Argonne NATIONAL LABORATORY

Advanced Technology Vehicle Benchmark and Assessment

2010 DOE Hydrogen Program and Vehicle Technologies Annual Merit Review

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Sponsored by Lee Slezak

Project ID # VSS016

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

U.S. DEPARTMENT OF ENERGY

Overview

60% complete on FY2010 tasks

- Timeline
  - Level 1
    - 2010 Honda Insight - 3Q09
    - 2010 Toyota Prius - 3Q09
    - 2010 Mini-E - 3Q09
    - 2010 Ford Fusion - 4Q09
    - 2010 Mercedes S400h - 1Q10
    - Start / Stop Vehicle Technology – TBD
    - Hyundai HEV – TBD
  - Level 2
    - 2010 Toyota Prius 2Q10 - 3Q10
  - Incremental DOE Projects
    - Ford TADA phase 2 - 2Q09
    - Ford TADA - 2010 TBD
    - GM TADA phase 1 - 3Q10
    - Coal-to-Liquid fuel VW Jetta TDI -3Q09
    - Hydrogen fuel truck durability study - 2Q09 and 2Q10
    - EV prototype for supplier
    - Codes and Standards test support

- Budget
  - 2010FY $1,450k
  - 2009FY~ $1,800k

- DOE strategic goals/barriers addressed:
  - Laboratory and field evaluations of HEVs, PHEVs and EVs
  - Codes and standards development
  - Continued support for model development and validation (AUTONOMIE) with test data
  - EV testing and charging evaluation

- Partners:
  - AVTA (Advanced Vehicle Technology Activity): DOE, INL, eTec
  - DOE, National laboratories, USCAR, OEMs, Suppliers, Vehicle Competitions

Relevance: Advanced Technology Benchmark

- Vehicle research: dynamometer testing
  - Vehicle system testing
    - Energy consumption (fuel + electricity)
    - Emissions
    - Performance
    - Vehicle operation and strategy
  - 'In-situ' component and system testing
    - Component performance, efficiency and operation over drive cycles
    - Component mapping
  - Technology assessment and goal setting
- **Importance: Enable petroleum displacement through data dissemination and technology assessment**
  - Establish the state-of-the-art automotive technology baseline for powertrain systems and components through data generation and analysis
  - Provide independent evaluation of technology
  - Generate data to support target creation and hardware/model validation

APRF

Advanced Powertrain Research Facility

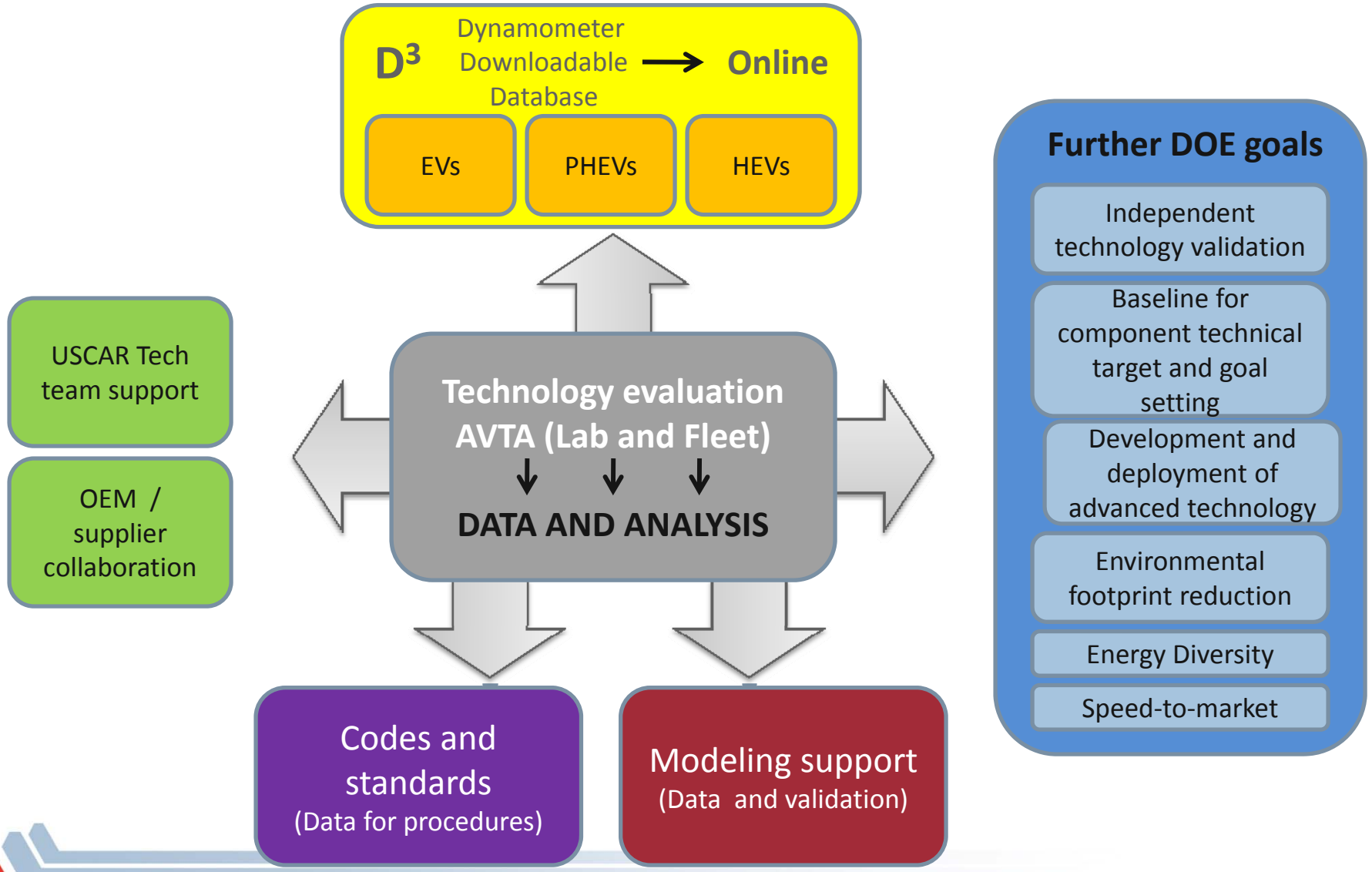
Objective:
Benchmark advanced technology vehicles and disseminate that information to U.S. OEM's, National Labs, and Universities

