Argonne NATIONAL LABORATORY

Advanced Technology Vehicle Lab Benchmarking – Level 1

2011 DOE Hydrogen Program and Vehicle Technologies Annual Merit Review

May 10, 2011

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Sponsored by Lee Slezak

Project ID # VSS033

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

- **Timeline**

  DOE Benchmarking started in 1998

  - **Recent Level 1 Testing**
    - Honda CRZ (M6)
    - MCC© Smart MHD
    - Mazda 3 i-Stop
    - Golf TDI Bluemotion
    - TADA GM PHEV Phase 1
    - TADA Ford Escape E85 PHEV Phase 3
    - Additional AVTA Vehicles for FY11

  - **Incremental DOE Projects (separate funding)**
    - EV prototype for supplier
    - Automotive X Prize
    - Hydrogen ICE trucks
    - Hyundai Lpi HEV
    - Codes and Standards test support

100% complete on FY2010 tasks
40% complete on FY2011 tasks

- **Budget**
  - 2011FY $850k

- **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, ANL, Ecotality
  - DOE, National Laboratories, USCAR, OEMs, Suppliers, Vehicle Competitions

Relevance: Advanced Technology Benchmark

- **Vehicle Research: Dynamometer Testing Elements**
  - 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

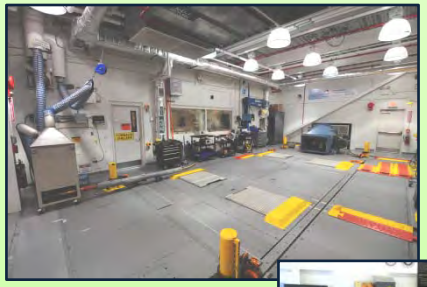
- Establish the state-of-the-art automotive technology baseline for powertrain systems and components through data generation and analysis
- Provide independent evaluation of technology
- Generate data to support target creation and hardware/model validation

APRF

Advanced Powertrain Research Facility

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

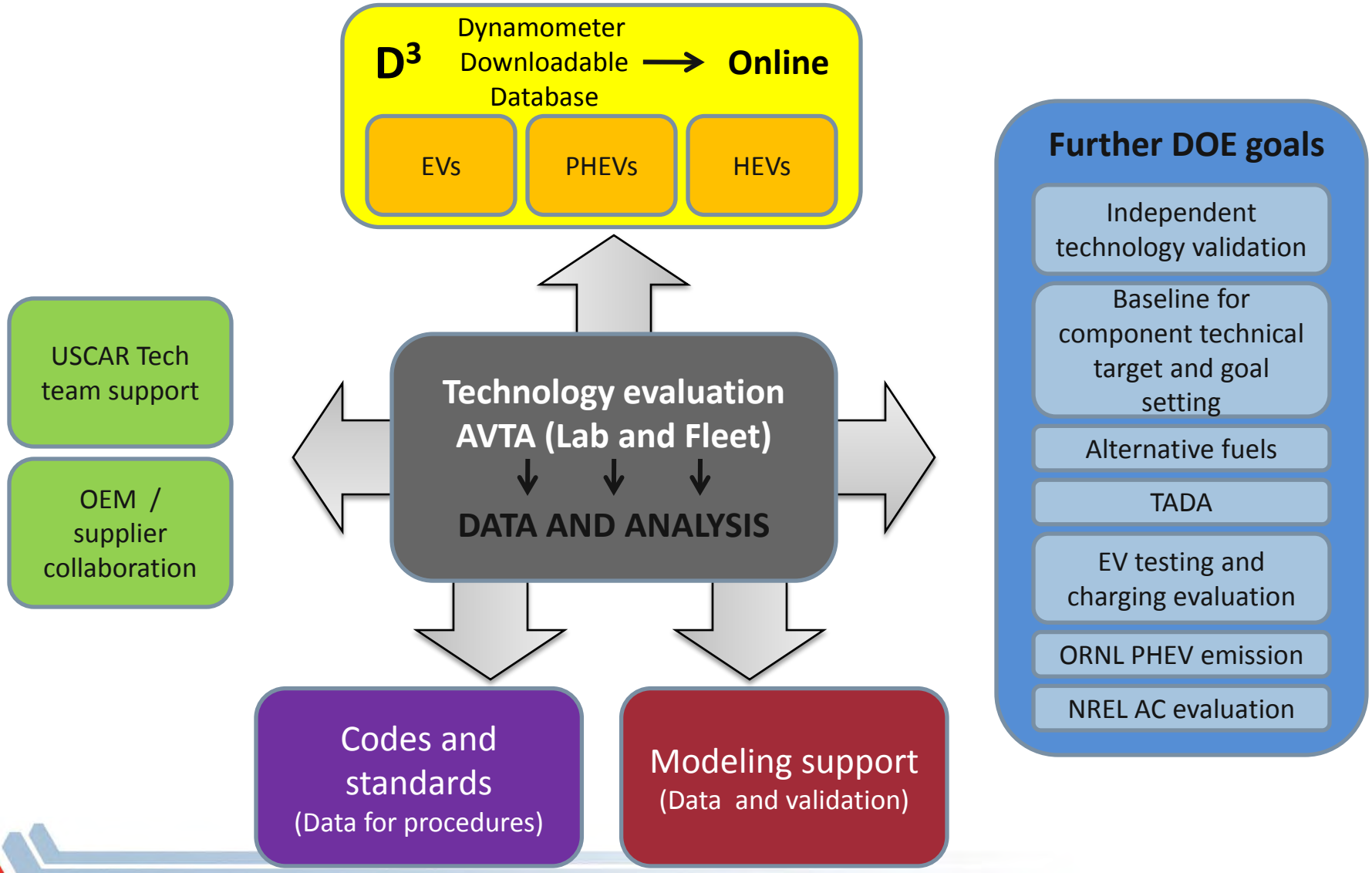
(APRF since 2000)



