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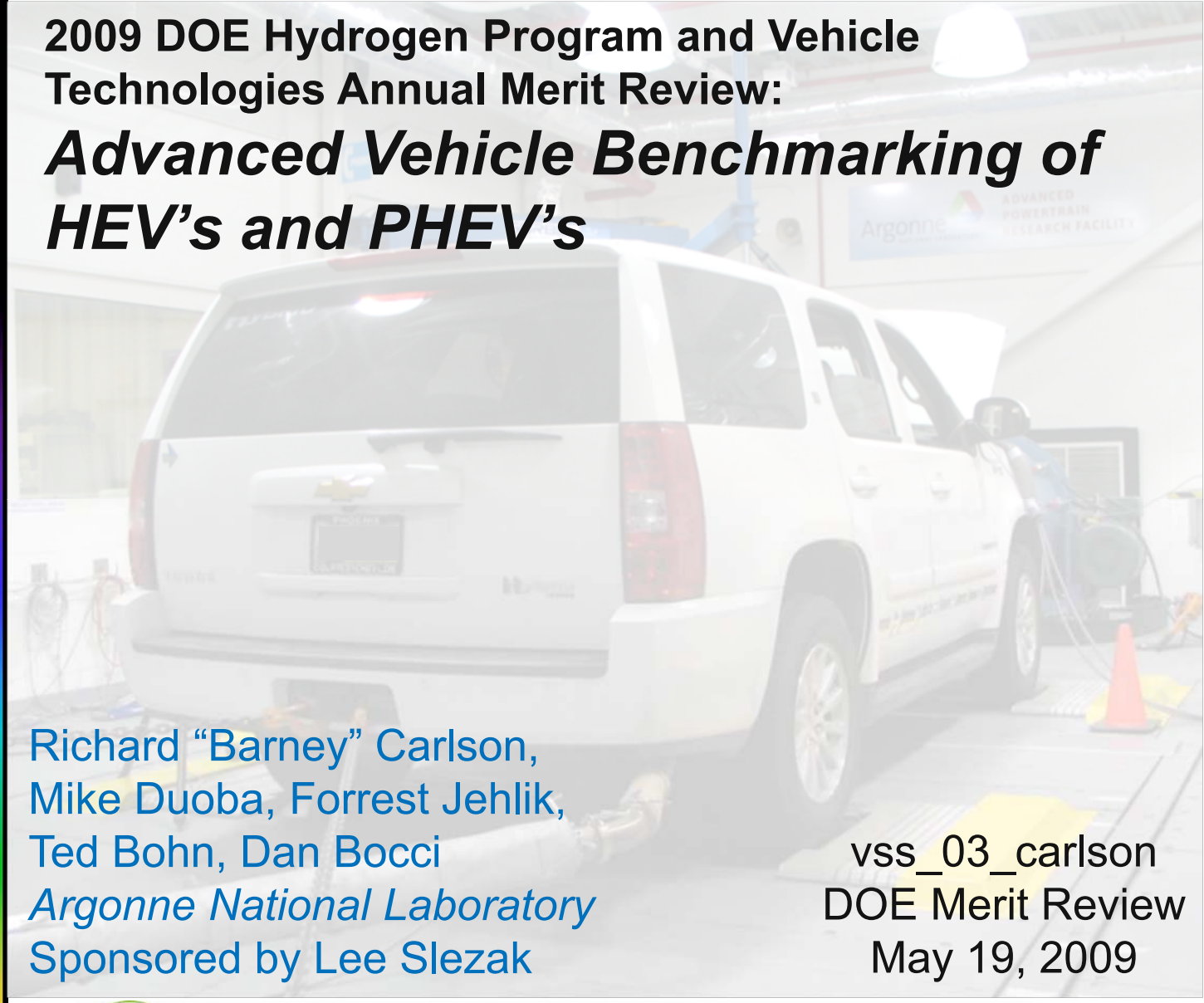
2009 DOE Hydrogen Program and Vehicle Technologies Annual Merit Review:

