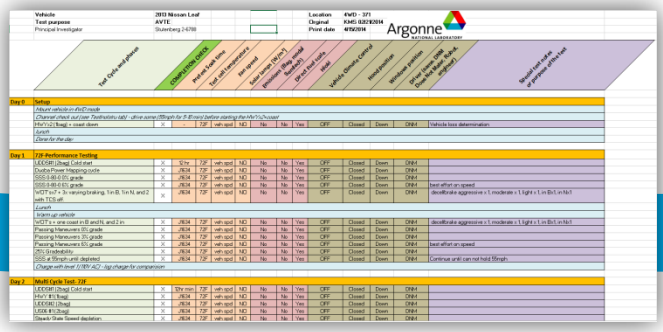

Data Dissemination

Data Management



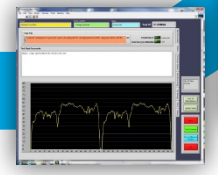
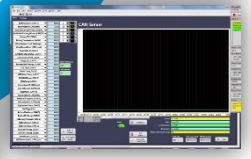


Logging of Vehicle Signals



Test Planning System

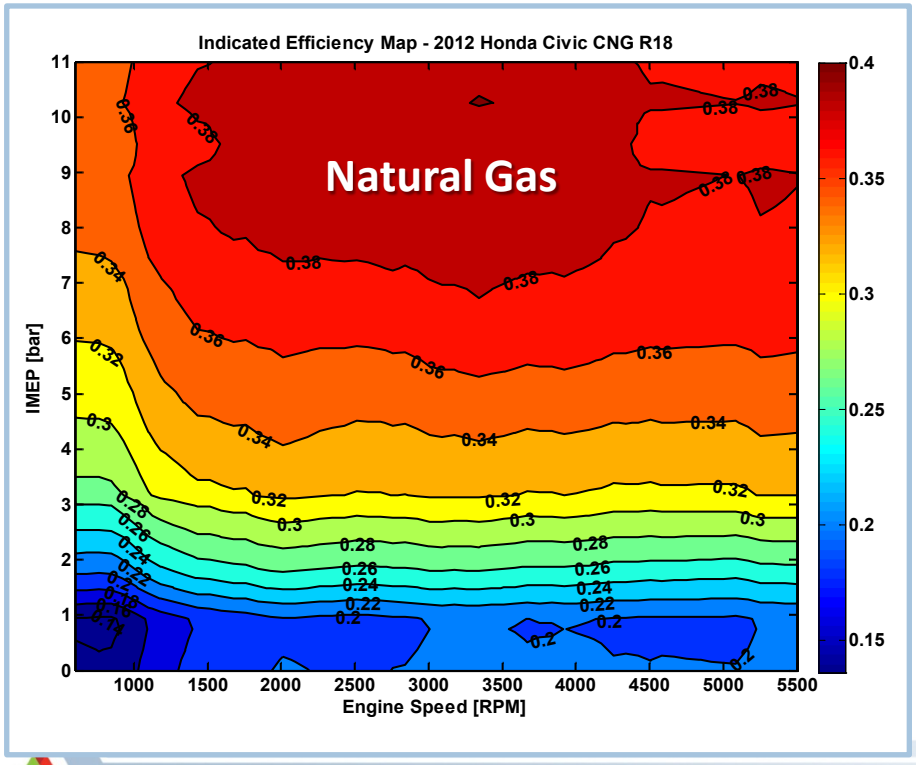
(SAE and research methods)