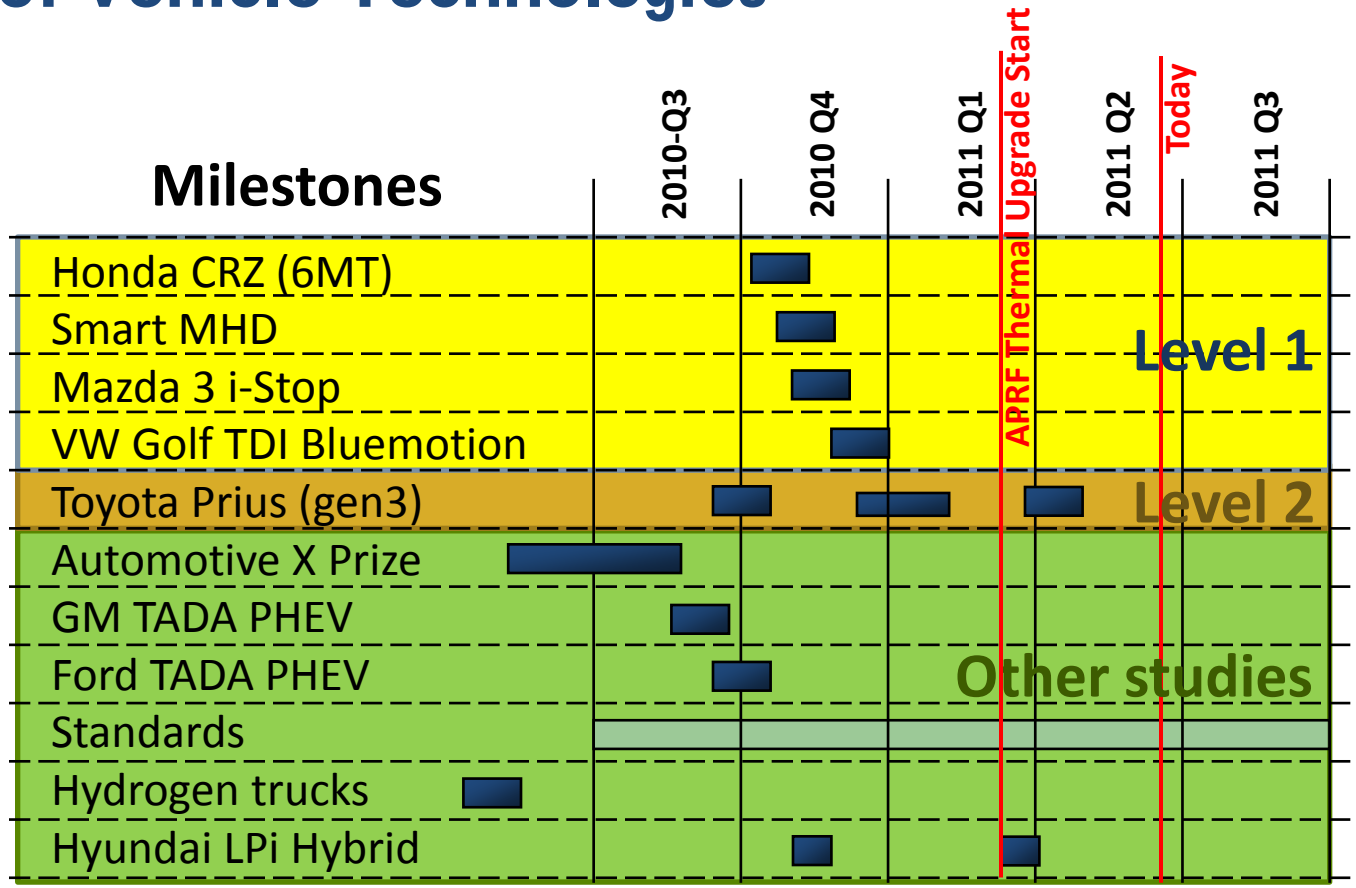
4WD chassis dyno

2WD chassis dyno

Relevance: Enable Petroleum Displacement through Data Dissemination and Technology Assessment



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




Honda CRZ (6MT)


Smart MHD


Mazda 3 i-Stop


BEV prototype


Ford TADA


GM TADA

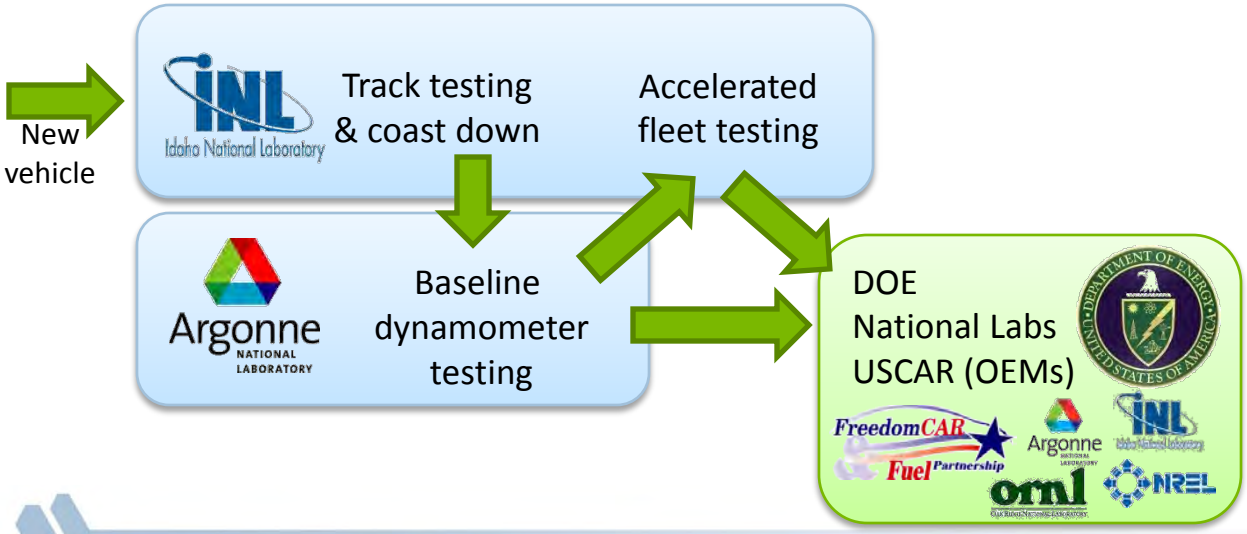

Automotive X Prize


VW Golf Bluemotion

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

- The vehicle benchmark activity has been refined during the past 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:**