Advanced Vehicle Benchmarking of HEV's and PHEV's



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Project Overview

Timeline

- HEV Benchmarking
  - Tahoe Hybrid: 2nd Qtr 2008
  - Altima Hybrid: 3rd Qtr 2008
  - 2010 Honda Insight: 3rd Qtr 2009
  - 2010 Toyota Prius: 4th Qtr 2009
  - 2010 Fusion Hybrid: 4th Qtr 2009
  - 2010 Saturn Vue Hybrid: 4th Qtr 2009
- PHEV Benchmarking
  - Three Escape PHEV conversions: FY08
  - Two Prius PHEV conversions: FY09

Budget

- Advanced Vehicle Benchmarking
  - FY08: $ 300k
  - FY09: $ 370k

Barriers

- Obtaining advanced technology vehicles is difficult due to proto-type nature of PHEV's
- Expense of Detailed vehicle instrumentation

Partners

- Idaho National Lab
  - AVTA Program

Objectives

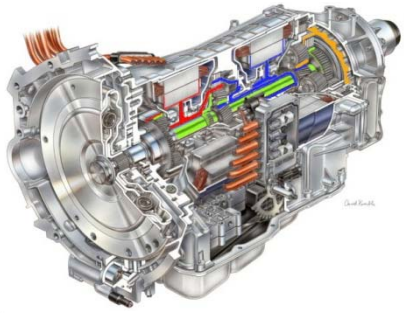
- Benchmark advanced technology vehicles and disseminate that information to U.S. OEM's, National Labs, and Universities

Milestones

- ***HEV***
  - GM Tahoe Hybrid benchmarking completed (Level 1+ instrumentation)
    - Full instrumentation of Level 2 except for invasive engine torque sensor
  - Nissan Altima Hybrid
- ***PHEV's Benchmarked***
  - Three Escape PHEV conversion
  - Two Prius PHEV conversion
  - One OEM PHEV
- ***Dynamometer Data Acquisition***
  - Developed a more robust and streamlined CAN bus data acquisition system

Chevrolet Tahoe Hybrid - 2Mode

- Engine: 6.0L V8 gasoline
  - Pushrod 2 valves per cylinder
  - Variable camshaft timing with late intake valve closing
  - Cylinder Deactivation (8 cyl. or 4 cyl.)
- Transmission: 2-Mode
  - Dual, 60kW permanent magnet, electric motors
  - 2 EVT modes (power-split)
  - 4 fixed gear ratios (parallel)
- Battery: Panasonic NiMH
  - 1.8 kWh (rated) / 0.5 kWh (usable)
  - Air cooled from cabin air
  - Typical peak power: 30kW
  - Instantaneous peak power: 60kW at WOT engine start



