Argonne NATIONAL LABORATORY

APRF

Advanced Powertrain Research Facility

Research Overview

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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

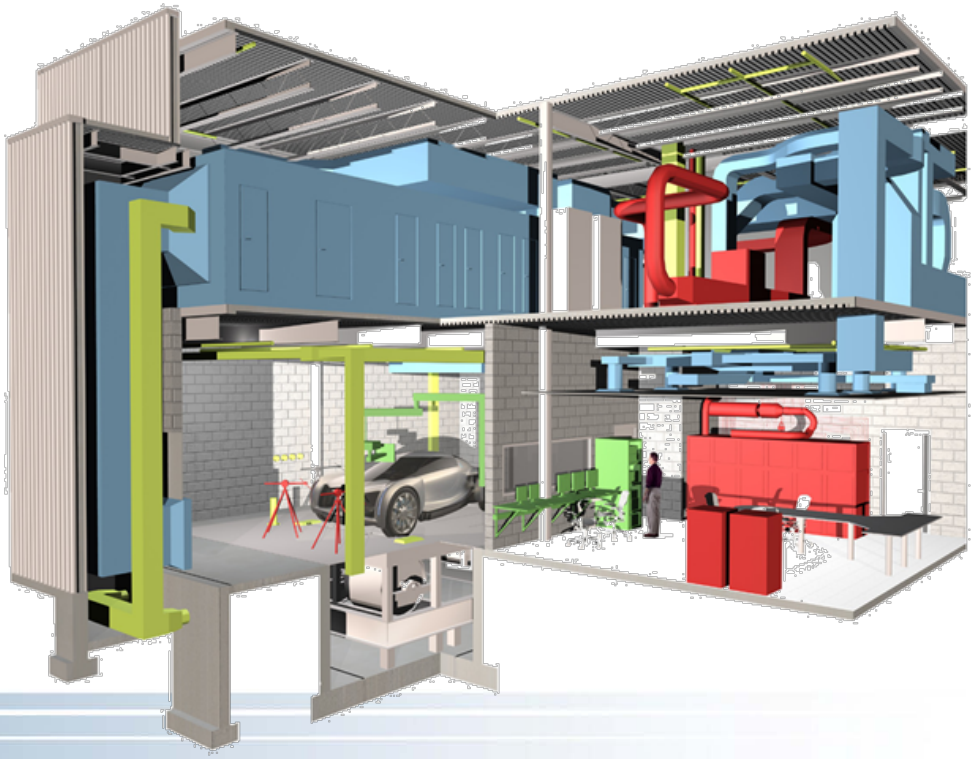
Overview

- Facility
- Dynamometer testing
- Instrumentation
- Tests
- Advanced Technology Vehicles
- Recent vehicles tested
- Impacts factors of energy consumption
- Plug-in hybrid
- Codes and standards development
- Summary and more…

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

- **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

"Be the eyes and ears of automotive technology development"
APRF since 2002



Systems

Chassis Dynamometer

Emissions Measurement

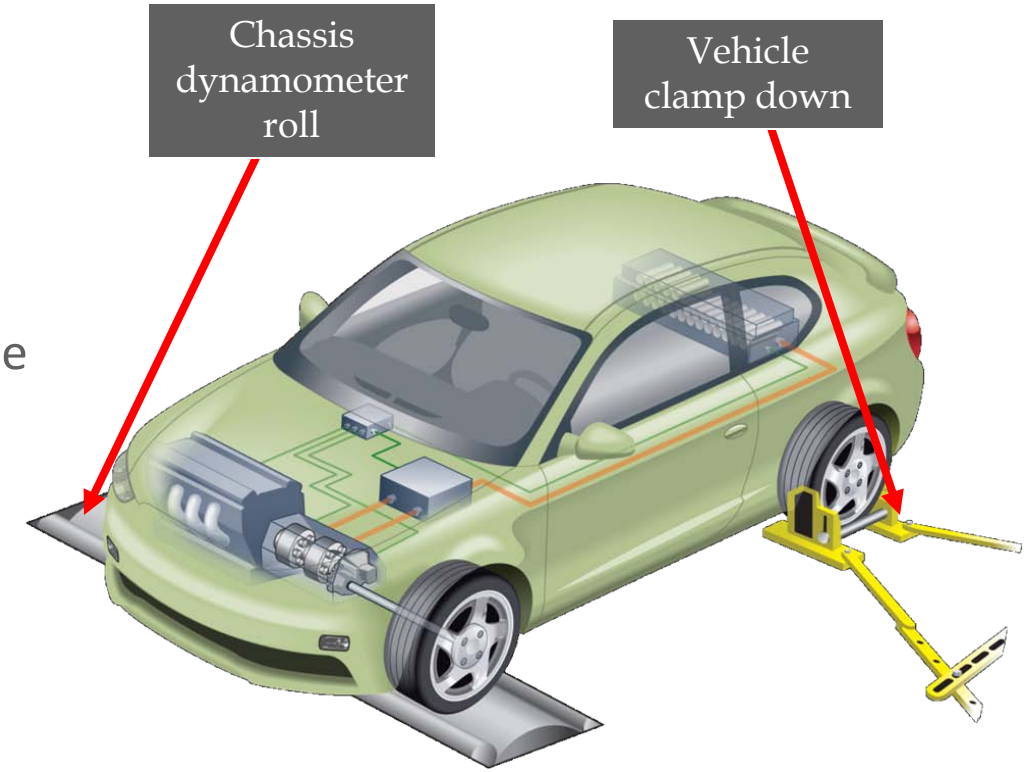
Air Handling

Data Acquisition

Safety

What is a Chassis Dynamometer?