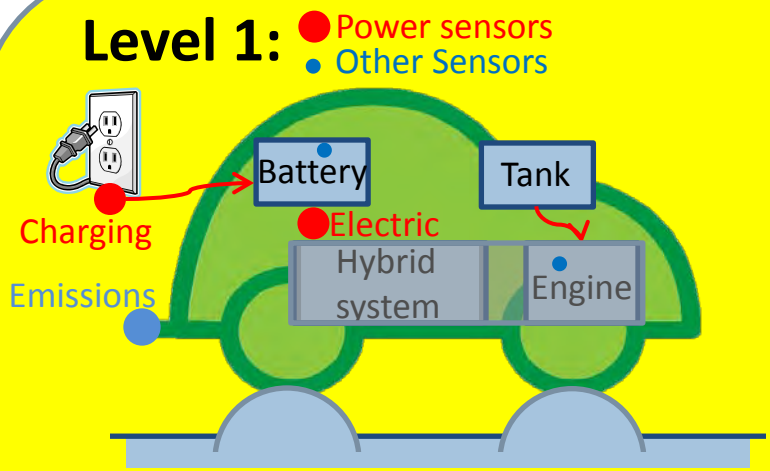
Wide range of vehicle technologies tested

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:



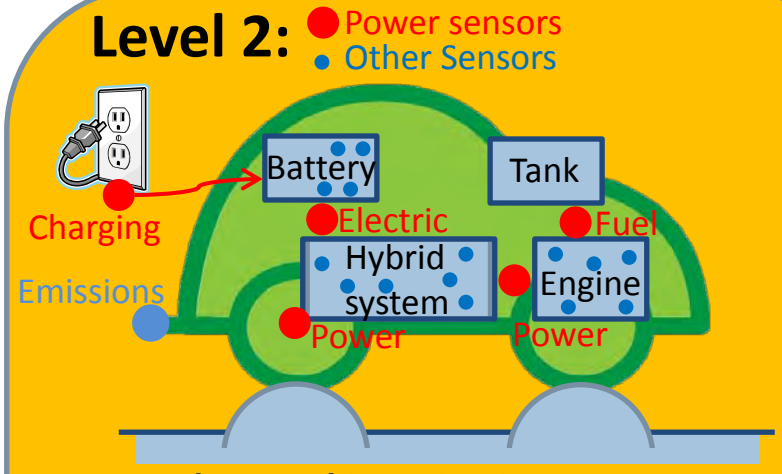
Basics instrumentation:

- 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

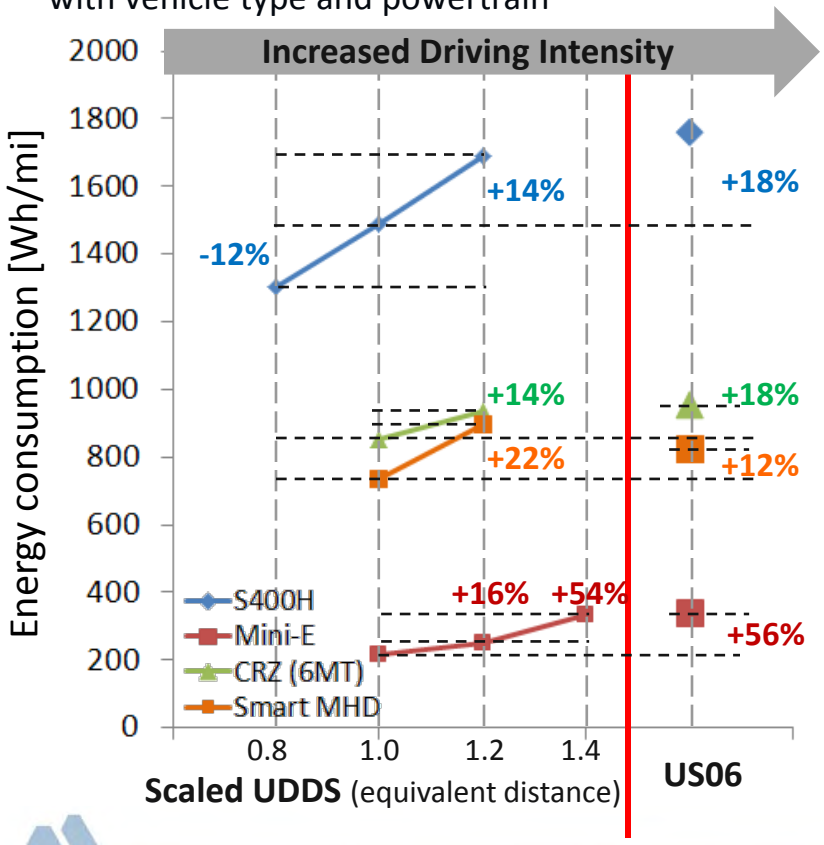
Purpose:

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

Accomplishments: Energy Consumption Impact Factors and Sensitivities

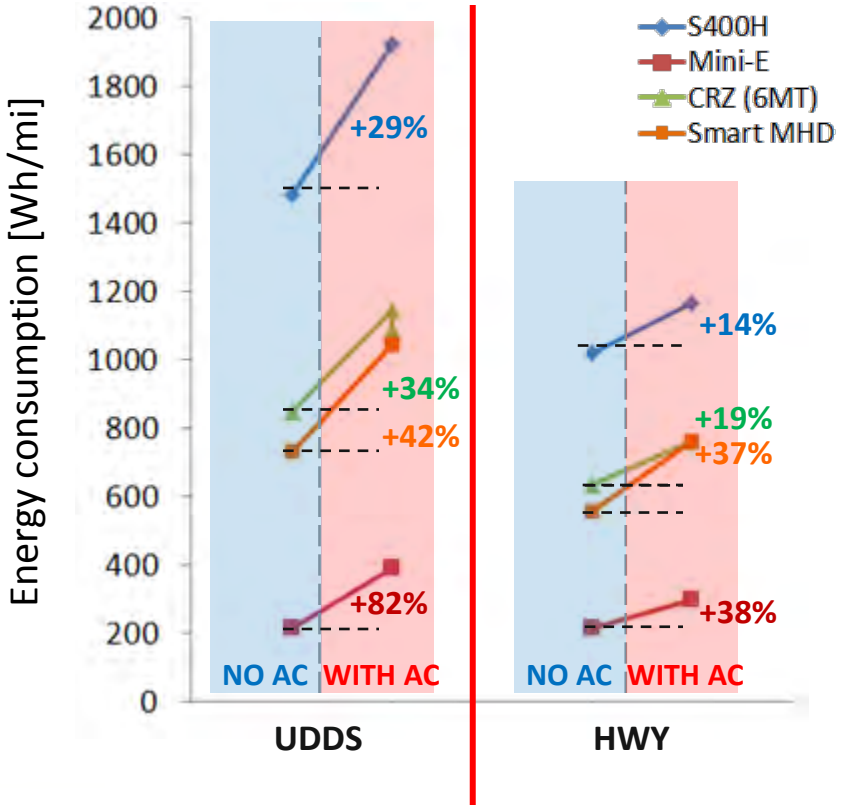
Driver intensity impact

- 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

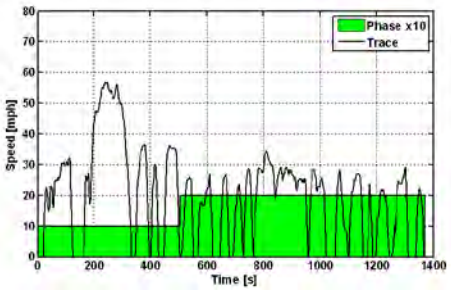


Air conditioning impact

- 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



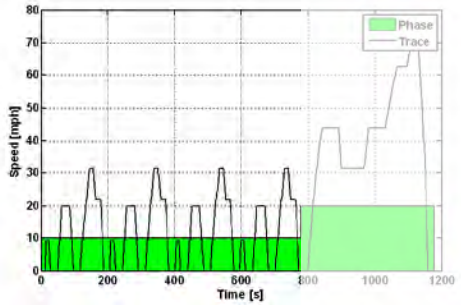
Accomplishments: Idle Stop Vehicle Study



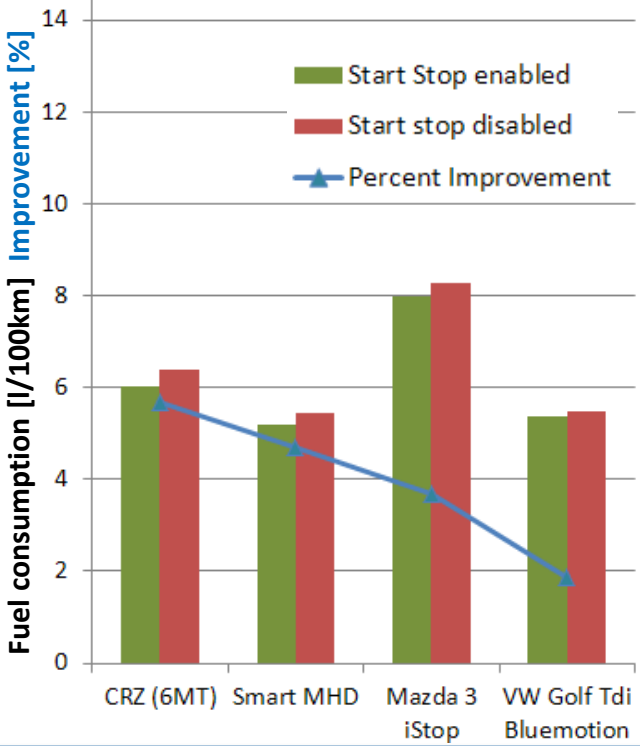
UDDS

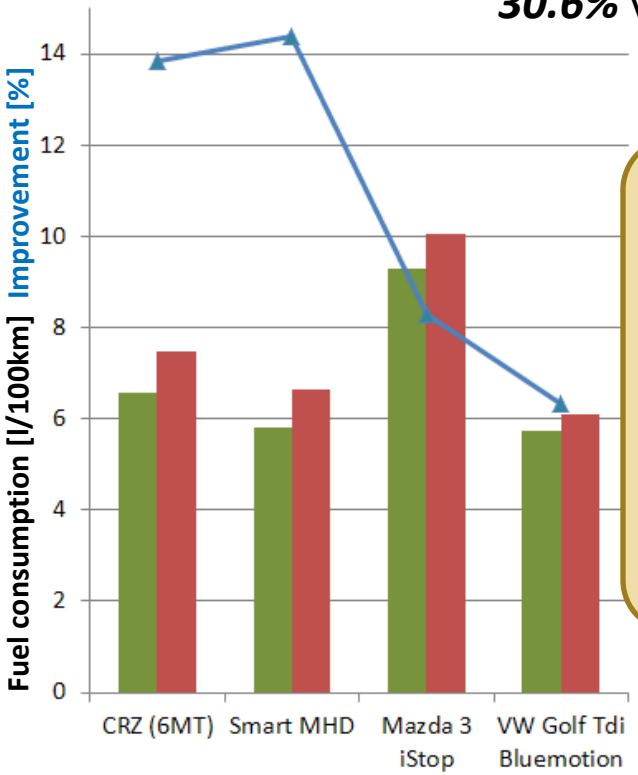
17.6% vehicle stop

NEDC (City)