Source: General Motors

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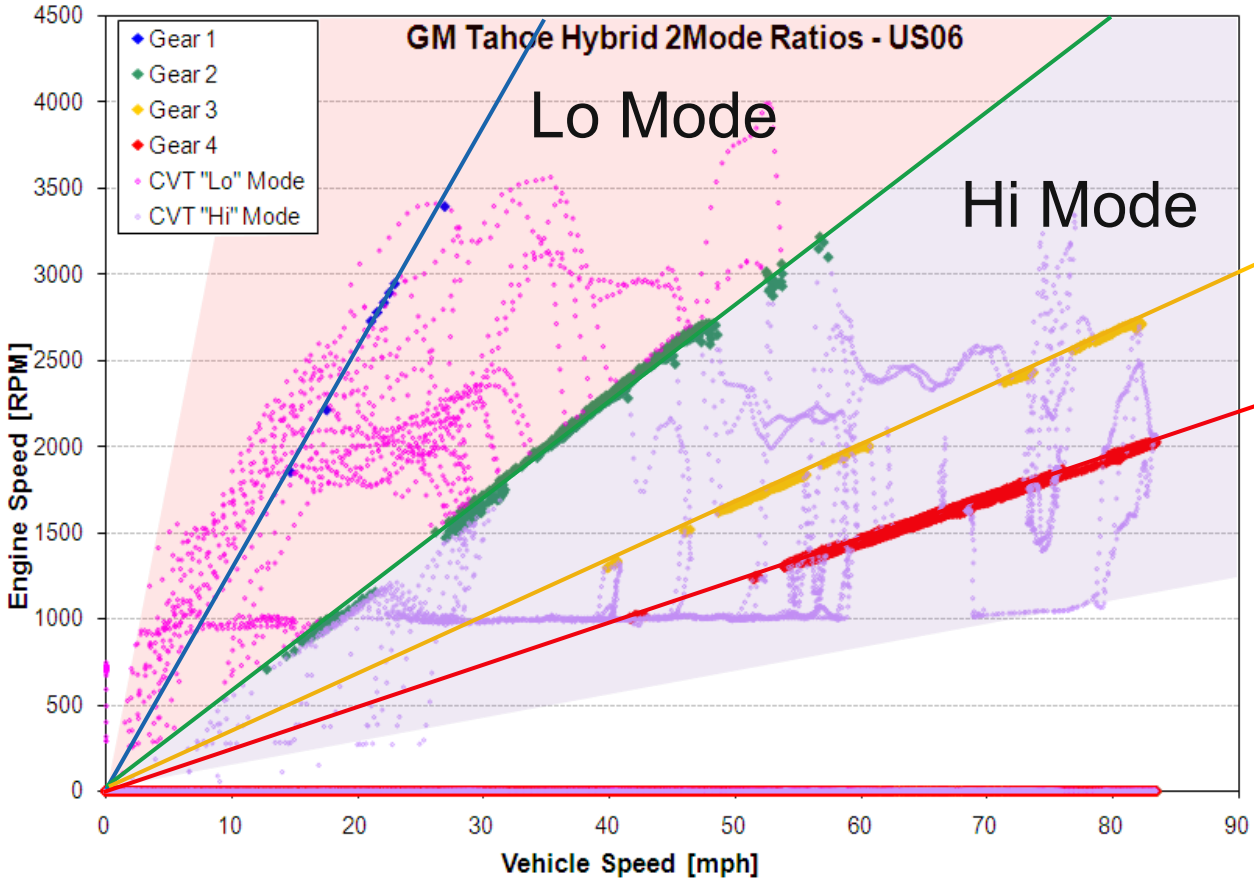