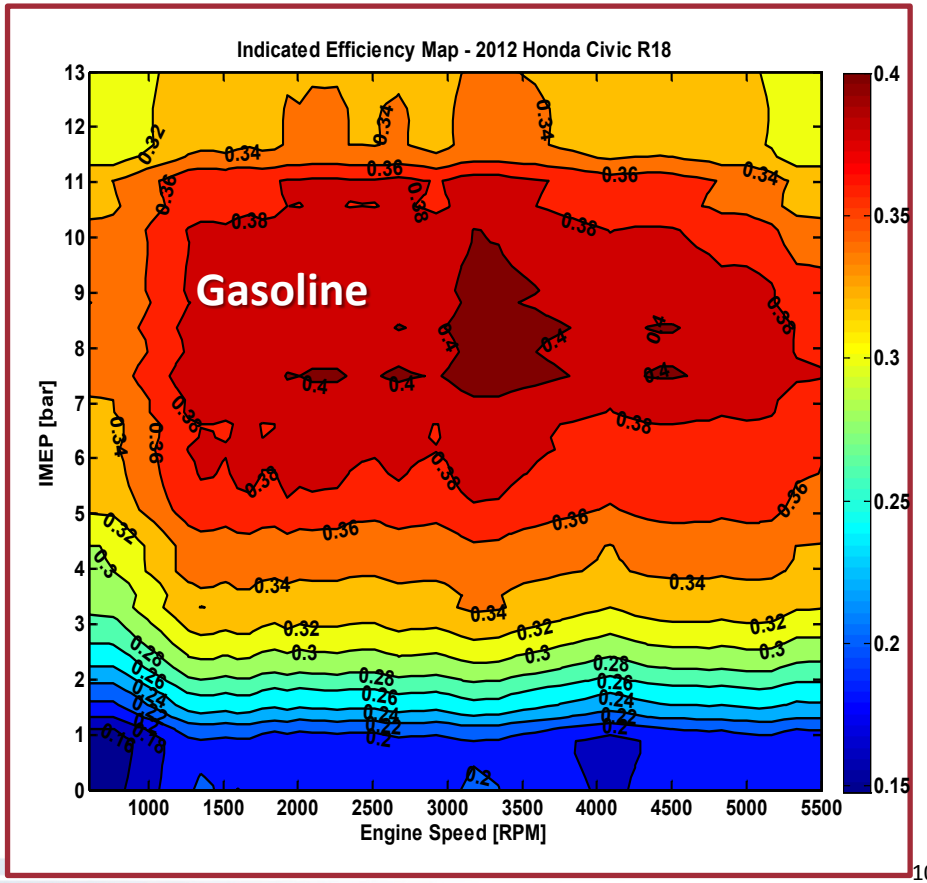




Flexible Testing with Custom Modular DAQ

Accomplishments: CNG vs Gasoline Engine Comparison through Indicated Efficiency

	CNG	Gasoline
UDDS FE	31.9 mpgge	34.8 mpg
Highway FE	49.5 mpgge	53.4 mpg
US06 FE	31.2 mpgge	32.7 mpg
0-80 mph	23.1 s	18.3 s