- Layman's version:
  - Treadmill for cars
- Engineering version:
  - Metal rollers connected to a device which emulates the vehicle inertia and the vehicle road load that the vehicle experiences on a real road



Why Bother with Dynamometer Testing?

Dyno features

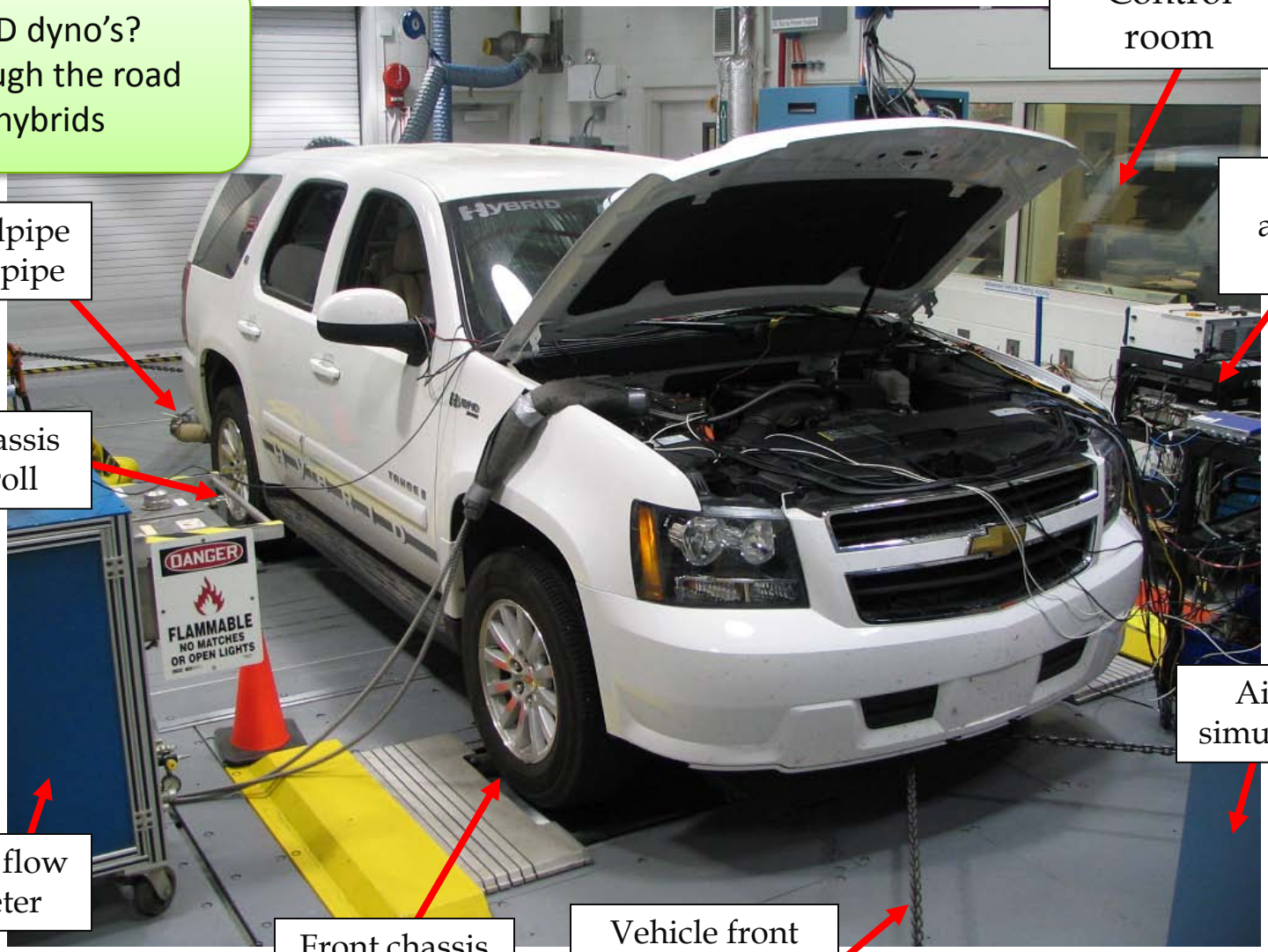
- Controlled test cell (temperature, humidity, solar load, …)
- Standard drive cycles
- Repeatability of results
- Laboratory emission equipment and instrumentation stationary in test cell