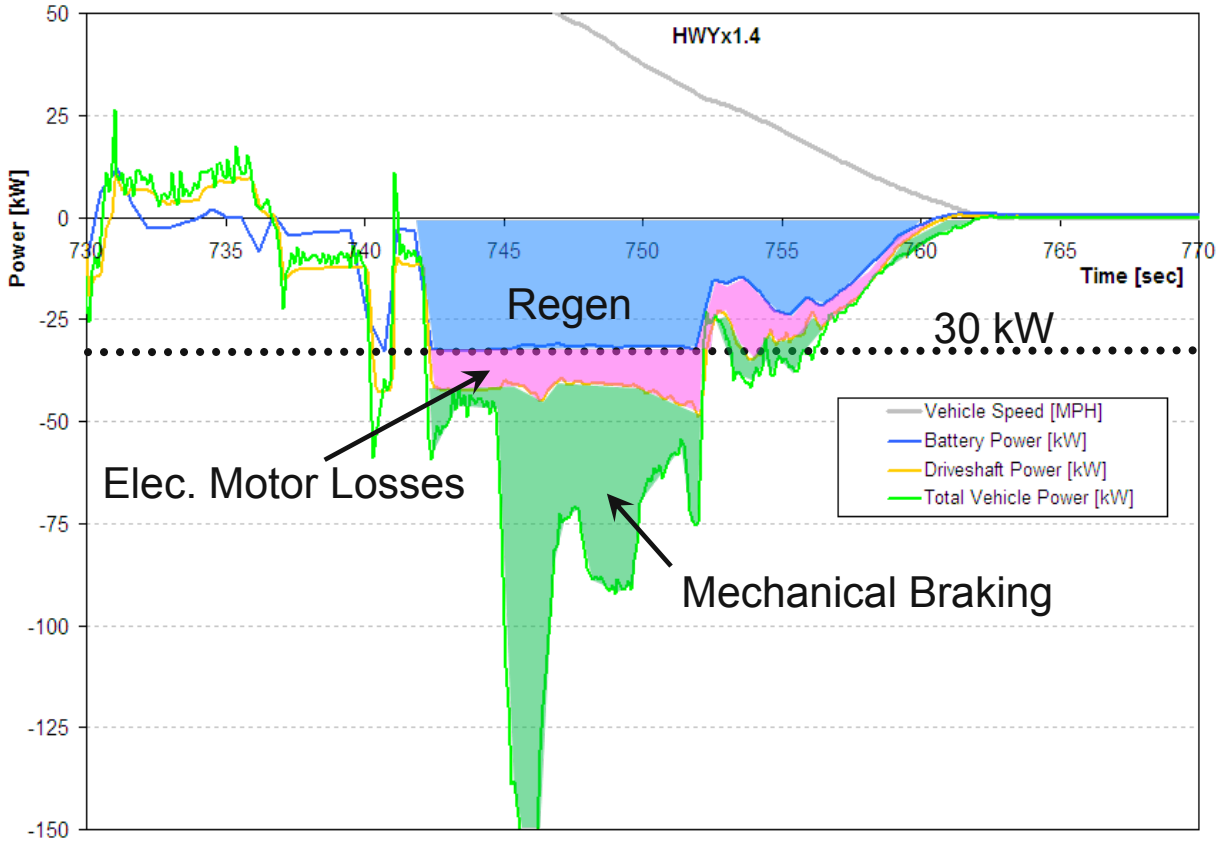
2Mode Transmission Combines Benefit of CVT and Step Gear