(APRF since 2000)

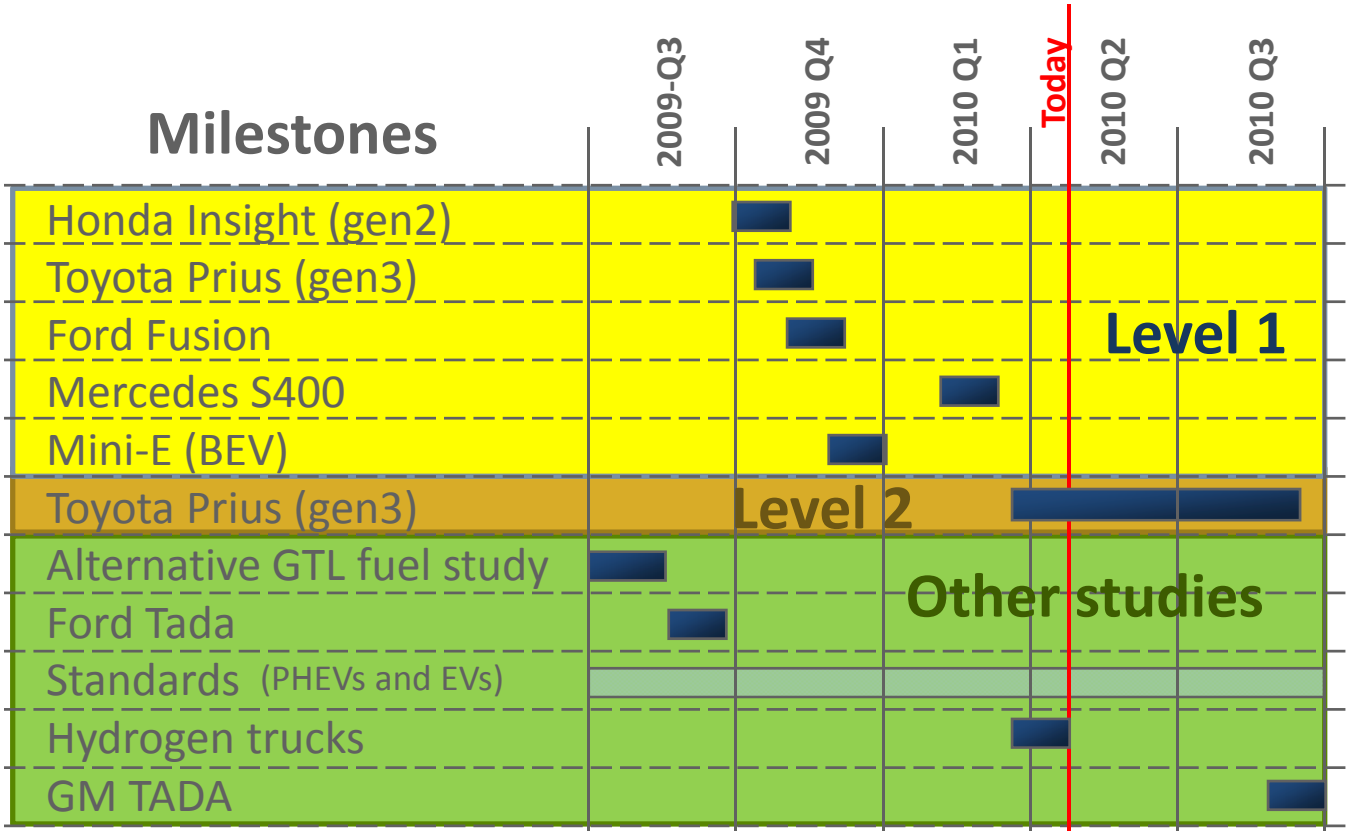
4WD chassis dyno

2WD chassis dyno

Relevance: Enable Petroleum Displacement through Data Dissemination and Technology Assessment