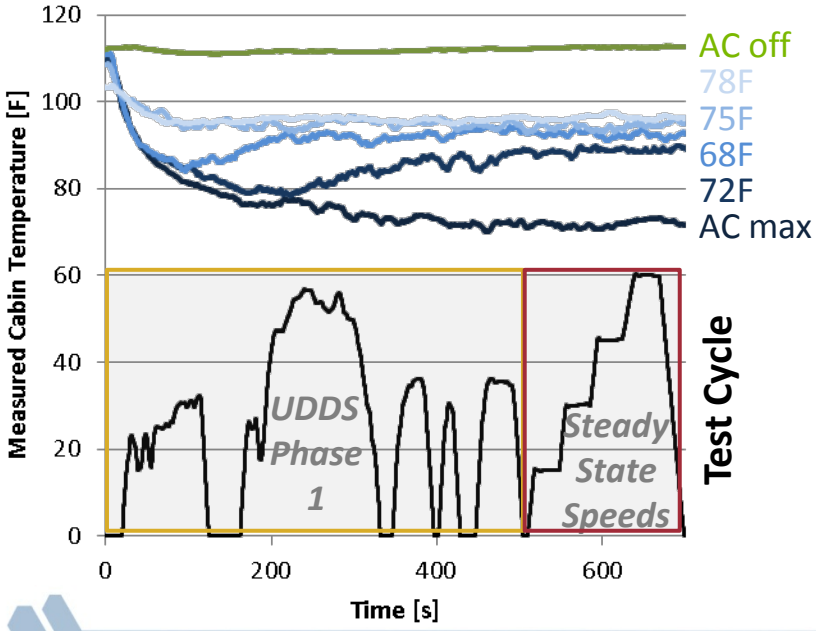




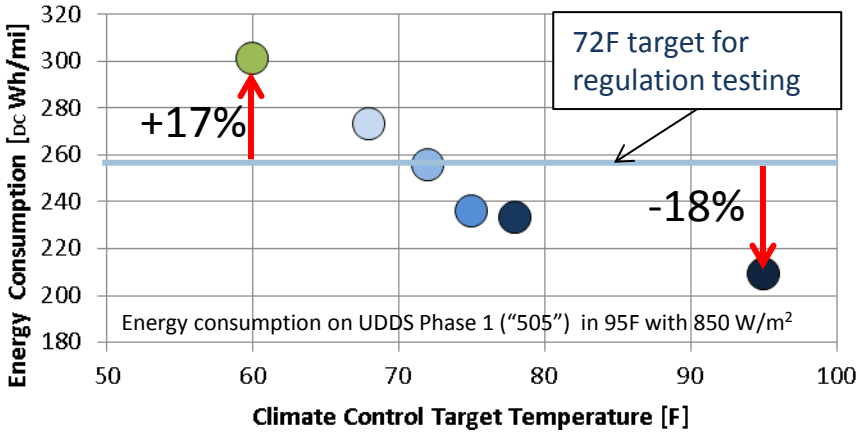
Accomplishments: Temperature Effects on BEV Range

Accomplishments:
Effect of Climate Control Setting on Consumption on "Sunny" 95F Day

Test Setup:
2014 Ford Cmax Energi
Charge depleting mode
95F with 850 W/m²

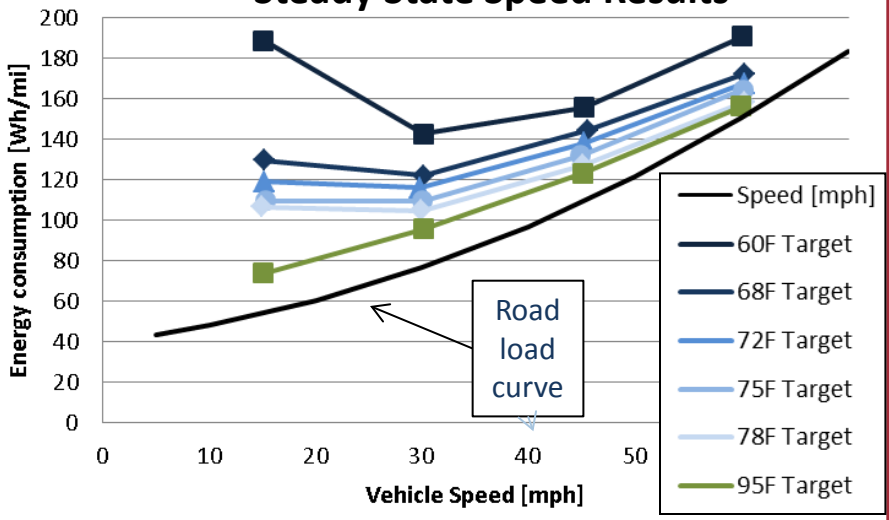


City Driving Results



→ *Cabin temperature setting can save or cost almost 20% in city driving on a hot day*