- 2 Modes (Low and High)
  - Power-split Hybrid
- 4 Fixed Gear Ratios
  - Parallel operation
  - More efficient at high speeds
  - Enables trailer towing of large mass
  - Enormous controls flexibility



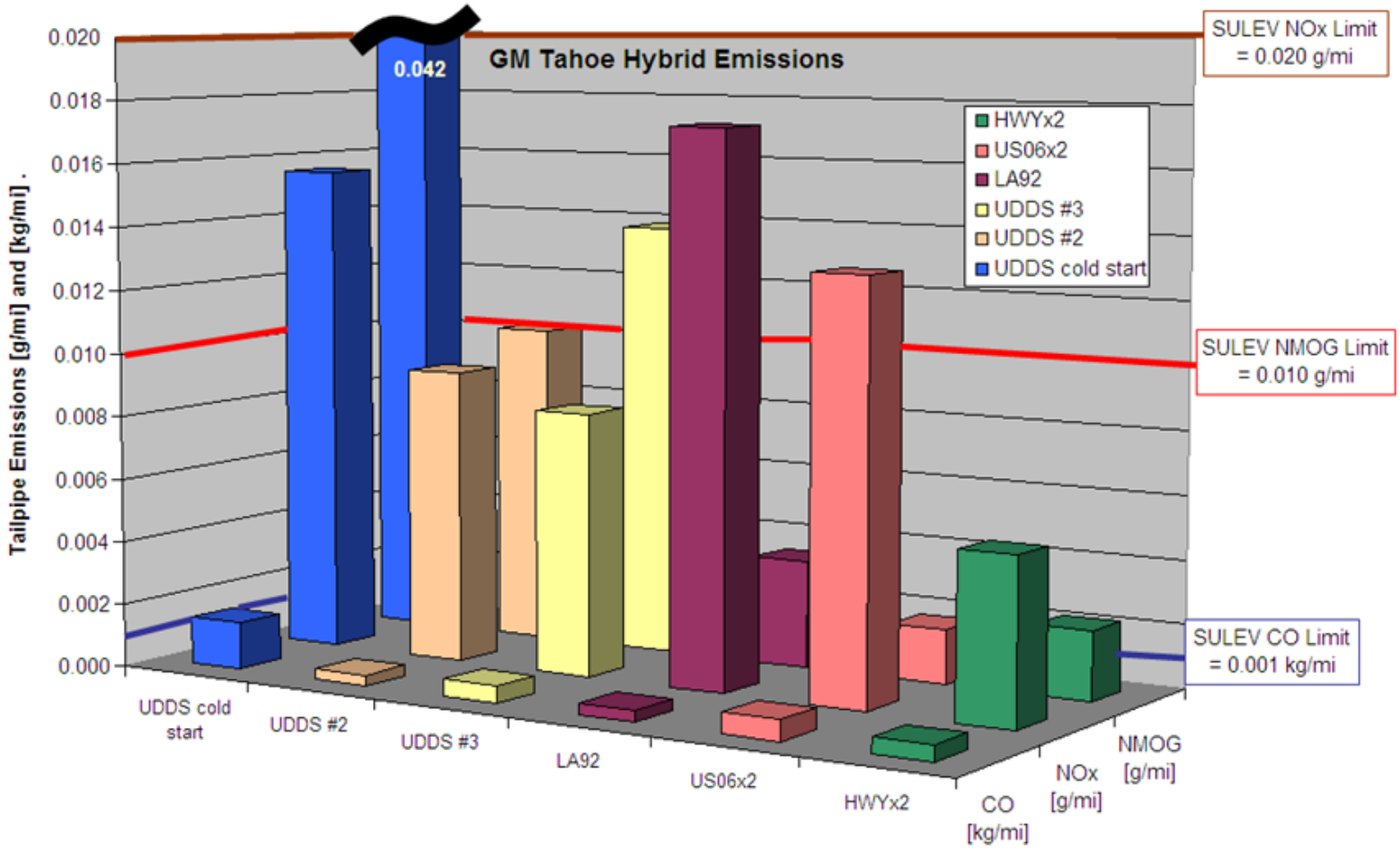
Full Regen Capability in RWD Tahoe Hybrid

- Full Regen Braking capability up to:
  - battery power limit of 30kW
  - driveshaft torque of -500Nm
  - 29 mph
- EV operation capable up to 28 mph



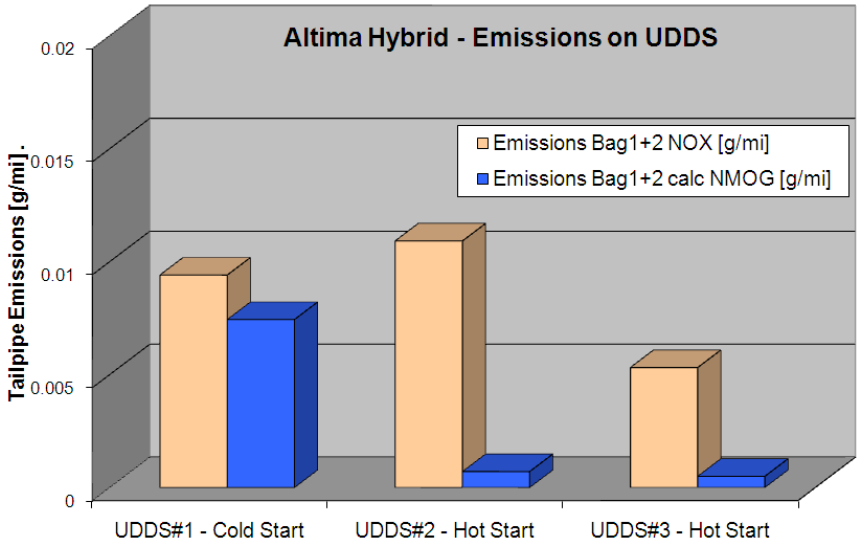
Tahoe Hybrid 2-Mode: Very Low Tail Pipe Emissions except for NMOG on UDDS

- Tailpipe emissions for most tests were within SULEV
- UDDS NMOG (cold and hot start) was within ULEV limits (not SULEV)