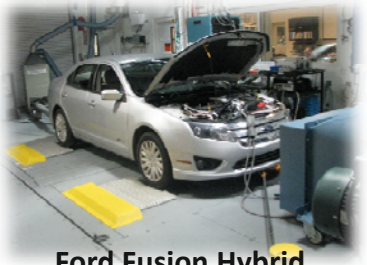


Milestones: APRF Provides Data for a Wide Variety of Vehicle Technologies




2010 Honda Insight


2010 Toyota Prius


Ford Fusion Hybrid


BEV prototype


Ford TADA

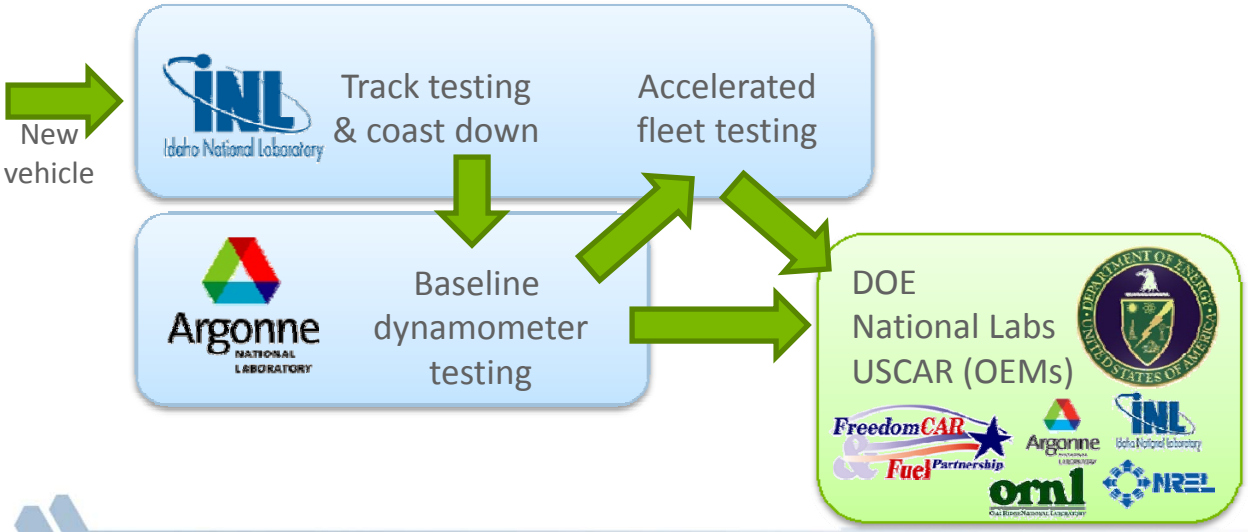

Jetta TDI (bio-fuels)


Mercedes S400H


Mini-E (BEV)

Approach/Strategy: A Well Established and Proficient Testing Approach Adjusted to Individual Vehicles

- The vehicle benchmark activity has been refined for over a decade. This results in:
  - Continuous improvement of testing procedures
  - Standard test plan including instrumentation and drive cycles (adjusted for individual vehicles)
  - Advanced and unique facility and instrumentation
  - Significant knowledge of testing and advanced vehicles
- AVTA (Advanced Vehicle Testing Activity) strategy:



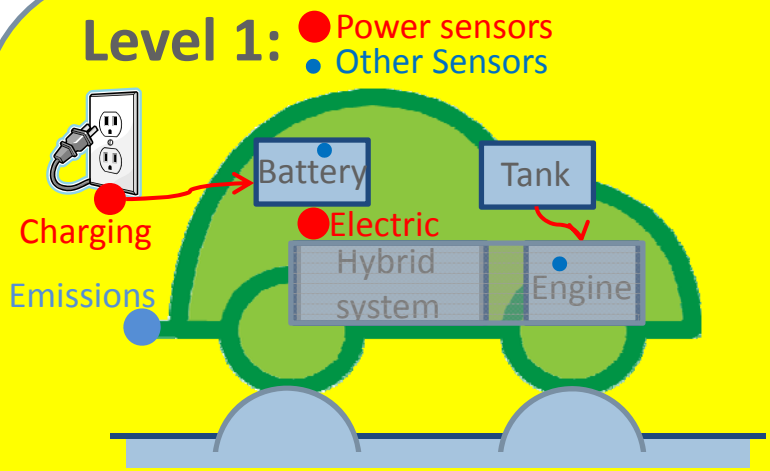
Wide range of vehicle technology tested

Powertrains
- Conventional
- Hybrid Electric (HEV)
- Plug-in HEV (PHEV)
- Battery Electric (BEV or EV)

Alternative fuels
- Hydrogen
- Ethanol, Butanol
- Diesel (Bio, Fisher-Tropsch)

Approach/Strategy: Dynamometer Vehicle Benchmark Testing Approach – Depth of Study Varies

Level 1:



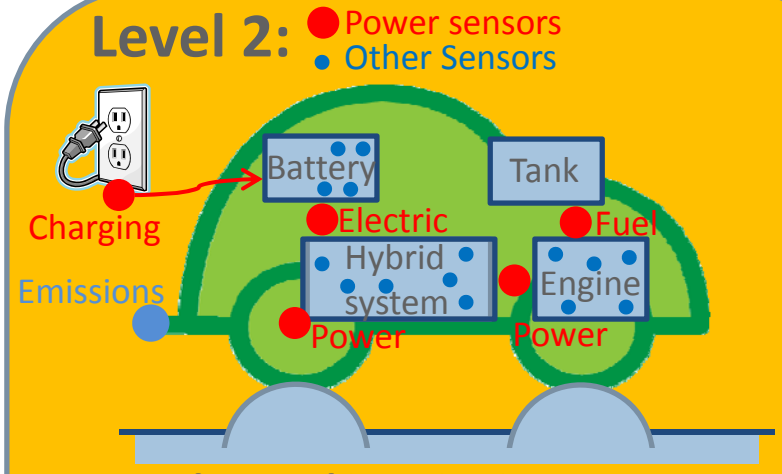
Basics instrumentation:

- Engine speed, fuel flow (bench), oil temp
- Battery, Charger V I (Hioki)
- CAN (if possible)
- Further … if required (but still non invasive)

Purpose:

- Vehicle operating parameter study
- Vehicle characterization (energy consumption, emissions level, performance)

Level 2:



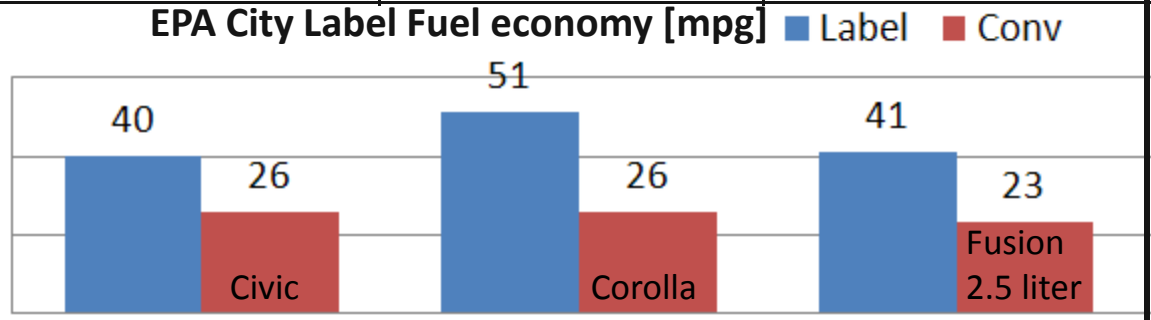
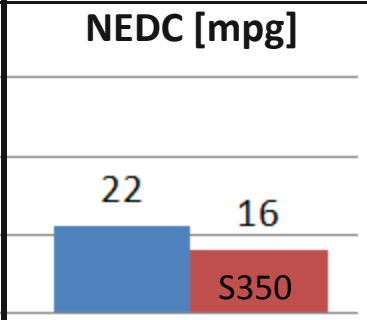
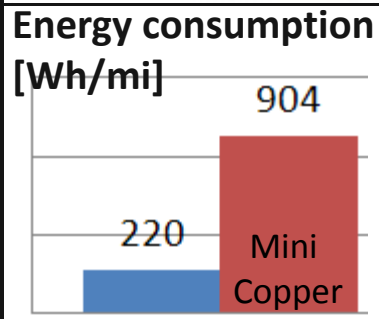
Complete and invasive instrumentation:

- Incremental to level 1
- Engine, shaft torque & speed sensors
- All major power flows (mechanical, electric,…)
- Component specific instrumentation

Purpose:

- Energy analysis, efficiency analysis on vehicle and components
- Component characterization in vehicle system

Accomplishments: Level 1 Testing Overview

2010 Honda Insight	2010 Toyota Prius	Ford Fusion Hybrid	Mercedes S400H	Mini-E (BEV)
				
EPA City Label Fuel economy [mpg] 			**NEDC [mpg]** 	**Energy consumption [Wh/mi]** 
Reason to test: • Value hybrid • Technology evolution	**Reason to test:** •State of the art hybrid •Thermal recovery system	**Reason to test:** •High fuel economy in mid-size sedan •High speed EV operation	**Reason to test:** •First major OEM Lithium Ion battery pack hybrid	**Reason to test:** •Modern Electric Vehicle benchmark •SAE J1634 development
Point of interest: •Compromise of cost to hybrid system effectiveness	**Point of interest :** •PHEV ready HEV	**Point of interest :** •Larger EV operation increase driver impact on fuel economy	**Point of interest :** •Uses Air conditioning system to actively cool the battery pack	**Point of interest :** •Even aggressive driving yields a range over 100 miles

Accomplishments: Tracking Power-Split Hybrid Evolution

Prius and Fusion illustrate most recent hybrid developments:
More Electric-Only Capability and Higher Fuel Economy

HEV Emissions Control Strategies

- Prius uses a prescribed fuel rate for catalyst warm-up
- Battery power is used to supplement engine power

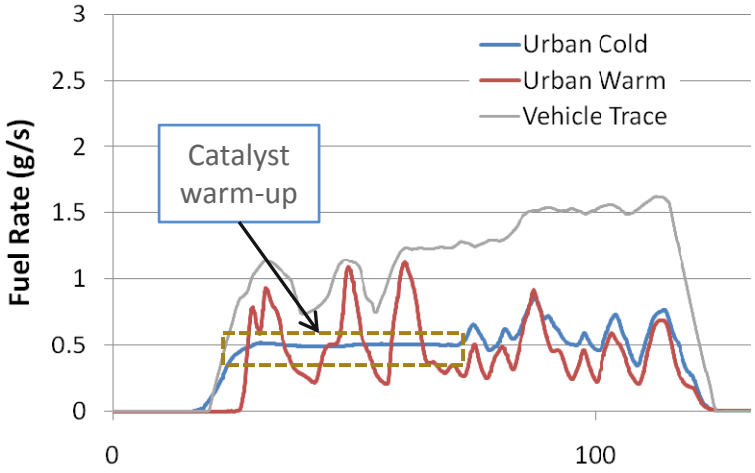
➢Strategy is very applicable to PHEV operation. Allows for flexible engine starting with acceptable emissions

Fuel Economy Variability

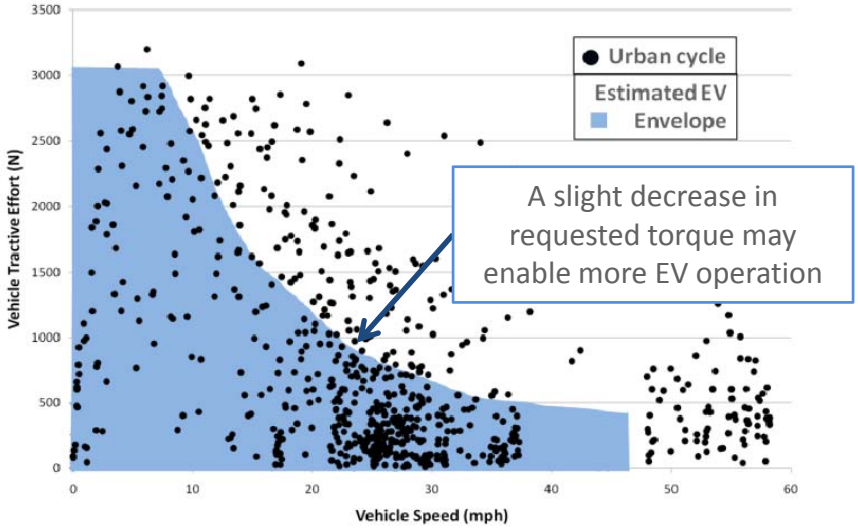
- Fusion EV capability is high-speed, but torque limited
- Location of EV envelope near urban operation results in significant fuel economy variability

➢Blended PHEVs will likely have similar issues affecting real-world fuel economy variability