30.6% vehicle stop





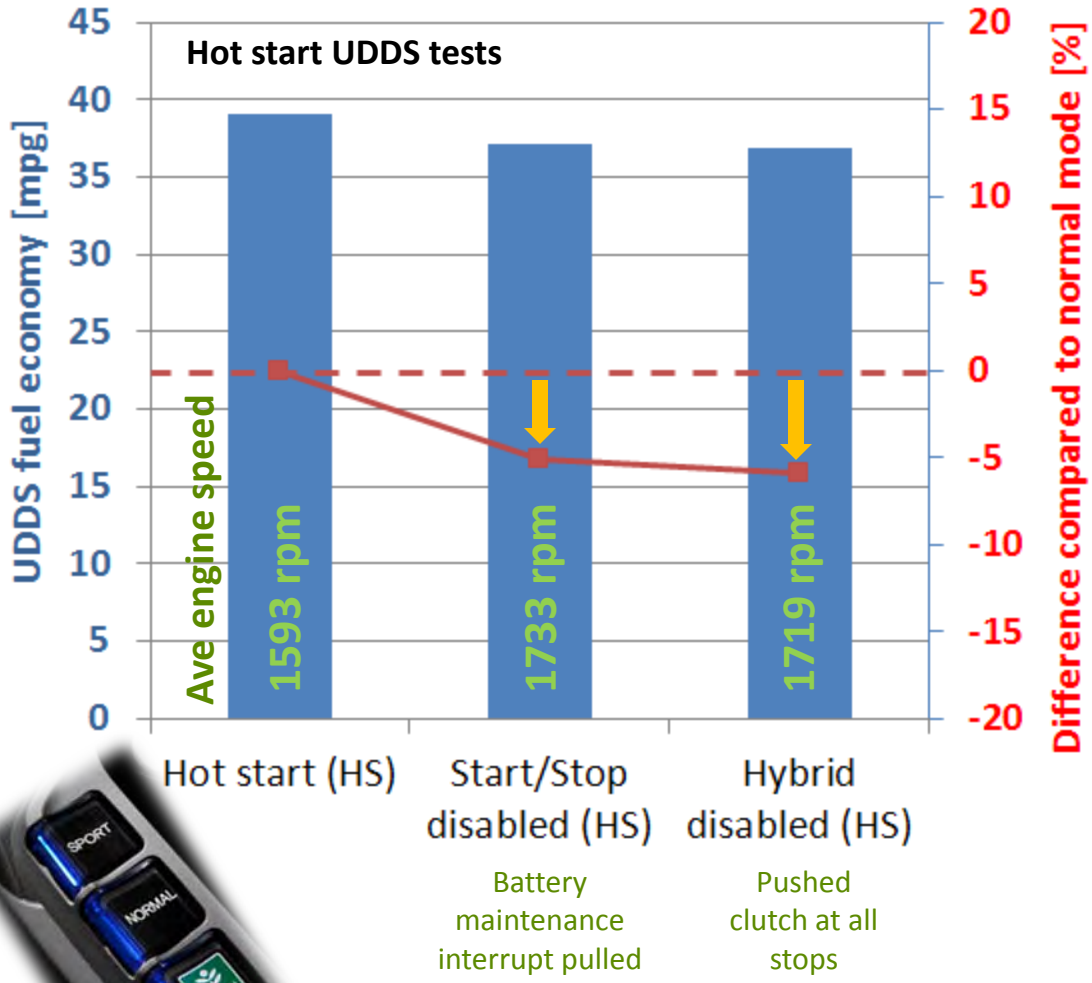
Notes:
- All tests here are hot start tests
- Average start stop improvement is based on the 4 test cars

Start stop vehicles are more popular in Europe, as the fuel efficiency gain is higher on the European certification cycles

→ Average start stop improvement ***4%***

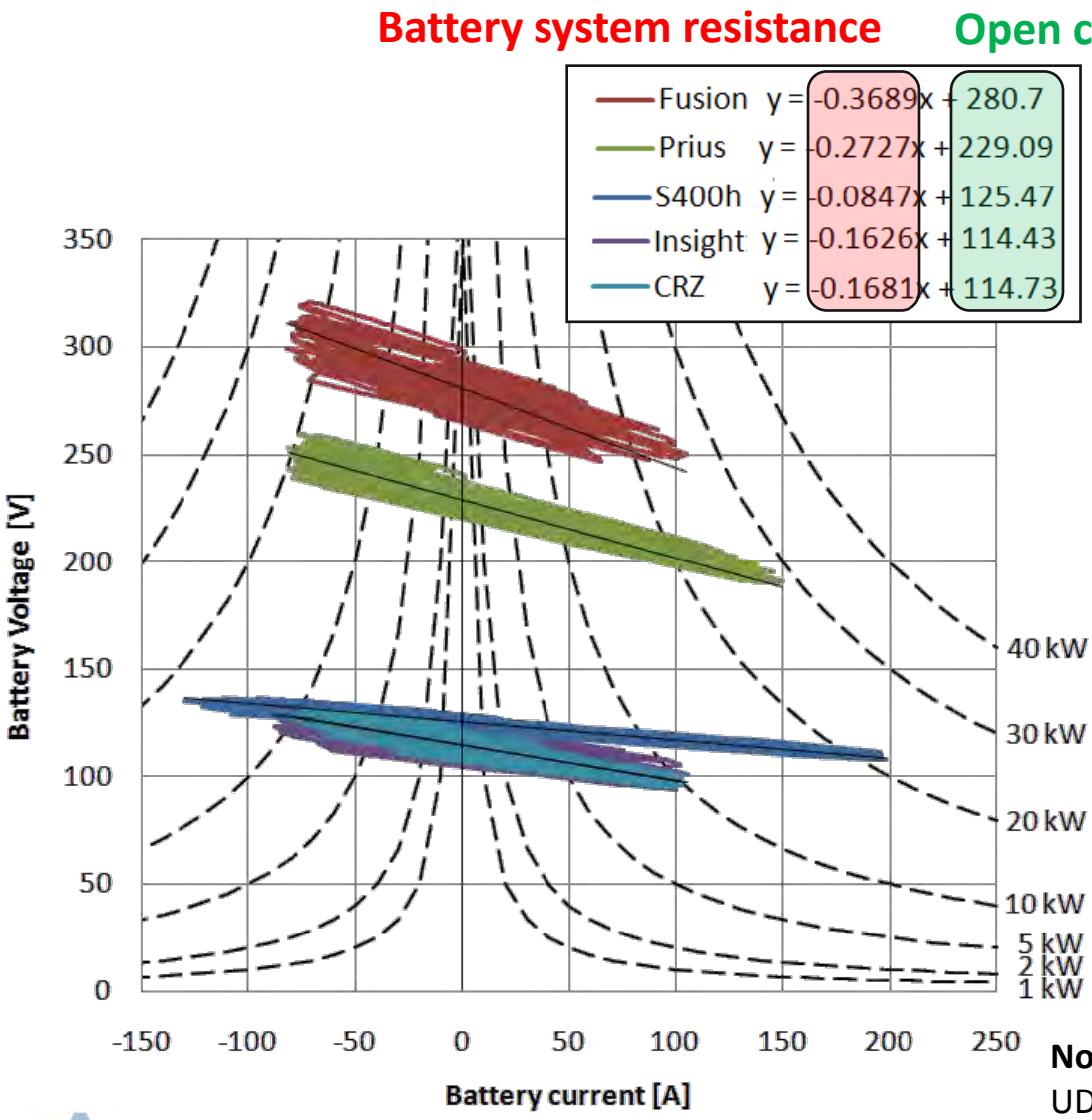
→ Average start stop improvement ***10%***