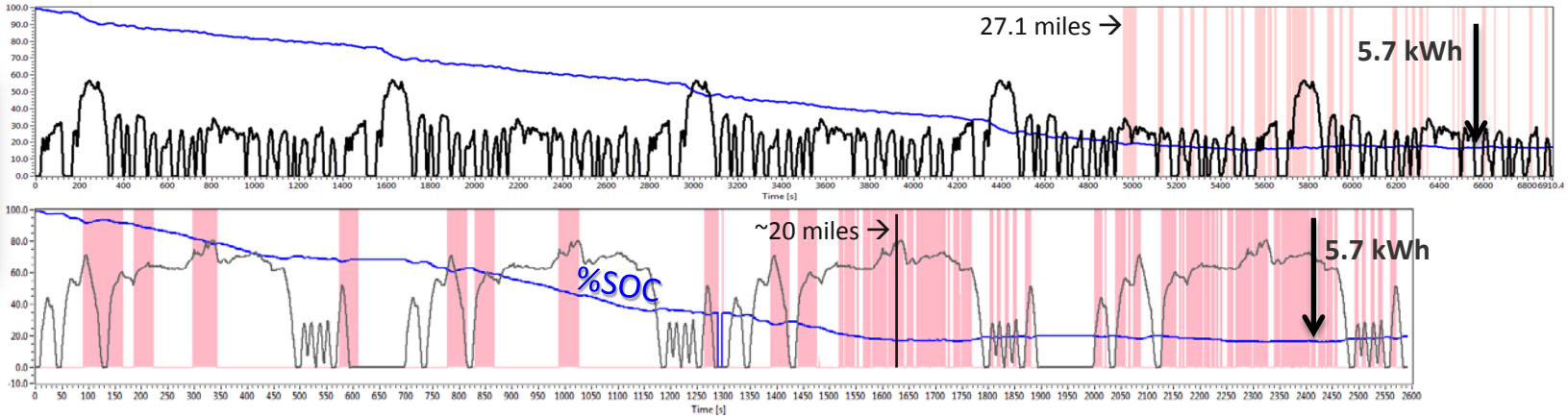
Steady State Speed Results



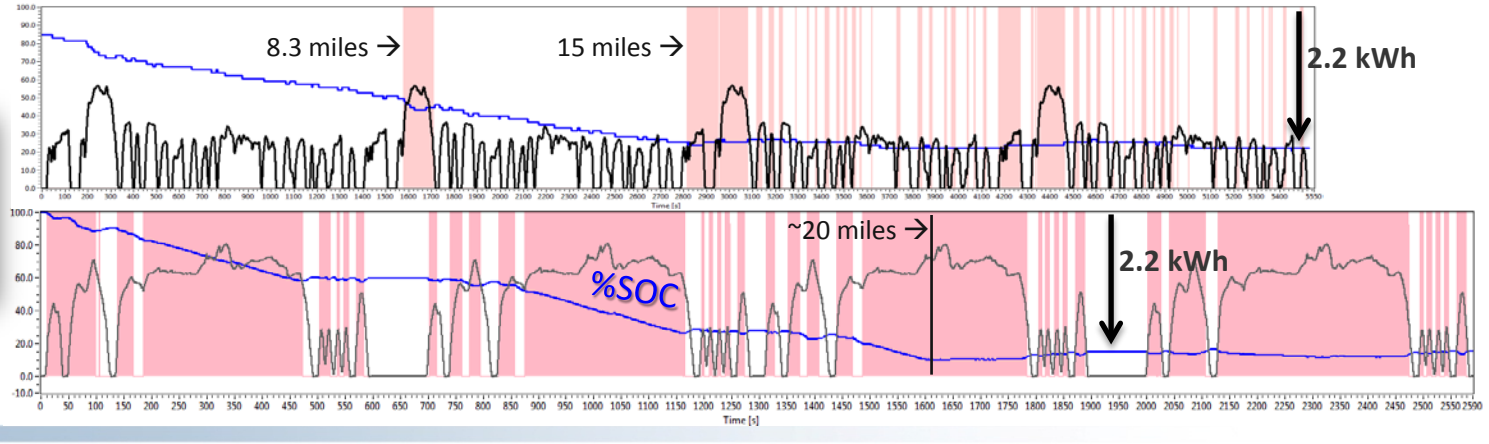
→ *Use the AC at high speeds, but at low speeds the AC power outweighs the powertrain power*