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

4 Wheel Drive Chassis Dynamometer

Why 4WD dyno's?
For through the road parallel hybrids



Control room

Data acquisition system

Heated tailpipe emissions pipe

Rear chassis dyno roll

Air flow simulator fan

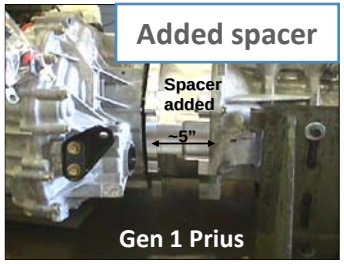
Fuel flow meter

Front chassis dyno roll

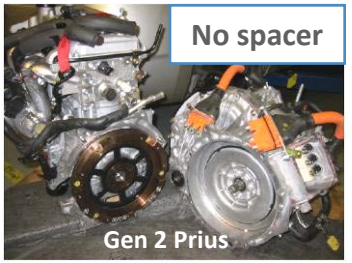
Vehicle front restraining chains

APRF Instrumentation and Features

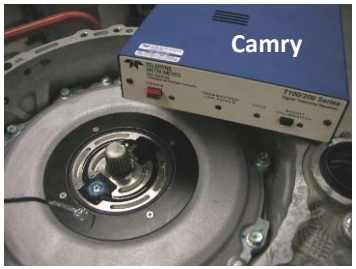
- Facilities
  - 4 wheel drive chassis dynamometer
  - 2 wheel drive chassis dynamometer
- Instrumentation
  - 5 gas emissions bench with CVS
  - Power analyzer
  - In house data acquisition system
  - Vehicle network decoding and recording
  - Indicating system
  - PEM, FTIR, Fast HC and NOX analyzers
- 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

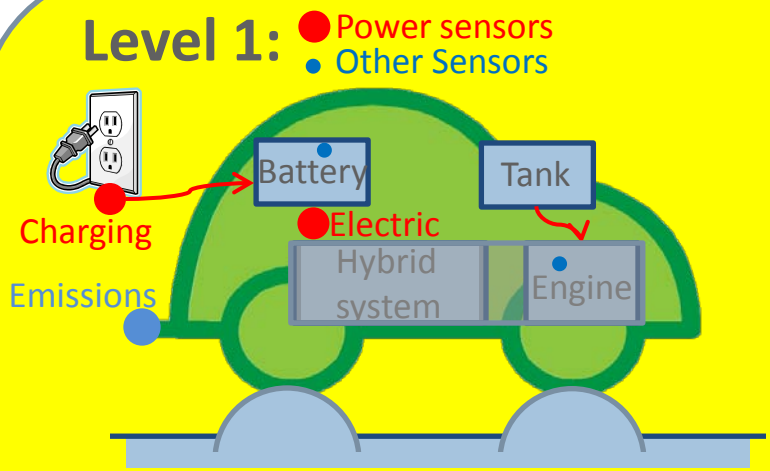


2007

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

Dynamometer Vehicle Benchmark Testing Approach – Depth of Study Varies

Level 1:



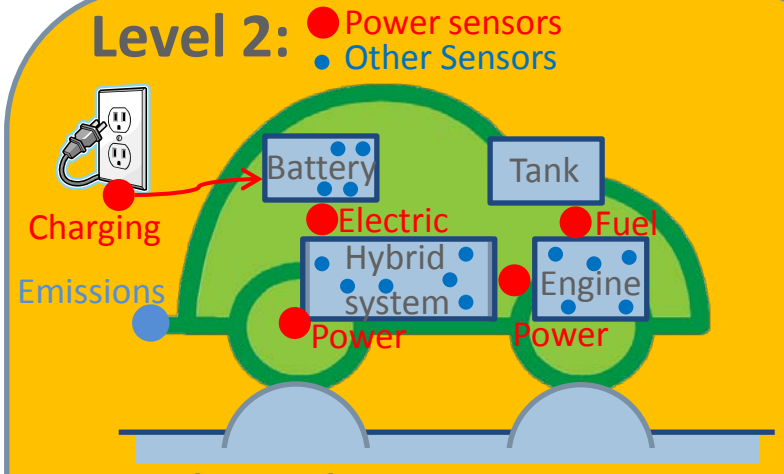
Basics instrumentation:

- 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:

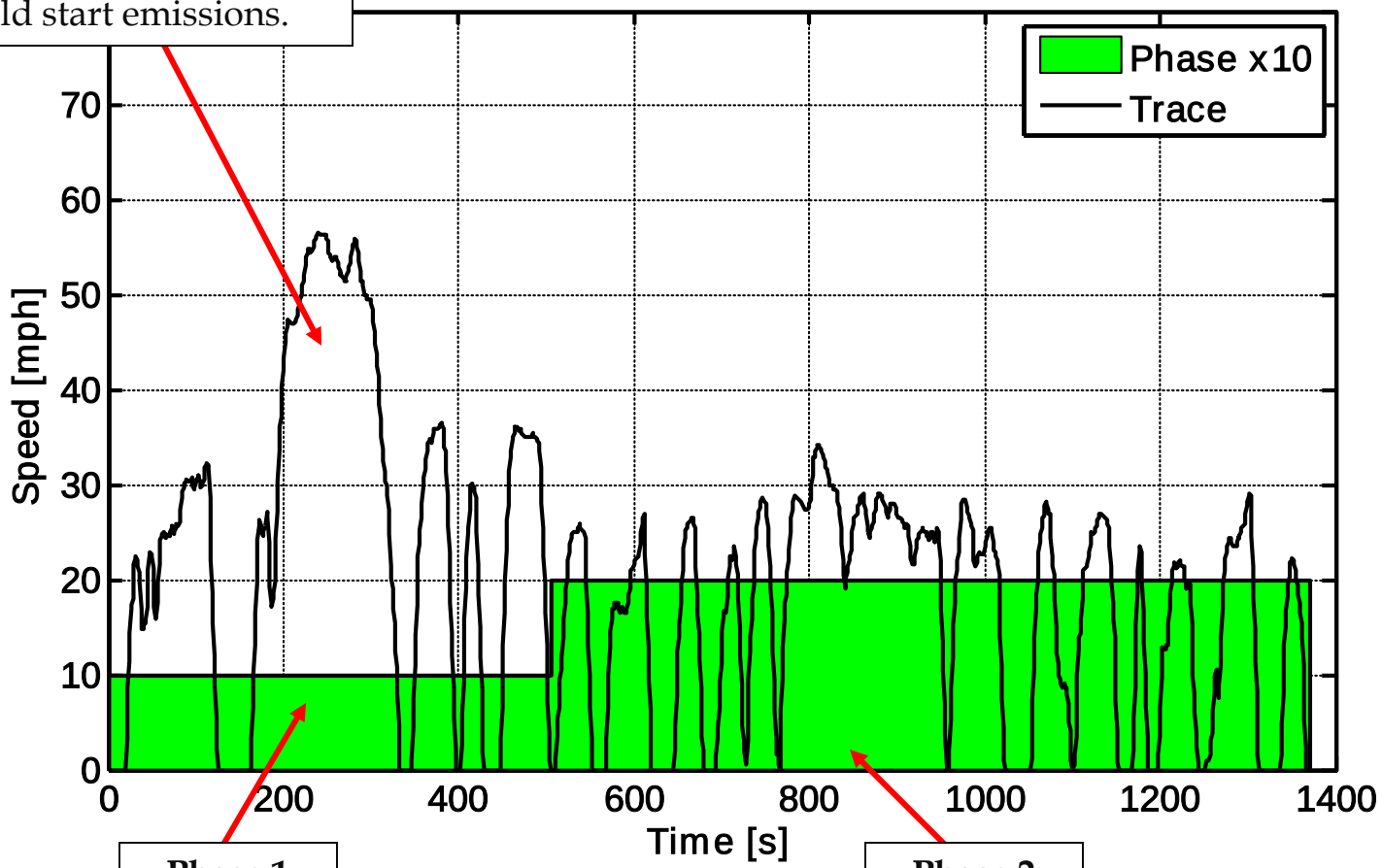
- Energy analysis, efficiency analysis on vehicle and components
- Component characterization in vehicle system

Drive Cycles

- A drive cycle is a vehicle speed profile as a function of time
- The driver follows the trace display on a screen
- Drive cycle violation occurs if the vehicle deviates from the trace by 2 mph $\pm$ 1 seconds
- A drive cycle can be characterized by different factors → avg speed, max acceleration, linear cycles, driven cycles, stop time…

EPA Certification City Test: UDDS

Hill 2
Challenge for control of cold start emissions.