Accomplishments: Honda CRZ Fuel Economy Improvements by Hybrid Modes



- This mild hybrid system provides over 5% improvement in fuel economy
- All test results based on EPA shift schedule
- Other testing shows a 12% improvement in fuel economy is possible by changing the shift schedule

Accomplishments: In-Vehicle Battery Performance



- The hybrids with greater electric vehicle capability have higher than average system voltages
- The lithium ion battery pack used in the M-B S400h has the lowest resistance
- Both the lower resistance and higher voltage contribute to lower the electric losses in the system

Note: The data is based on UDDS, Highway and US06.

Collaborations and Coordination with Other Institutions

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

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

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

Collaborations with Other Projects

Advanced Powertrain Research Facility and Expert Staff is used to support a large number of DOE activities for tremendous leverage

Examples of Benchmarking Research Utilized in FY11 AMR

Task	Lead	Project #
HEV, PHEV, EV Test Standards Development and Validation	ANL	VSS052
Codes and Standards Support for Vehicle Electrification	ANL	VSS053
Data Collection for Improved Cold Temperature Thermal Modeling	ANL	VSS050
Autonomie Plug & Play Architecture	ANL	VSS009
AVTA HEV, NEV, BEV and HICEV Demonstrations and Testing	INL	VSS021
Integrated Thermal Management for Electric Drive Vehicle (AC usage)	NREL	VSS046

- Additional projects include TADA, PIAXP, EcoCAR

Collaborations: Contributing to Technology Development

Electric Vehicle Supplier Test

- EV prototype
  - Testing with major supplier
  - EV for J1634 development
- In-lab data analysis led to suggested technology improvements

Win!
Win!

BEV prototype

TADA Advanced PHEV Testing

(Technology Assessment and Deployment Activity)

- Data used for SAE J1711™ development
- OEM vehicles → wider EV range and better control led to a more refined PHEV compared to conversions
- 5-cycle data collected with testing at OEM for cold and hot testing