Prius Cold Engine Starting Strategy



Fusion EV Envelope and Urban Operating Points



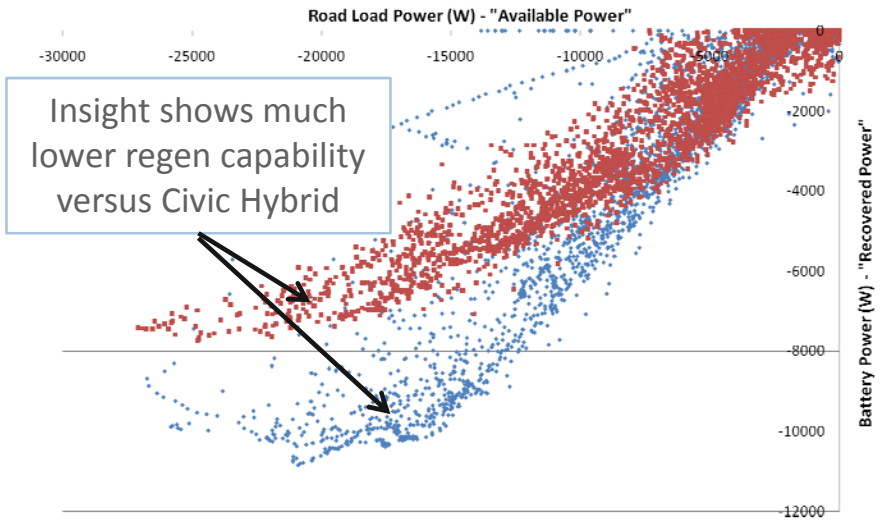
Accomplishments: Evaluation of More Mild Hybrids

Insight demonstrates the limitations of reducing motor and battery usage in order to reduce system cost or prolong component life

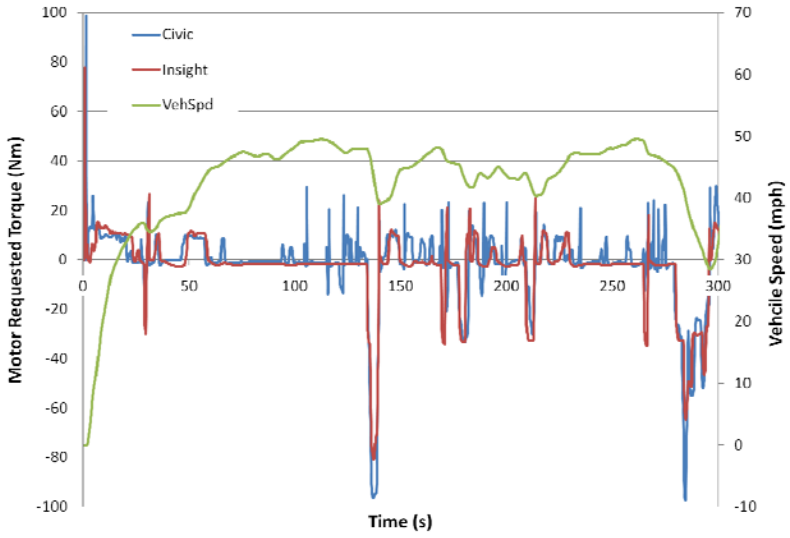
•Due to a more limited hybrid system and despite reduced road load, the 2010 Honda Insight provides similar Urban FE and decreased Hwy FE relative to the previously designed Civic Hybrid. This is primarily due to:

- Reduced regenerative braking capability
- Generally less hybrid system operation (more “mild”)

Civic Hybrid versus Insight Regen Capability



Civic versus Insight Hwy Hybrid System Usage



➢**Mercedes S400h shows similar limitations due to battery usage restrictions to prolong life**

Accomplishments: Alternative Fuel Benchmark

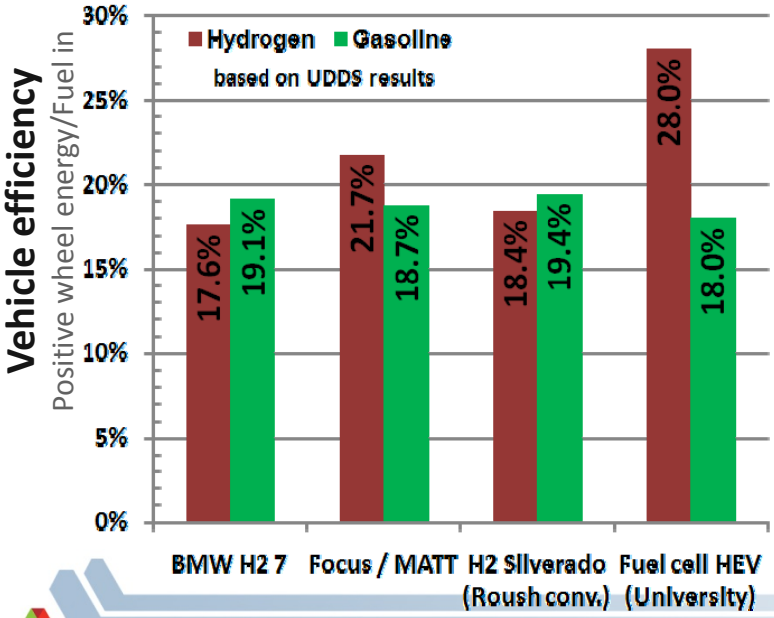
Alternative fuels contribute to Petroleum displacement

Hydrogen powertrains

- Hydrogen can displace 100% of petroleum
- Combustion engines are extremely clean

➢Hydrogen powertrains are efficient and clean, but the storage and infrastructure need a breakthrough

Hydrogen and gasoline powertrain efficiencies on UDDS cycle



Coal-To-Liquid, Gas-To-Liquid diesel study

•Sasol designed:

- CTL to replicate US Ultra Low Sulfur Diesel properties
- GTL to replicate European diesel properties