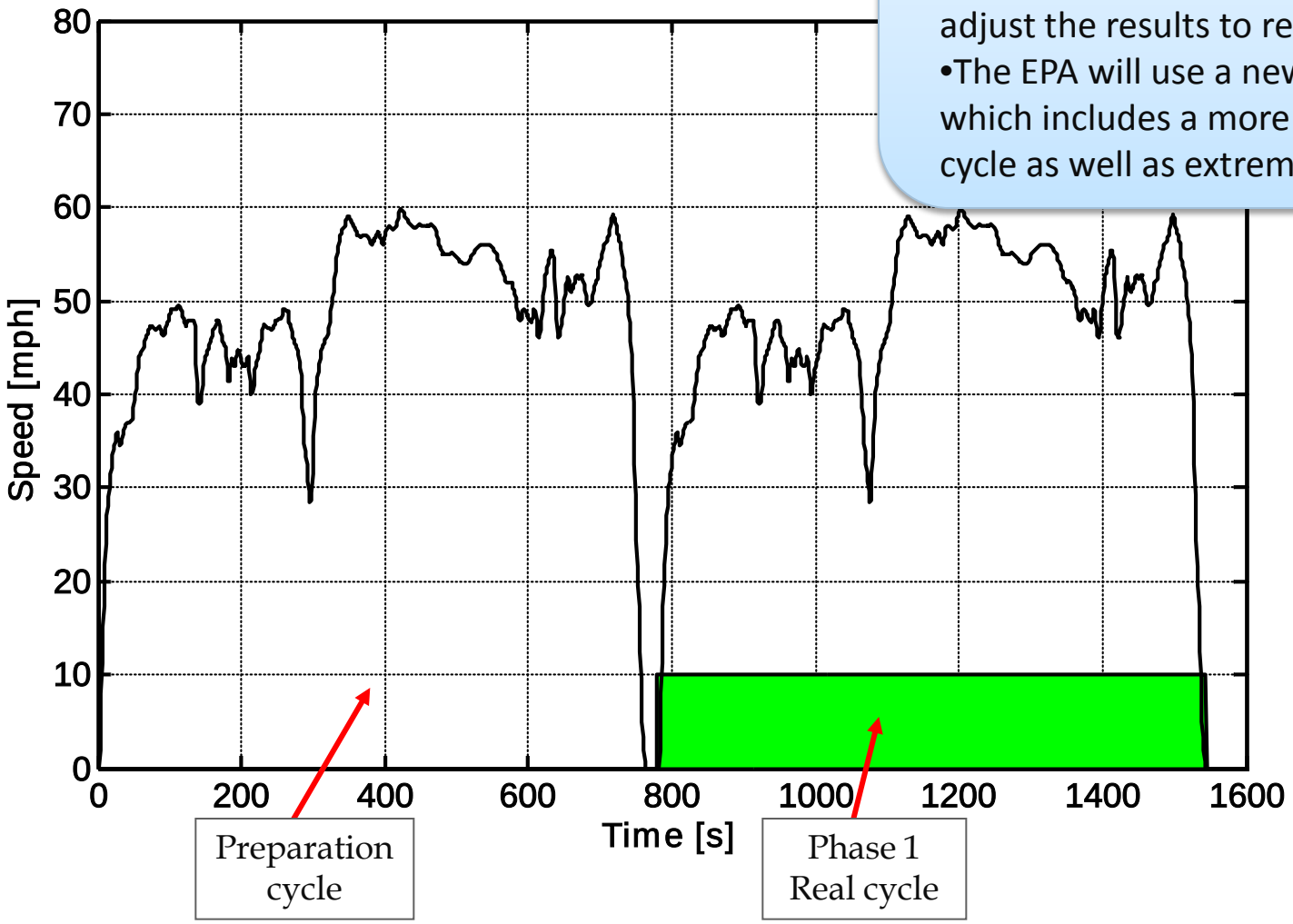


Phase 1
Known as:
-'505'
-Bag 1

Phase 2
Known as:
-Bag 2

EPA Certification Highway Test:

- These EPA cycles were generated in 1975 and do not represent today's driving style which is more aggressive
- Fuel economy correction factors adjust the results to reflect change
- The EPA will use a new 5 cycle test which includes a more aggressive cycle as well as extreme temperatures



What are Advanced Technology Vehicles?

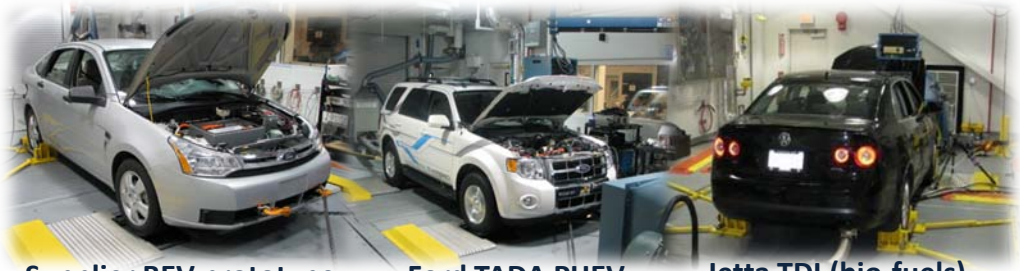
- Hybrid vehicles
- Plug-in hybrid vehicles
- Battery Electric vehicles
- Alternative fuel vehicles
  - Hydrogen
    - Internal combustion engine
    - Fuel cell
  - Diesel
- OEM proprietary prototypes
- Plug-in hybrid conversion vehicles
- Conventional vehicles:
  - down sized boosted engine
  - 7 speed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

BEV Tesla

ANL PHEV prototype

Hydrogen
Fuel cell

Hydrogen internal combustion engine



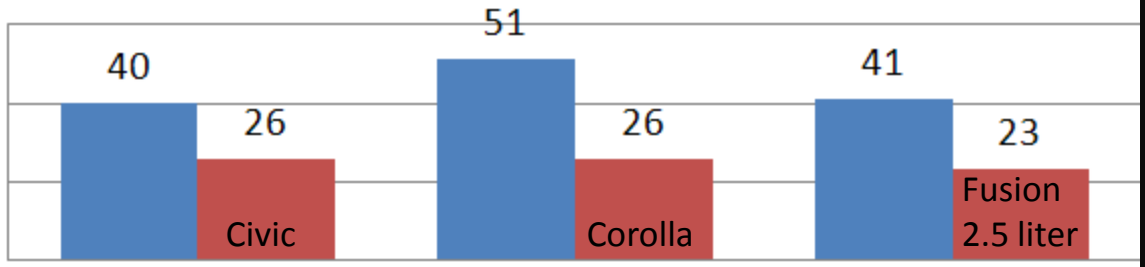
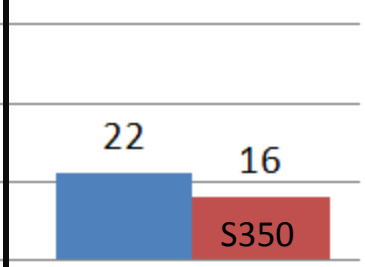
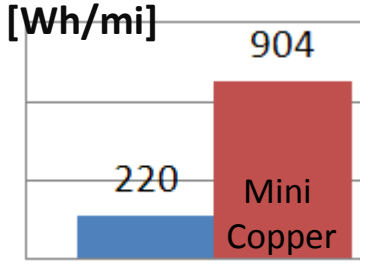
Supplier BEV prototype

Ford TADA PHEV

Jetta TDI (bio-fuels)