Nissan Altima Hybrid

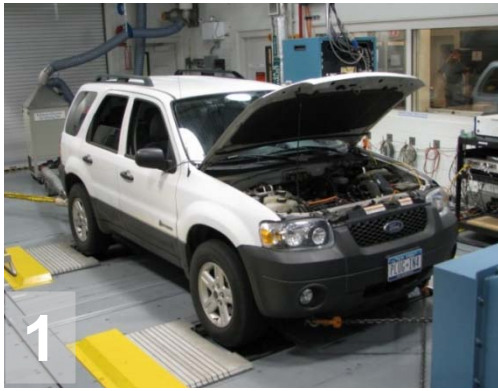
- Same powertrain as Camry Hybrid except larger engine (2.5L) produced by Nissan
  - Same transmission and power electronics
  - Same NiMH battery
- Fuel economy comparison
  - Altima Hybrid: better city fuel economy
  - Camry Hybrid: better Hwy fuel economy
- Altima Hybrid attained SULEV emissions



	Altima Hybrid	Camry Hybrid
EPA Reported Fuel Econ (mpg)	35 City 33 Hwy	33 City 34 Hwy
Dyno Test Results Fuel Econ (mpg)	33.5 City 32.3 Hwy	32.9 City 34.3 Hwy
Test Weight (lbs)	3750	4000
Engine Size [L]	2.5 L	2.4 L
Engine Comp Ratio	9.6:1	12.5:1
Engine-On Time Hot UDDS [%]	33.3	35.4

Three Escape PHEV Conversions

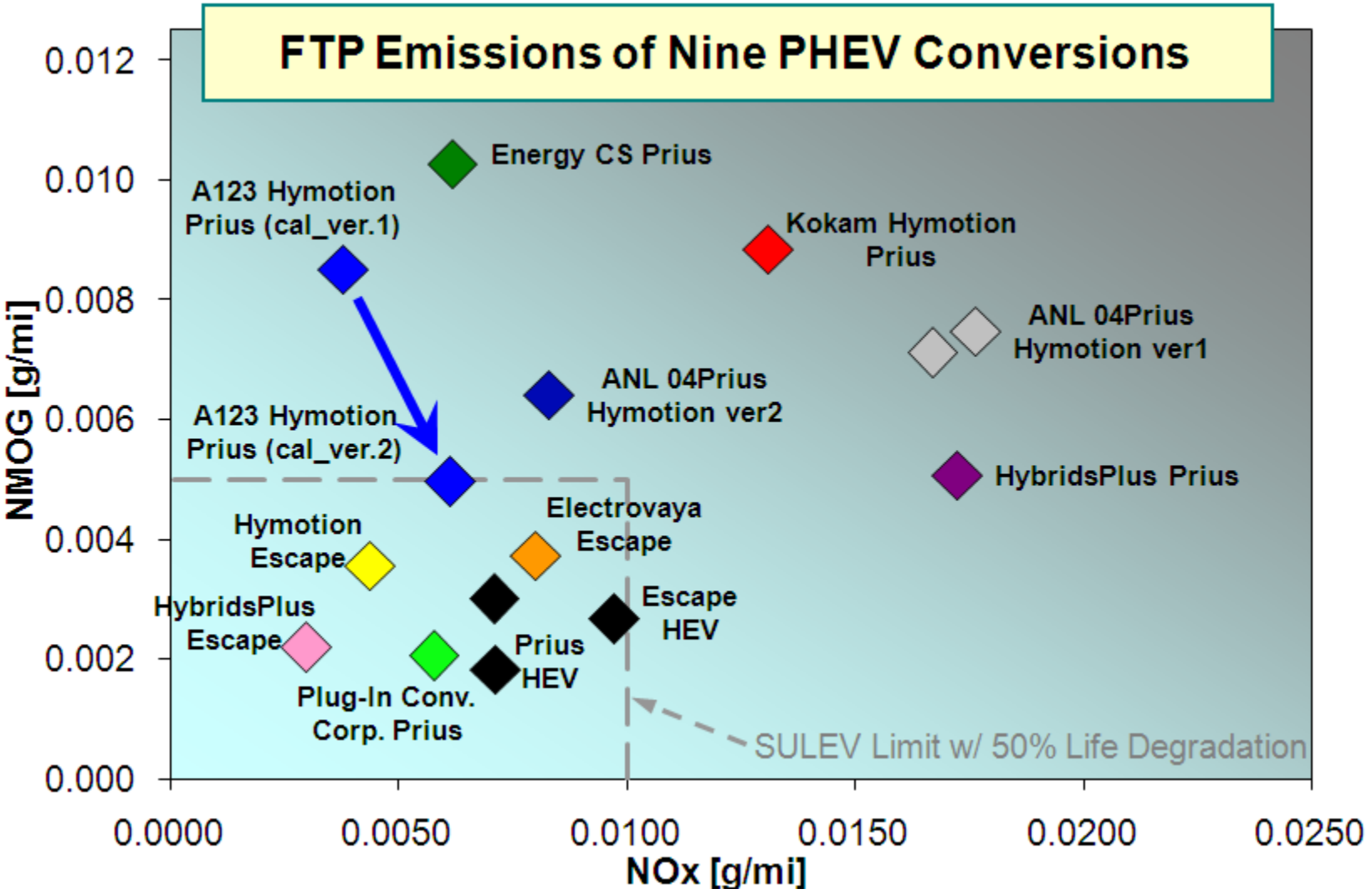
1. Hybrids-Plus Escape PHEV
   - Battery replacement conversion using A123 Li-Ion cells
2. Hymotion Escape PHEV
   - Battery add-on system using A123 Li-Ion cells and DC/DC converter to deliver power to powertrain
3. Electrovaya Escape PHEV
   - Battery add-on system using Electrovaya Li-Ion cells and Series Pass Regulator to deliver power to powertrain