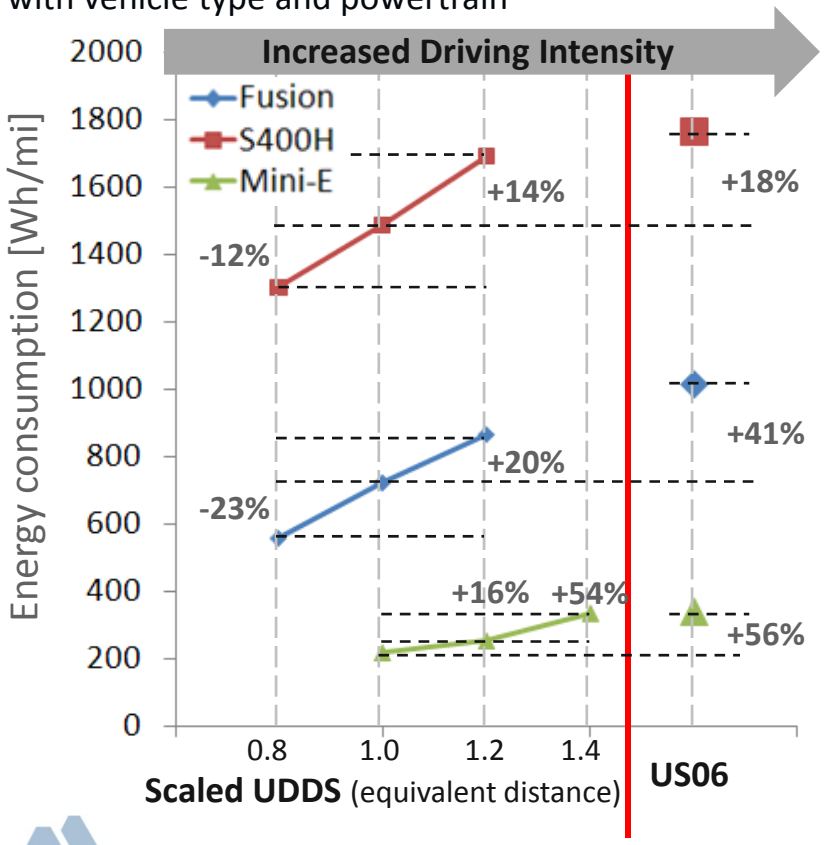
➢The energy consumption and emissions showed that designed fuels are within 10% of the target fuel results

First use at APRF of FTIR to measure non regulated emissions

Accomplishments: Energy Consumption Impact Factors and Sensitivities

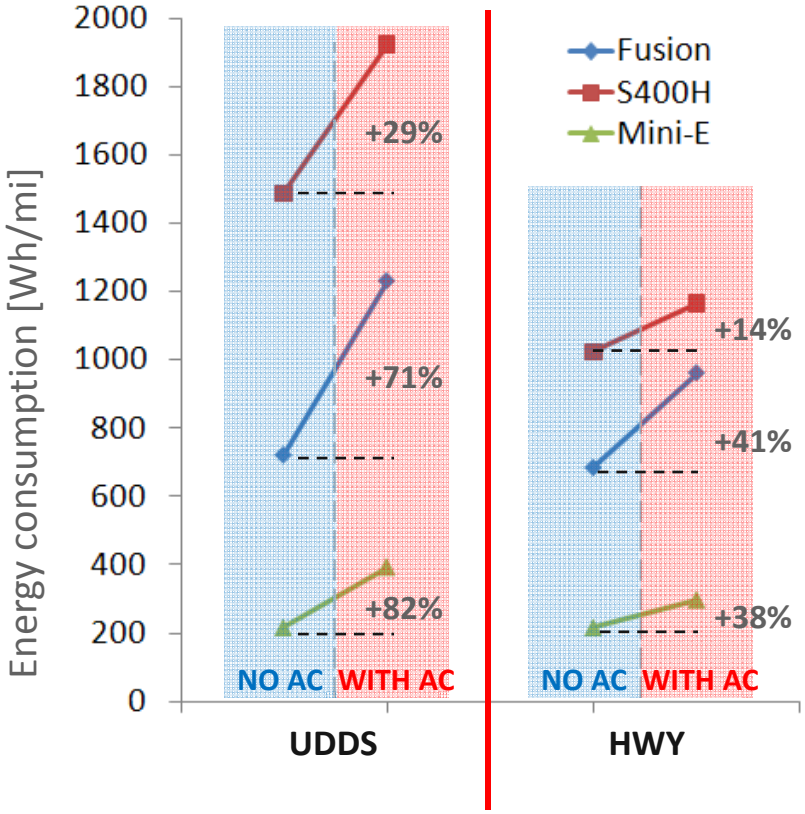
Driver intensity impact

- Electric vehicle energy consumption is most sensitive to driver aggressiveness which has a direct impact on range
- Impact of driver intensity on energy consumption varies with vehicle type and powertrain



Air conditioning impact

- The AC impact can increase energy consumption by over 70%
- Impact of air conditioning usage is largest in city driving since extra energy is consumed during stops



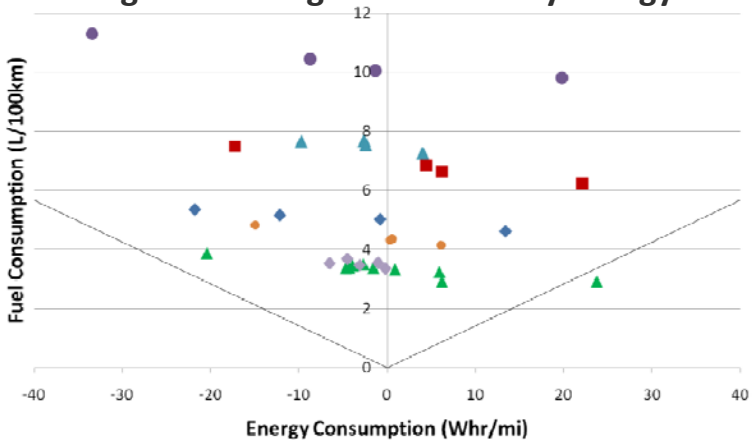
Accomplishments: Data Supports Standards Development