Accomplishments: "Blended" PHEV Fuel Displacement Varies Heavily on Design and Controls

- Both vehicles can drive a UDDS cycle in electric mode, but not the aggressive US06 cycle
- EV power capability limits quick discharge of on-board battery energy, which limits fuel displacement

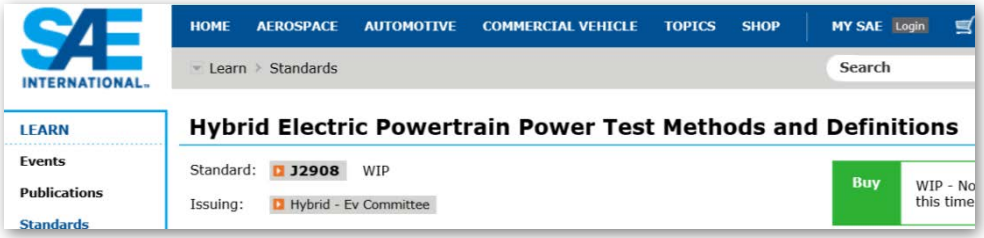


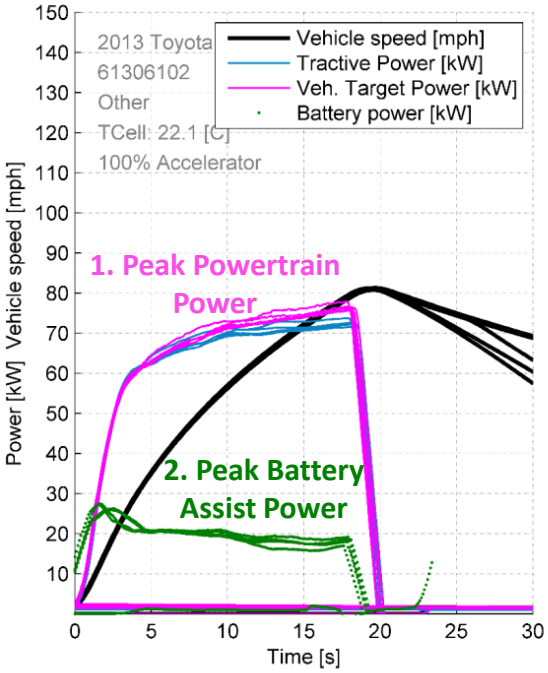
= Periods of Engine-Assist



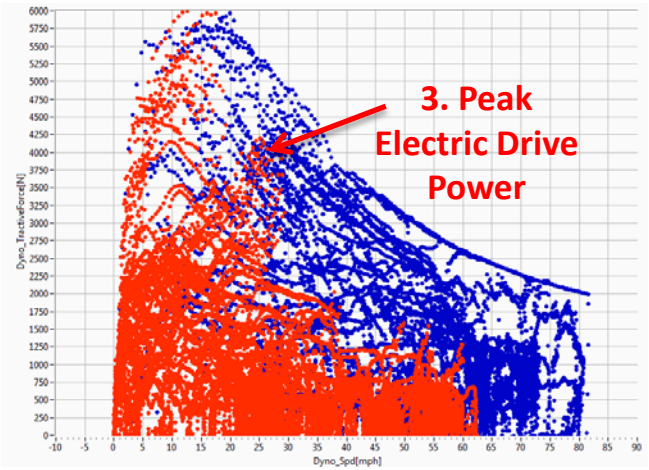
Accomplishments: Assist in Codes and Standards