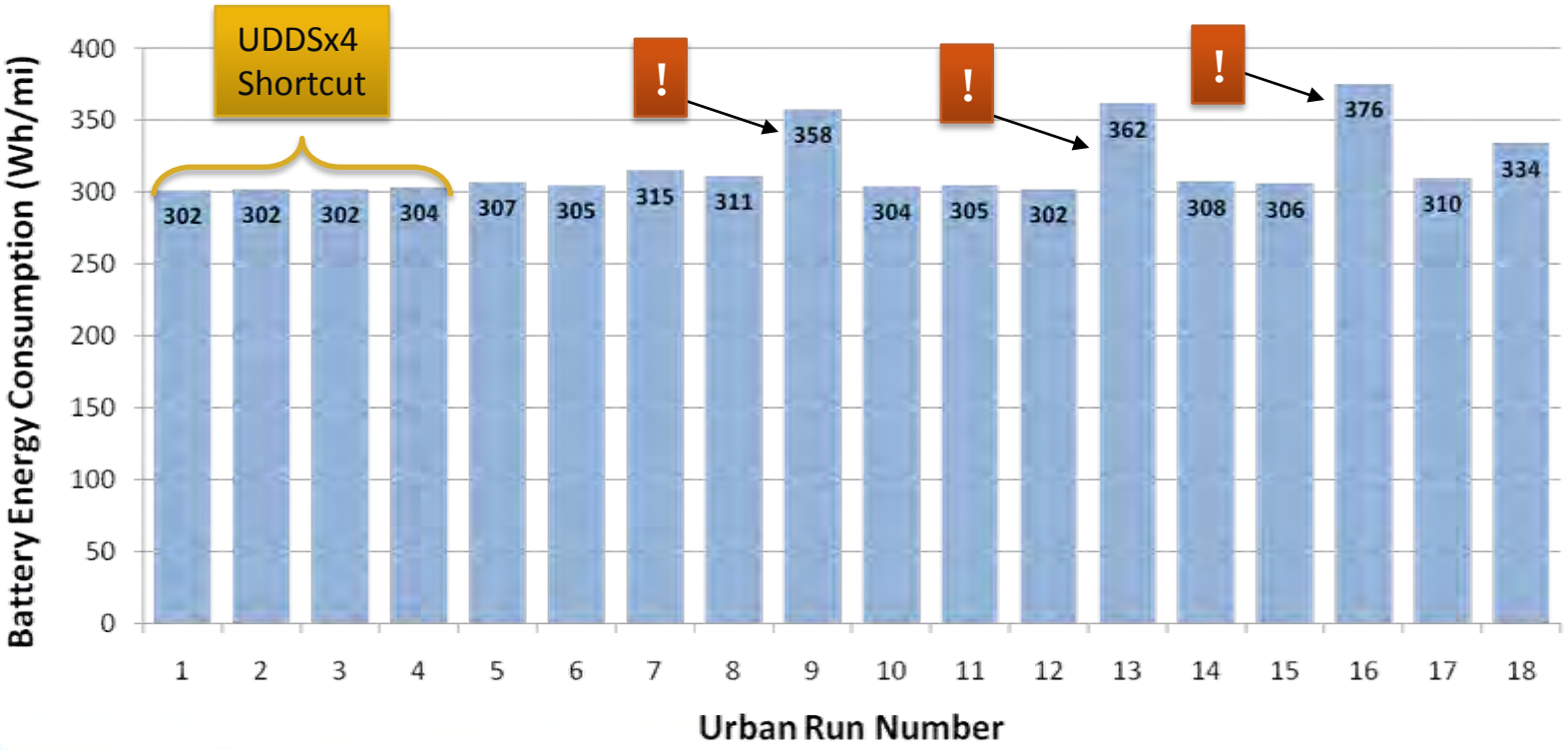
GM TADA vehicle

Ford TADA vehicle

Collaborations: Data Supports Standards Development

- New EV range can be upward of 150 miles (or over 12 continuous test hours)
- A new short cut method is investigated to determine range using:
  - Energy consumption
  - Capacity test

- Sample test of SAE J1634 committee
- The data shows :
  - No Warm up penalties & consistent regen braking
  - Additional consumption during component cooling after many miles



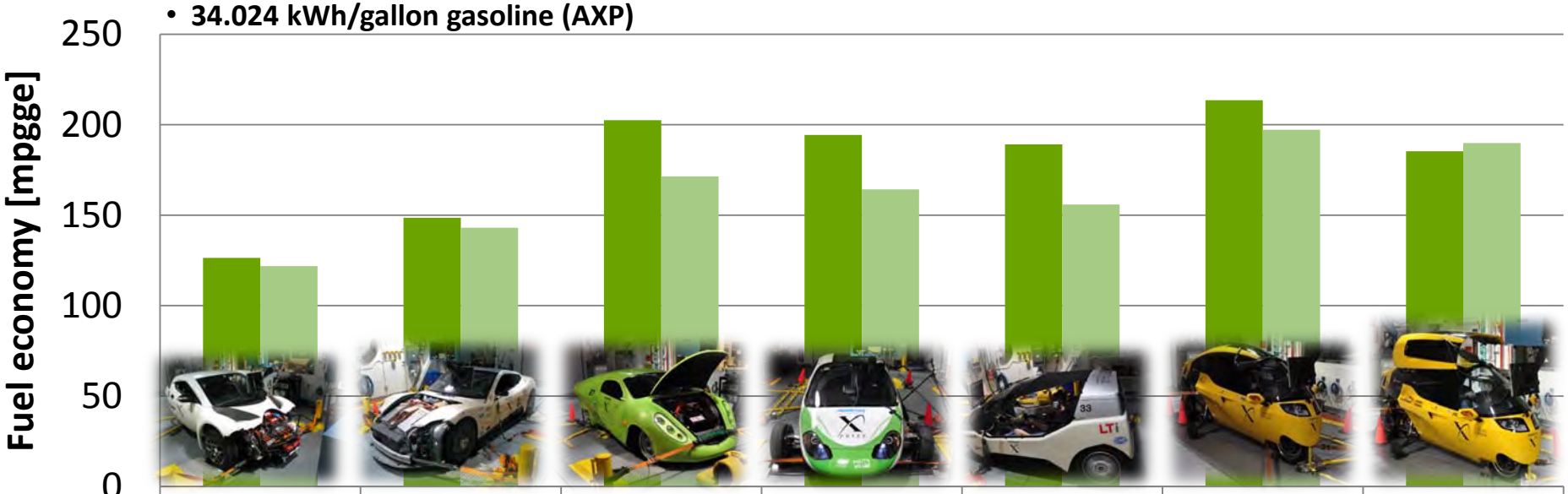
Collaborations: PIAXP

PROGRESSIVE AUTOMOTIVE X PRIZE

- BEV testing and charging experience
- Safe, accurate and smooth event
- Experience with unusual cars

Assumptions:

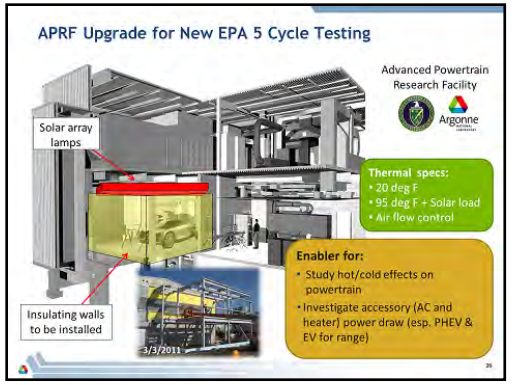
- **Data based on AC Wh/mile**
- **34.024 kWh/gallon gasoline (AXP)**



	ZAP	Raceabout Association	Li-Ion Motors	Aptera	TW4XP	X-Tracer (#72)	X-Tracer (#79)
Dyno	126.4	148.6	202.5	194.3	189.1	213.5	185.3
Finals	121.8	143.0	171.4	164.3	155.9	197.2	189.9

Proposed Future Work

- **Continue mission to benchmark vehicles and components in a systems context**
  - ATVA program participation (the FY12 vehicles will depend on AVTA selection and purchase availability)
    - Possible EVs: Nissan Leaf
    - Possible PHEVs: Toyota Prius
    - Possible HEVs: Hyundai Sonata
  - Technology Assessment
  - Perform Level 2 in-depth analysis with DOE-selected vehicles
  - Support standards development with data collection
- Testing approach
  - Introduce extended Level 1 with more CAN cracking
- Facility upgrade: 4WD test cell climate control
  - 5-cycle fuel consumption testing (focusing on HEV and EV)
  - Investigate vehicle system limitations from extreme operation conditions and propose technical solutions
  - Improved A/C and heater impact assessment of energy consumption



Summary

- The **Level 1 Benchmark Activity** promotes introduction of petroleum displacement technologies through data dissemination and technology assessment by:
  - Establishing 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
  - 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 across government, industry and other national labs through use of shared test vehicles and extensive data dissemination

Background Slides

What Advantages Does Dynamometer Testing Offer?