Open and public test data, which can be shared among committee members is critical to standards development and validation for multiple stakeholders

Understanding and incorporating test data identifies practical problems during the standard development:

- Procedure development and validation
- Improved SOC correction methodology (necessary for certain PHEVs)
- Battery energy allocation methods
- End-of-test criteria development

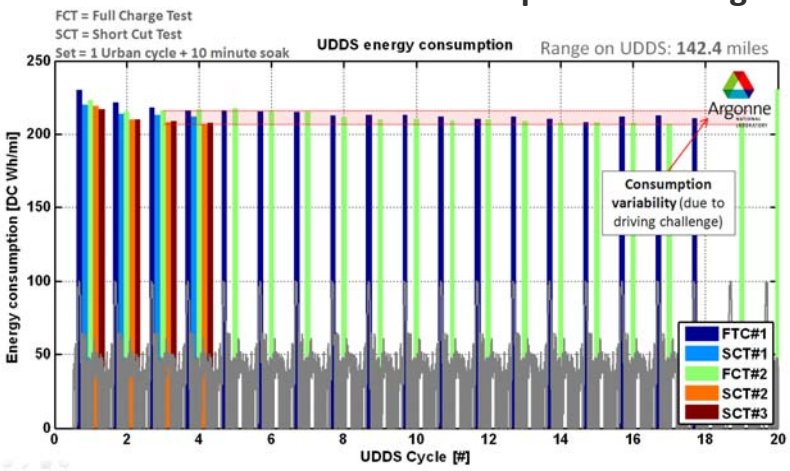
J1711: Charge Sustaining Fuel vs Battery Energy Trends



J1634 focused testing provided insight into:

- Procedure development and validation
- Shortcut versus full testing results
- Shortcut limitations due to thermal transients
- Consumption impacts of vehicle variability
- Charge energy variability

J1634: Shortcut versus Full Depletion Testing



Accomplishments: Collaborations Contributing to Technology Development

Electric Vehicle supplier

- Early prototype
  - First testing for supplier
  - First EV for J1634 development
- In-lab data analysis led to suggested technology improvements

BEV prototype

TADA

- Data used for SAE J1711™ development
- OEM vehicles → wider EV range and better control led to a more refined PHEV compared to conversions
- In-lab data analysis led to altered controls on Ford TADA

Ford TADA vehicle

Collaborations and Coordination with Other Institutions

J1711 HEV & PHEV test procedures
J1634 EV test procedures
Grid Interoperability

SAE International

AVTA (Advanced Vehicle Testing activities)
- Baseline dynamometer testing of vehicles

INL Idaho National Laboratory · Argonne

APRF

DOE technology evaluation
- DOE requests
- National Lab requests

NREL · ornl Oak Ridge National Laboratory · INL Idaho National Laboratory · Argonne National Laboratory

Automonie
- Support of modeling and simulation with data

AUTONOMIE

USCAR, tech teams and OEMs
- Shared test plans, data and analysis

FreedomCAR & Fuel Partnership

Proposed Future Work

- Benchmark Continuation of Vehicles and Components in System Context
  - ATVA program participation (the final vehicles will depend on AVTA selection and availability)
    - Possible EVs: Nissan Leaf, MMC iMiEV, Ford Focus, Ford Transit Connect, BMW, Think
    - Possible PHEVs: Toyota Prius and Chevy Volt
    - Possible HEVs: Honda CRZ and Chinese HEV
  - Technology Assessment
  - DOE selected vehicle(s) for in-depth Level 2 research
  - Support standards development with data
- Testing approach
  - Level 1 extension with more CAN cracking
  - Level 2 extended collaboration
- Facility upgrade: climate test cell upgrade (in progress)
  - 5 cycle fuel consumption testing (including PHEV, EV)
  - Investigate vehicle system limitation from extreme operation conditions and propose technical solutions
  - Improved AC and heater impact assessment of energy consumption

Remaining Vehicles to Test 2010FY

- Hydrogen truck
- Level 2 Prius
- Level 1 Hyundai HEV
- GM TADA vehicle
- Ford TADA vehicle
- Further EV for J1634™
- Codes/Standards work

Summary

- The benchmark activity enables petroleum displacement through data dissemination and technology assessment by:
  - Establishing the state of the art automotive technology baseline for powertrain systems and components through data and analysis, with support for target setting
  - Providing independent evaluation of technology
  - Enabling optimized system and component development with compare and contrast opportunity across multiple manufacturers
  - Generating test data for model development and validation to encourage speed-to-market of advanced technology
  - Supporting codes and standards development for unbiased technology weighting

- ANL has benchmarked a wide range of technologies (FC, EV, PHEV, HEV, and alternative fuels) with a refined and recognized process to deliver quality data

- The benchmark activities are a collaborative effort from the test preparation to the data and analysis dissemination

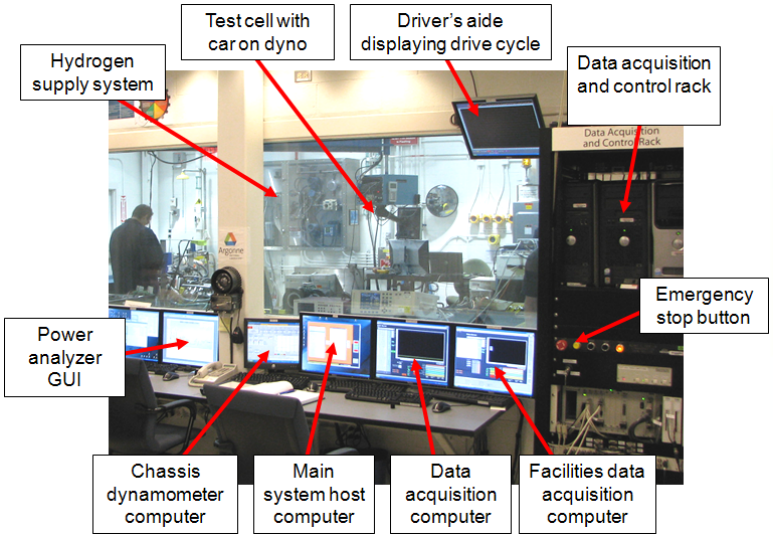
- The benchmark activities and data are highly leveraged