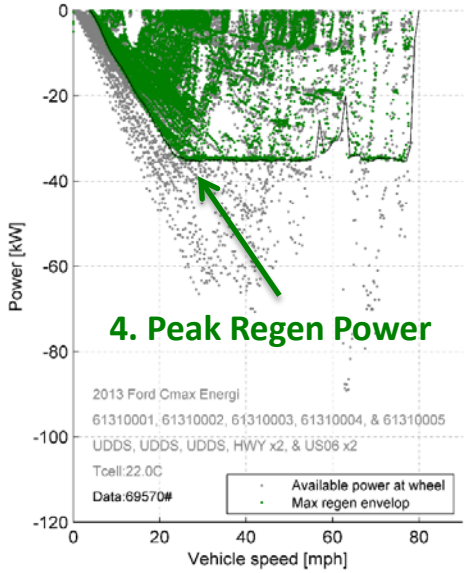
Level 1 Argonne Benchmarking Tests Are Prototypes for Power Rating Procedures (SAE J2908)





Four (4) different power ratings considered in SAE J2908, they are:

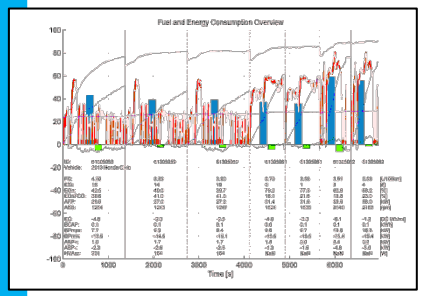


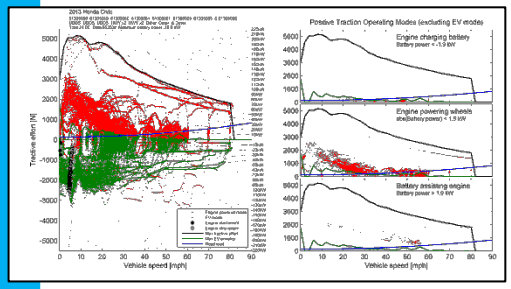


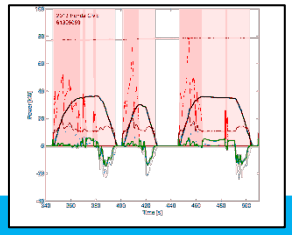
Accomplishments: Data Analysis and Reporting

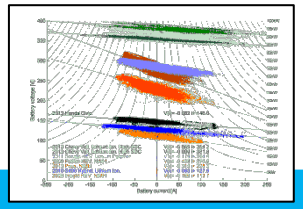
Data Management Tool

Analysis and Reporting Tools



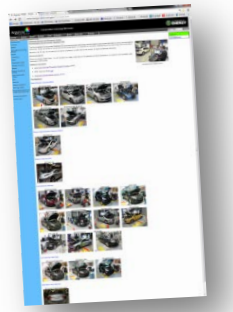






D^3

Vehicle Database organized by vehicle type



Page for each vehicle

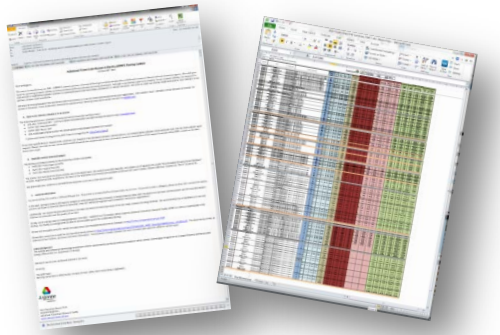
- Images
- Brief description
- Key technologies
- Analysis presentation (when available)
- Test summary results
- 10Hz data download