PROGRESSIVE AUTOMOTIVE X PRIZE

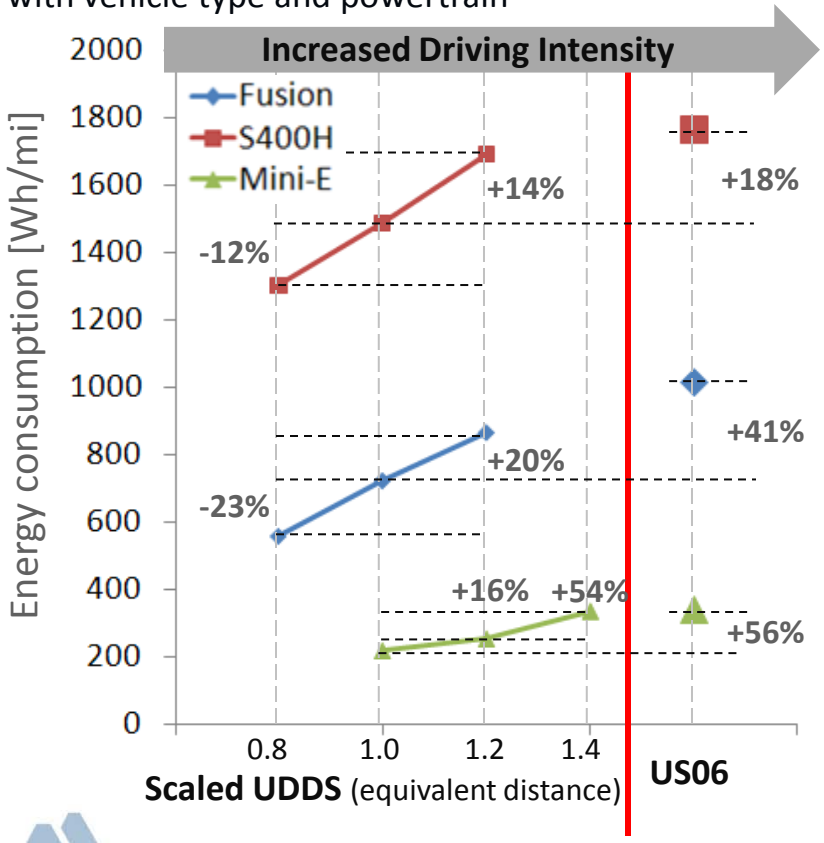
Example of recent public vehicles tested in FY11