Background Slides

ARGONNE'S OBJECTIVE: Provide to DOE and Partners the Best Advanced Vehicle Test Data

"Be the eyes and ears of technology development"

- **Advanced Powertrain Research Facility (APRF)**
  - Purpose built for DOE benchmarking
  - State-of-the-art 4WD chassis dynamometer
  - Custom multi-input data acquisition specific to hybrid vehicle instrumentation
- Staff at cutting edge of test procedures for new advanced vehicles
- Inventing new and novel instrumentation techniques



Systems

Chassis Dynamometer

Emissions Measurement

Air Handling

Data Acquisition

Safety

Benchmarking Facility Achievements

- **4WD Dynamometer Facility** designed as most advanced test facility anywhere (EPA followed a year later)
- **Landmark Regen Study of HEVs on 4WD Dynamometer**
- **Built Custom Powertrains / Vehicles** for benchmarking configurations not available otherwise
- **Suite of Vehicle "Hacking" Tools** and procedures developed to read proprietary vehicle network data for any OEM vehicle
- **Only PHEV Data Available from APRF**. Available for download via searchable database website
- **ANL-EPA 4WD Road Load Study** investigated coast-down procedures and accuracy of dynamometer
- **ANL–INL AVTA Testing Program** provides standard tests before vehicle are put in fleet testing
- **ANL-ORNL Benchmarking** leverages APRF data and instrumentation techniques for e-motor testing

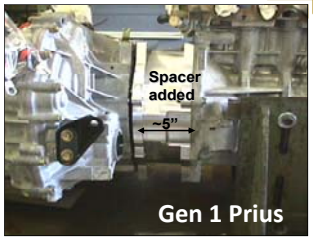
Prototype Platform Testing

In-House Data Acquisition

Vehicle Benchmarking

“Level 2” - In-Depth Testing and Analysis

- Temperatures
- Direct fuel measurement (fast, accurate)
- Battery energy, thermal management
- Axle torque
- Pioneered in In-Vehicle Engine Torque



1999

2004

2006

2007

Torque from internally gauged input shaft and Indicated torque

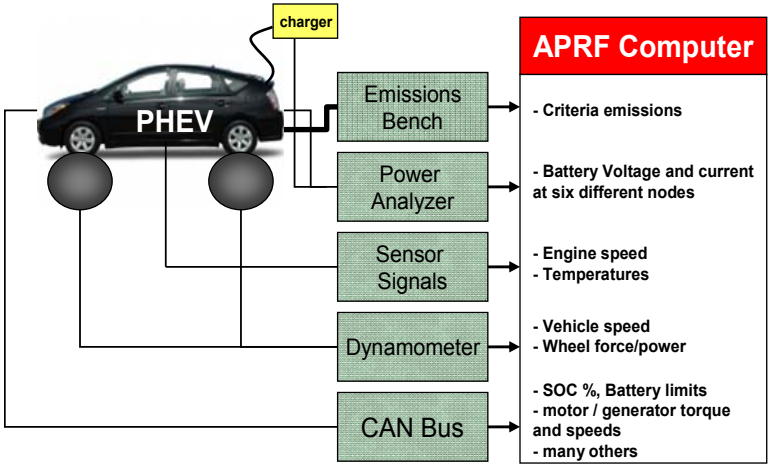
APRF Equipment and Features

Link Models to Hardware

Hydrogen Test Capability
gaseous and liquid H_2

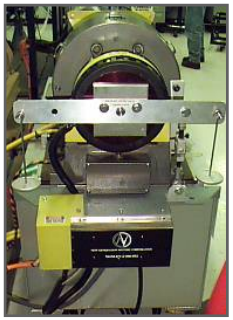
Vehicle Benchmarking

6 Channel Power Meter and Power Analyzer

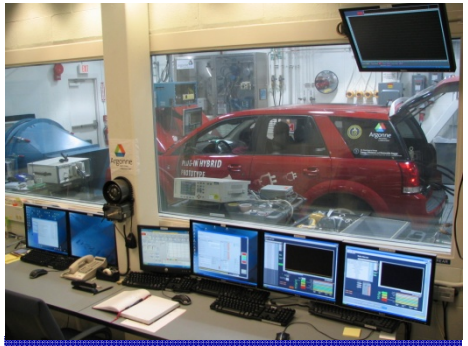


Multi-fuel Compatible Emissions Bench

Comprehensive Database Of Hybrids and PHEV's



Component Testing



In-House Data Acquisition

PHEV's Tested

- **Prius Conversions**
  1. Hymotion (Kokam) Prius (highly instrumented)
  2. HybridsPlus Prius (highly instrumented)
  3. Hymotion (A123 ver1) Prius
  4. EnergyCS Prius ver.1 and ver.2
  5. Hymotion (A123 ver2) Prius
  6. Plug-In Conversions Corp. Prius
- **Escape Conversions**
  6. Electrovya Escape
  7. Hymotion Escape
  8. HybridsPlus Escape
- **OEMs**
  9. Renault Kangoo
  10. OEM PHEV Mule (NDA-protected)
  11. Insight HEV Level 1 testing
  12. Prius HEV Level 1 testing
  13. TADA Ford Escape
  14. (at BMW) Mini E BEV

Latest PHEV Conversions Demonstrate SULEV Attainment