- All three Escape PHEV conversions attained SULEV

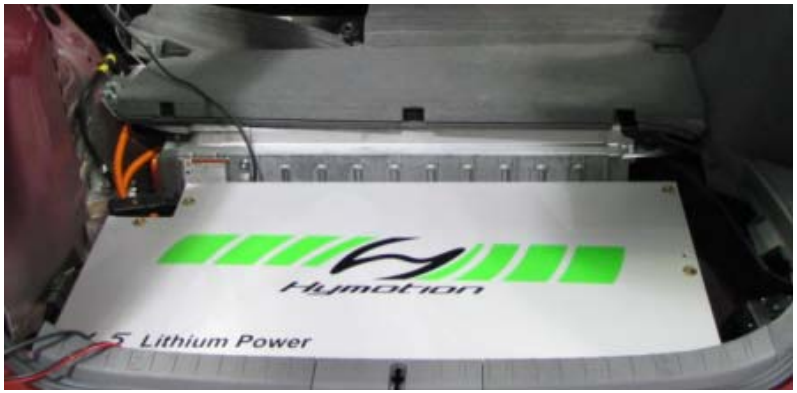
Escape Conversion PHEV	Battery Usable Capacity [kWh]	CD Range [mi]	EAER [mi]	UF Fuel Economy (UDDS) [mpg]	UF Elec. Consumption (UDDS) [AC Wh/mi]
Hybrids-Plus	9.8	60	24.4	51.4	145
Hymotion	6.8	35	15.9	43.7	143
Electrovaya	6.0	60	15.0	39.6	148