Test Summary Results

Each test has a unique test ID

10Hz raw data files

Files named by unique test ID



Bi-Monthly Update

- Images
- Brief description
- Key technologies
- Analysis presentation (when available)
- Test summary results
- 10Hz data download
- Full Signal List

www.transportation.anl.gov/D3/

Coordination: Existing Collaborations with Other Institutions

J1711 HEV & PHEV test procedures
J1634 EV test procedures
SAE International

International
- KATECH (Korea)
- ISO
- JARI (Japan)
- IEA
- Joint Research Centre (EU)

AVTA (Advanced Vehicle Testing Activity)
Baseline dynamometer testing of vehicles
INL Idaho National Laboratory, Argonne National Laboratory

APRF


DOE technology evaluation
- DOE requests
- National Lab requests

NREL, ornl, INL Idaho National Laboratory, Argonne National Laboratory

AVTC (Advanced Vehicle Technology Competition)
Universities
AVTC, GM, EcoCAR2 PLUGGING IN TO THE FUTURE

USCAR, tech teams and OEMs
Shared test plans, data and analysis
USDRIVE DRIVING RESEARCH AND INNOVATION FOR VEHICLE EFFICIENCY AND ENERGY SUSTAINABILITY

Autonomie
Support of modeling and simulation with data
AUTONOMIE

Chrysler – CTC
GM – Powertrain, Milford
Ford – Powertrain, APTL

Proposed Future Work: Level 1 Benchmark Will Continue with Emphasis on Thermal Testing

AVTA Vehicles (as of Apr 2014):

- 2014 Ford Fusion Energi
- 2013 Ford Focus BEV
- 2014 Smart EV
- 2014 Dodge RAM Start/Stop + 8 spd
  - Future CNG conversion
  - Enhanced Lead-Acid Battery modification
- 2014 Honda Accord PHEV
- Further potential AVTA vehicles:
  - 2015 Mazda6 i-ELoop / Mazda6 Diesel
  - 2015 Chevrolet Cruze Diesel
  - 2015 Mitsubishi Outlander PHEV
  - 2015 Audi A3 e-tron PHEV
  - 2015 BMW i3 EV / BMW i3 Range Extender
  - 2015 Chevrolet Spark EV
  - 2014 Chevrolet Impala Bi-fuel

2012 Mitsubishi i-MEV
- **Completed** AVTA Baseline
- SAE J1634 Shortcut Validation with Robot Driver

2013 Nissan Leaf
- **Completed** AVTA Baseline
- Thermal testing with heat pump

Other Level 1 Vehicles

- 2015 Via VTRUX Van PHEV
- CVT vehicle Rental probably 2014 Nissan Altima

Level 2 Vehicles + ANL Vehicles

- 2013 Ford Focus BEV retest
- 2014 Honda Accord PHEV
- 2013 VW Passat EcoBoost CNG bi-fuel
- 2014 Jeep Cherokee Thermal research collaboration with Chrysler

Summary

- **Level 1 Benchmark Activity** continues to provide precise laboratory test data for a wide range of vehicle technologies that address DOE goals
  - Establish the state-of-the-art automotive technology baseline for powertrain systems and components through data collection and analysis
  - Providing independent evaluation of technology and support for DOE target setting
  - Generating test data for model development and validation to encourage speed-to-market of advanced technologies
  - Supporting codes and standards development for unbiased technology weighting
- **Accomplishments from Level 1 testing**
  - Refined data management, analysis, and reporting capabilities
  - Continued evaluation of thermal impact on energy consumption and powertrain operation of conventional, alt fuel, and electrified vehicle technologies
  - AVTA vehicle testing in-progress in collaboration with INL
  - Test results and raw data available publicly at the Downloadable Dynamometer Database website (http://www.transportation.anl.gov/D3/)
  - Enhanced signal and testing lists available to OEM & DOE Partners
- **Continued Link to Industry** is an important component of vehicle testing
  - Sharing best test practices, facility hardware recommendations, data analysis methods
  - Industry technology experts provide insight into what data is of interest, assisting in testing direction