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

Sample results: Energy Consumption Impact Factors and Sensitivities

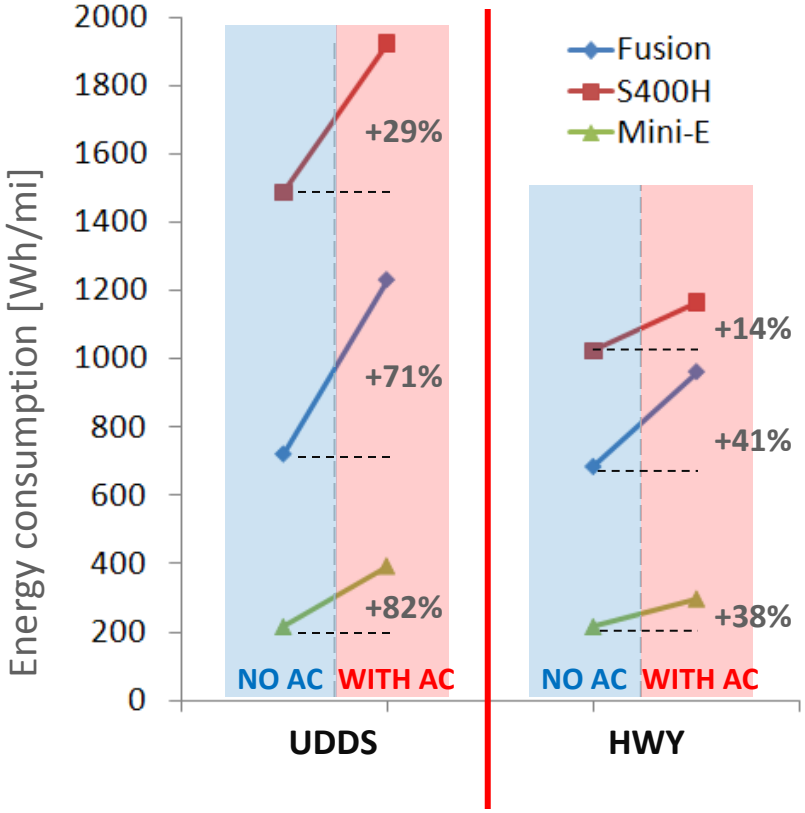
Driver intensity impact

- 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

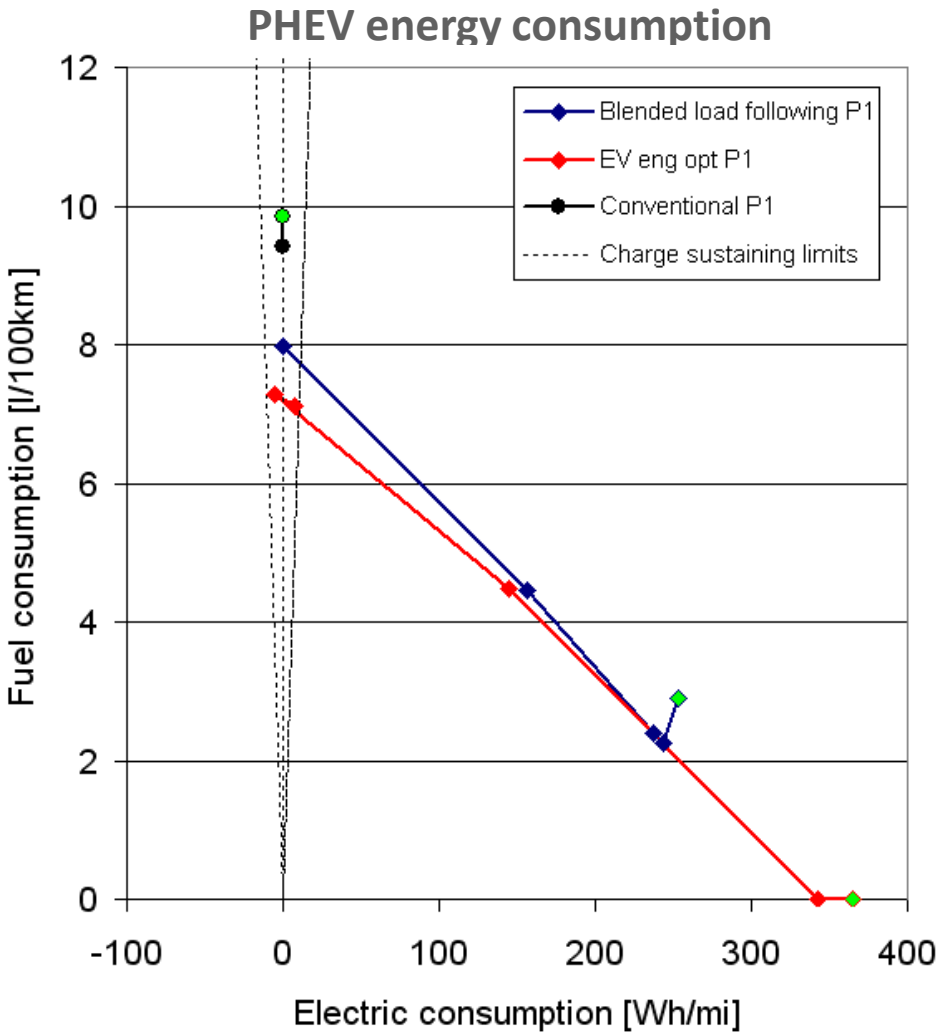


Air conditioning impact

- 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



Plug-in hybrids: the 2 dimensional problem

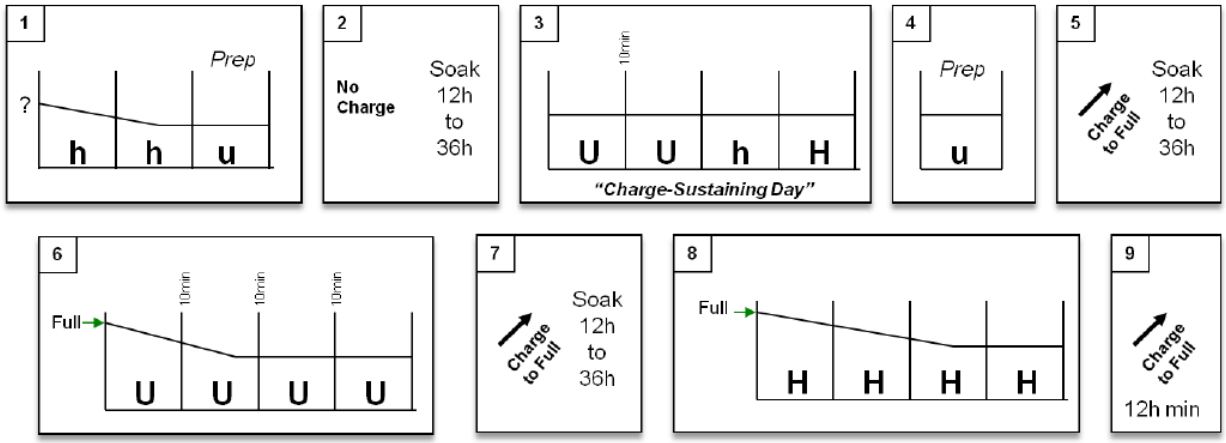


- Plug-in hybrids use energy from
  - Fuel (tank)
  - Electricity (battery pack)
- First the vehicle will deplete the battery energy and thus displace fuel
  - Blended
  - EV capable
- Once the battery is depleted the vehicle operates in a charge sustaining mode

•What is fuel economy now?
•It will vary from good mpg to infinite mpg in some cases
•How to test these cars

Standards Development: SAE J1711 HEV and PHEV Test Procedures

Uppercase = data taken, **Lowercase** = no data taken, **U** or **u** = UDDS, **H** or **h** = HFEDS



Steps:

1. Vehicle arrives with unknown SOC, deplete until CS operation, must test at least 1 UDDS in CS mode and satisfy NEC charge-balance criteria
2. Put vehicle in soak for 12 to 36h, NO CHARGE
3. Run CS FTP-HFEDS (UDDSx2 and HFEDSx2), other "hot-start" CS tests can be run on this day
4. Run separate UDDS prep for UDDS FCT next day
5. Put vehicle on charge and soak for 12 to 36h, vehicle brought back to dyno ready to test within one hour of vehicle taken off charge
6. Run UDDS FCT
7. Charge to Full and Soak
8. Run HFEDS FCT
9. Charge to Full