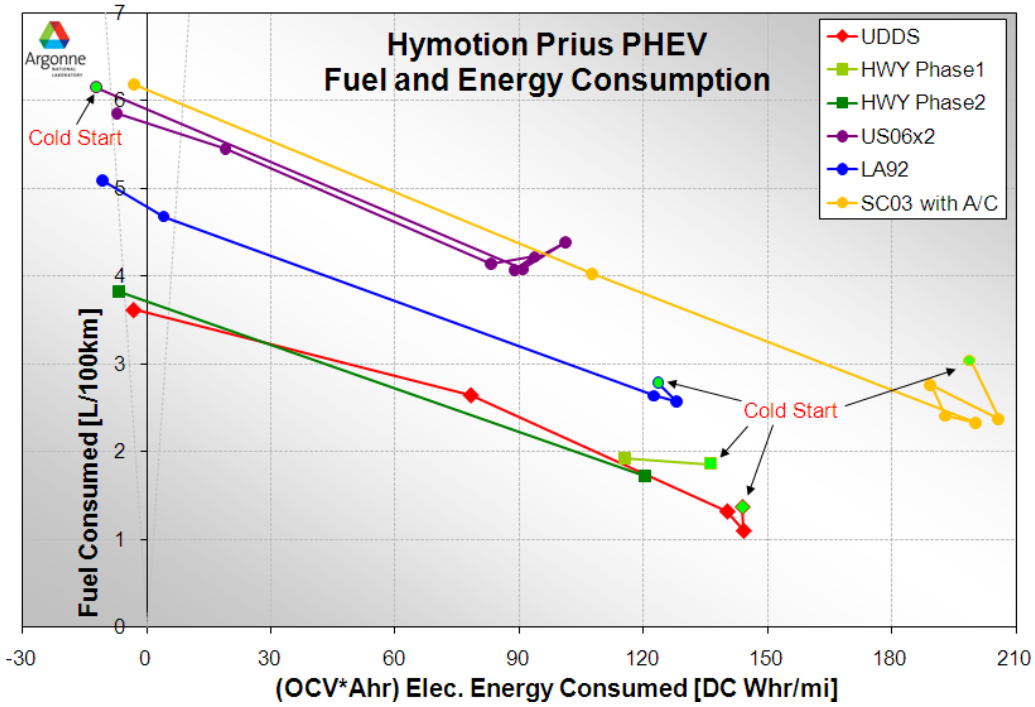
Several PHEV Conversions Achieved SULEV Attainment



Production Hymotion Prius PHEV

- 5 kWh Li-Ion Battery System
- 3.6 kWh usable
- Utility Factor Weighted Fuel Economy
  - UDDS: 91 mpg / 98 AC Wh/mi
  - HWY: 84 mpg / 91 AC Wh/mi
  - US06: 50 mpg / 81 AC Wh/mi
  - LA92: 64 mpg / 94 AC Wh/mi
  - SC03: 50 mpg / 101 AC Wh/mi
- Charge Depletion Range: 30 mi
- Equivalent All-Electric Range: 15 mi
- Roundtrip Electrical Efficiency: 70%





Plug-In Conversions Corp. Prius PHEV

- Battery Replacement Conversion
  - 6.1 kWh rated NiMH Gold Peak batteries (30 Ah)
  - 3.8 kWh usable
- Utility Factor Weighted Fuel Economy
  - 89 mpg / 95 AC Wh/mi (UDDS)
  - 85 mpg / 100 AC Wh/mi (HWY)
  - 50 mpg / 95 AC Wh/mi (US06)
  - 64 mpg / 101 AC Wh/mi (LA92)
- Charge Depletion Range: 24 mi
- Equivalent All-Electric Range: 14 mi
- Roundtrip Electrical Efficiency: 70%

Future Work

- Proposed Upgrade APRF capability for Sub-Freezing FTP and Hot SC03 with solar heat load capabilities
  - For 5-cycle testing capability

- HEV's to be benchmarked
  - 2010 Honda Insight
  - 2010 Toyota Prius
  - 2010 Saturn Vue 2Mode
  - 2010 Ford Fusion Hybrid
- PHEV's to be benchmarked
  - Daimler Sprinter PHEV

Summary

- Benchmarking data use to validate PSAT vehicle models
  - Tahoe Hybrid 2-Mode
  - Hymotion Prius PHEV

- Recent Conversion PHEV have shown SULEV attainment with engine-on operation soon after key start (i.e. no EV range)

- Data from testing is available to the public on Argonne's website database
  https://webapps.anl.gov/vehicle_data/