Technical Back-Up Slides

Advanced Powertrain Research Facility
4WD Chassis Dynamometer Thermal Test Cell

Argonne NATIONAL LABORATORY

U.S. DEPARTMENT OF ENERGY

"Research and Data Driven Lab"
"Independent Public Data"

• Test cell features

- ✓ 4WD chassis dynamometer
  - Variable wheel base (180inches max)
  - 250 hp/axle
  - 300 to 12,000 lbs.. inertia emulation
- ✓ Radiant sun energy emulation 850W/m^2 (adjustable)
- ✓ Variable speed cooling fan (0–62mph)
- ✓ Gaseous fuel and hydrogen capable
- ✓ Diesel: Dilution tunnel, PM, HFID

• Thermal chamber

- ✓ EPA 5 cycle capable (20°F, 72°F and 95°F + 850W/m^2 solar load)
- ✓ Demonstrated as low as 0°F
- ✓ Intermediate temperatures possible

• Research aspects

- ✓ Modular and custom DAQ with real time data display
- ✓ Process water available for cooling of experiment components
- ✓ Available power in test cell
  - 480VAC @ 200A
  - 208VAC @ 100A
- ✓ ABC 170 Power supply capable to emulate electric vehicle battery
- ✓ Custom Robot Driver with adaptive learning
- ✓ Several vehicle tie downs
  - chains, low profile, rigid,…
  - 2, 3 and 4 wheel vehicle capable
- ✓ Expertise in testing hybrid and plug-in hybrid electric vehicles, battery electric vehicles and alternative fuel vehicles

• Special instrumentation

- ✓ High precision power analyzers (testing and charging)
- ✓ CAN decoding and recording
- ✓ OCR scan tool recording
- ✓ Direct Fuel Flow metering
- ✓ Infra Red Temperature camera
- ✓ In cylinder pressure indicating systems
- ✓ In-situ torque sensor measurement
- ✓ 5 gas emissions dilute bench with CVS (modal and bag emissions analysis)
- ✓ FTIR, Mobile Emissions unit
- ✓ Raw and Fast HC and NOx bench
- ✓ Aldehyde bench for alcohol fuels

***APRF** (Advanced Powertrain Research Facility)*

ver. Jan2012

Advanced Powertrain Research Facility
2WD Chassis Dynamometer

Argonne NATIONAL LABORATORY

U.S. DEPARTMENT OF ENERGY

"Research and Data Driven Lab"
"Independent Public Data"

• Test cell features

- ✓ 2WD Light Duty / Medium Duty chassis dynamometer
  - 300 hp
  - 300 to 14,000 lbs.. inertia emulation
  - 10,000 lbs.. max weight driven axle
- ✓ Multiple cooling fans available
- ✓ Vehicle lift (max 10,000 lbs..)
- ✓ Remotely located control room with conference area

• Research aspects

- ✓ Modular and custom DAQ with real time data display
- ✓ Flexible to adopt any drive cycle
- ✓ Available power in test cell
  - 480VAC @ 200A & 100A
  - 208VAC @ 50A, 30A & 20A x3
- ✓ ABC 170 power supply capable to emulate electric vehicle battery
- ✓ Custom Robot Driver with adaptive learning
- ✓ Expertise in testing hybrid and plug-in hybrid electric vehicles, battery electric vehicles and alternative fuel vehicles

• Special instrumentation

- ✓ High precision power analyzers (testing and charging)
- ✓ CAN decoding and recording
- ✓ OCR scan tool recording
- ✓ Direct Fuel Flow metering
- ✓ Infra Red Temperature camera
- ✓ In cylinder pressure indicating systems
- ✓ In-situ torque sensor measurement
- ✓ SEMTECH-DS (Mobile Emissions unit) with AVL DVE mass flow sensor

APRF (Advanced Powertrain Research Facility)

ver. Jan2012