Notes:

- Vehicle soaks while on charge
- Charge energy in (7) is applied to FCT in (6)
- Charge energy in (5) should be similar to charge energy in (7)
- HWY prep not required before HWY FCT in (8), last CS cycles in (6) are suitable
- Sequence ends with full charge in (9)

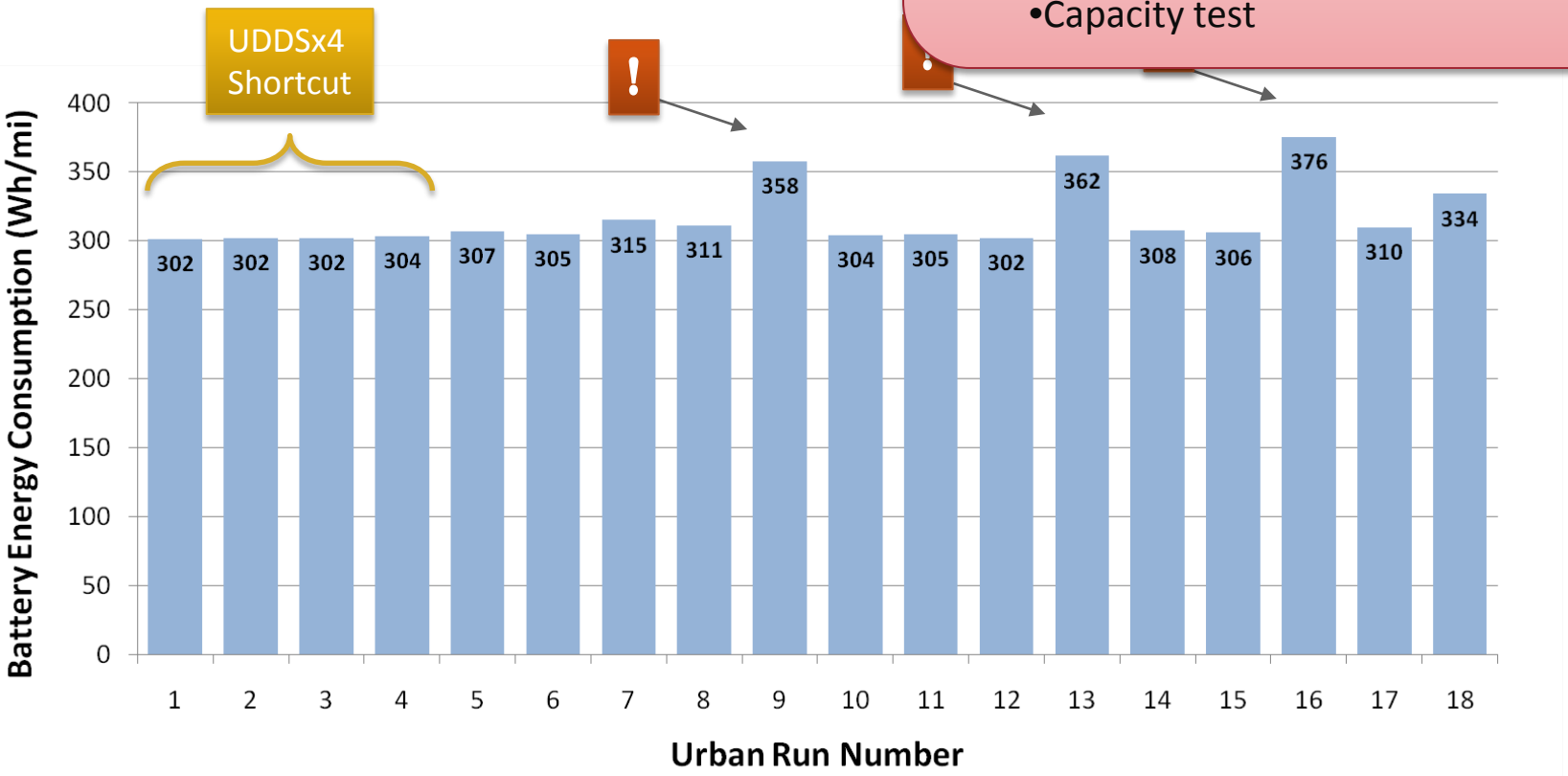
Codes and Standards – J1634 EV Test Procedures

Development of Shortcut test - Varying Consumption Rates

For this vehicle:

- Warm-up penalties non-existent.
- Regen consistent
- Additional consumption during componen

•New electric vehicles can have a range of 150+ miles which translates to 12 hours of continuous testing
•A new short cut method is investigated to determine range using:
  •Energy consumption
  •Capacity test



Summary and more…

SAE J1772 AC Charge Coupler approved January 2010

- The APRF has great expertise in testing advanced technology vehicles
- The expertise and data generate is used to advance codes and standards
- Here is the stuff I did not talk about
  - Modeling and simulation
    - Autonomie
  - Hardware in the Loop
    - Engine in the Loop
    - Battery in the Loop
    - Modular Automotive Technology Testbed
  - Green racing
  - More codes and standards
    - Charge plug
    - Motor rating
    - Testing methods
  - Advanced Technology Vehicle Competitions
    - EcoCAR
  - And more…