Dyno features

- Controlled test cell (temperature, humidity, solar load, …)
- Standard drive cycles
- Repeatability of results
- Laboratory emission equipment and instrumentation stationary in test cell

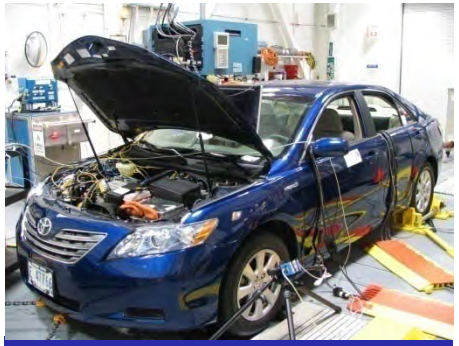
Dyno Benefits:

- Repeatable emissions and energy consumption (fuel and/or electric energy consumption)
- Enables comparisons between different vehicles
- Vehicle development and calibration
  - Component calibration
  - Control strategy
  - System behavior

Advanced Powertrain Research Facility

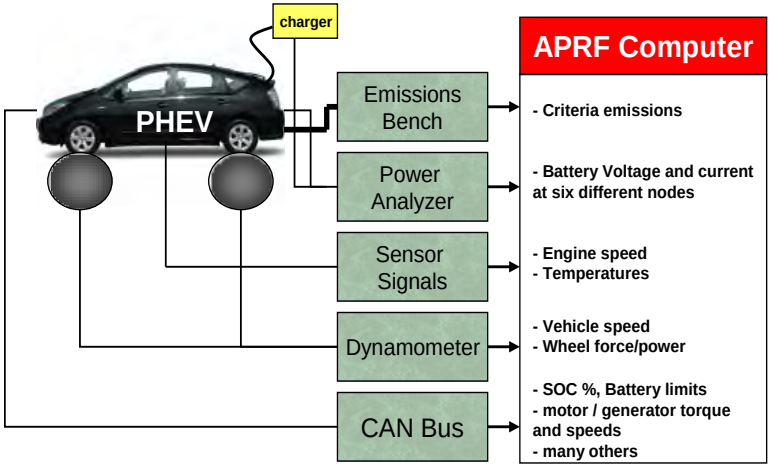
Link Models to Hardware

Hydrogen Test Capability
gaseous and liquid H2

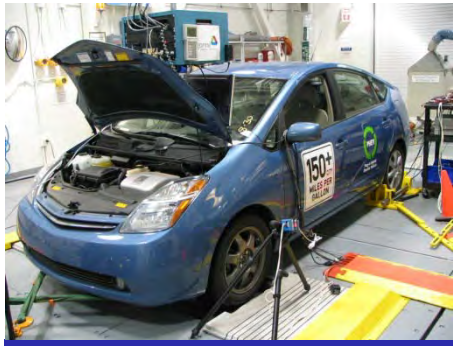


Vehicle Benchmarking

6 Channel Power Meter and
Power Analyzer

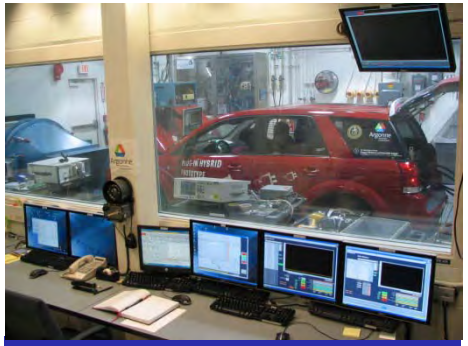


Multi-fuel Compatible
Emissions Bench



Comprehensive Database
Of Hybrids and PHEV's

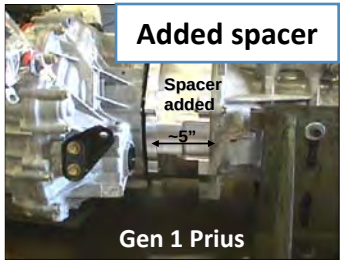
Component Testing



In-House Data Acquisition

APRF Instrumentation and Features

- **Test Cell Facilities**
  - 4-wheel drive chassis dynamometer
  - 2-wheel drive chassis dynamometer
- **Instrumentation**
  - 5-gas emissions bench with CVS
  - Power analyzer
  - In-house data acquisition system
  - Vehicle network decoding and recording
  - Indicating system
  - PEM, FTIR, Fast HC and NOX analyzers
- **Features**
  - Hydrogen capable test cell
  - Robotic driver
  - Vehicle-size power supply to emulate battery packs
  - APRF prototypes
  - Component testing expertise in system environment
  - Online data base of tests, results and presentations



1999

2004

2007

Torque from internally gauged input shaft transferred with telemetry as well as indicated torque

APRF Upgrade for New EPA 5 Cycle Testing

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Solar array lamps

Insulating walls to be installed

Thermal specs:
- 20 deg F
- 95 deg F + Solar load
- Air flow control

Enabler for:
- Study hot/cold effects on powertrain
- Investigate accessory (AC and heater) power draw (esp. PHEV & EV for range)

What are Advanced Technology Vehicles?

- Hybrid vehicles
- Plug-in hybrid vehicles
- Battery Electric vehicles
- Alternative fuel vehicles
  - Hydrogen
    - Internal combustion engine
    - Fuel cell
  - Diesel
- OEM proprietary prototypes
- Plug-in hybrid conversion vehicles
- Conventional vehicles:
  - down sized boosted engine
  - 7 speed dual clutch transmissions

BEV Tesla

ANL PHEV prototype

Hydrogen
Fuel cell

Hydrogen internal combustion engine

Supplier BEV prototype

Ford TADA PHEV

Jetta TDI (bio-fuels)

PROGRESSIVE AUTOMOTIVE X PRIZE