

U.S. Department of Energy - Advanced Vehicle Testing Activity

Hybrid Electric, Plug-in Hybrid Electric, and Hydrogen Internal Combustion Engine Testing Activities

Intermountain Conference on the Environment

Idaho State University, September 2007

Jim Francfort

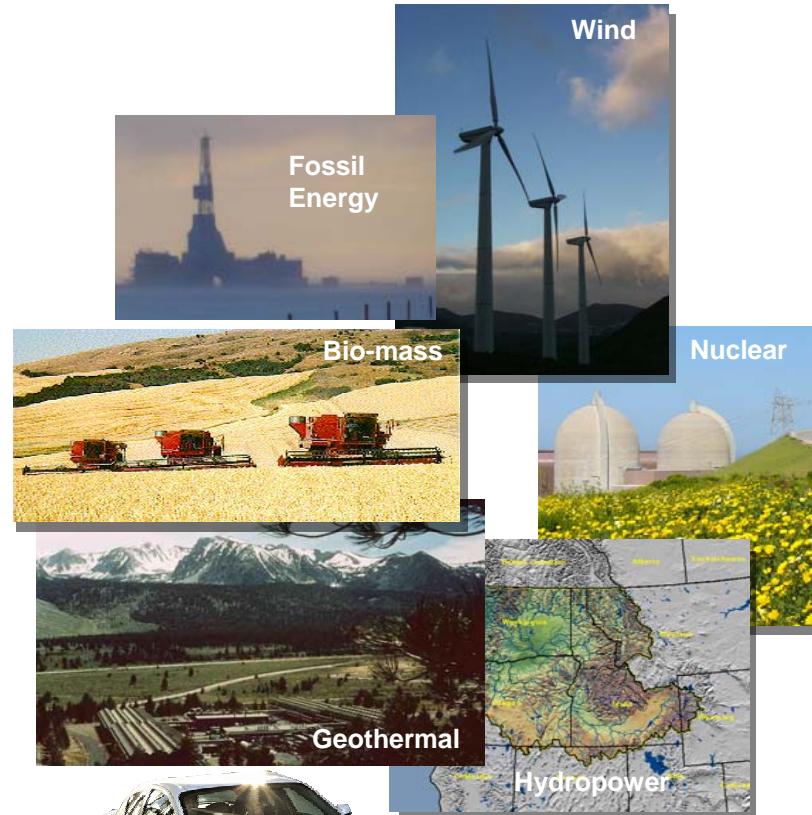


Presentation

- INL and AVTA background, history and goal
- Test methods
- Testing Results
 - Hybrid electric vehicles (HEVs)
 - Plug-in hybrid electric vehicles (PHEVs)
 - Hydrogen station and hydrogen internal combustion engine (HICE) vehicles
- Webpage address for this presentation and ~300 test reports and fact sheets

Idaho National Laboratory

- The INL is an Eastern Idaho based U.S. Department of Energy (DOE) multi-program laboratory conducting research, development and demonstrations to help “ensure the nation’s energy with safe, competitive and sustainable energy systems.....”
- Managed for DOE by Battelle Energy Alliance
- 61 patent applications and 4 R&D 100 awards in 2006
- 890 square mile site with 3600 staff



AVTA Background and Goal

- The Advanced Vehicle Testing Activity (AVTA) is part of the U.S. Department of Energy's FreedomCAR and Vehicle Technologies Program
- The AVTA is primarily conducted by the Idaho National Laboratory (INL) and Electric Transportation Applications (ETA - Phoenix, AZ), with Argonne National Laboratory performing dynamometer testing
- AVTA Goal
 - Provide benchmark data to technology modelers, research and development programs, and target setters
 - Assist fleet managers in making informed vehicle purchase, deployment and operating decisions

AVTA Testing History

- **Plug-in hybrid electric vehicles**
 - 3 models tested, 4 more starting
- **Hybrid electric vehicles**
 - 12 models, 3 million test miles
- **Hydrogen ICE (internal combustion engine) vehicles**
 - 6 models, 400,000 test miles
- **Full-size electric vehicles**
 - 40 EV models, 5+ million test miles
- **Neighborhood electric vehicles**
 - 15 models, 200,000 test miles
- **Urban electric vehicles**
 - 3 models, 1 million test miles

Baseline Performance Testing

- Initial closed track testing conducted near Phoenix, AZ
 - Testing includes coastdown (determination of dynamometer coefficients), acceleration, top speed, charging, and durability tests
- Depending on vehicle technology, a two- to five-day dynamometer testing regime is used that includes:
 - Urban Dynamometer Driving Schedule (UDDS) and Highway Fuel Economy Test (HWFET) primary dynamometer test cycles
 - Charge depleting and sustaining test cycles
 - Includes air conditioning (AC) off and on cycles
 - Hot and cold starts for emissions testing
 - PHEV testing includes at least 26 drive cycle tests

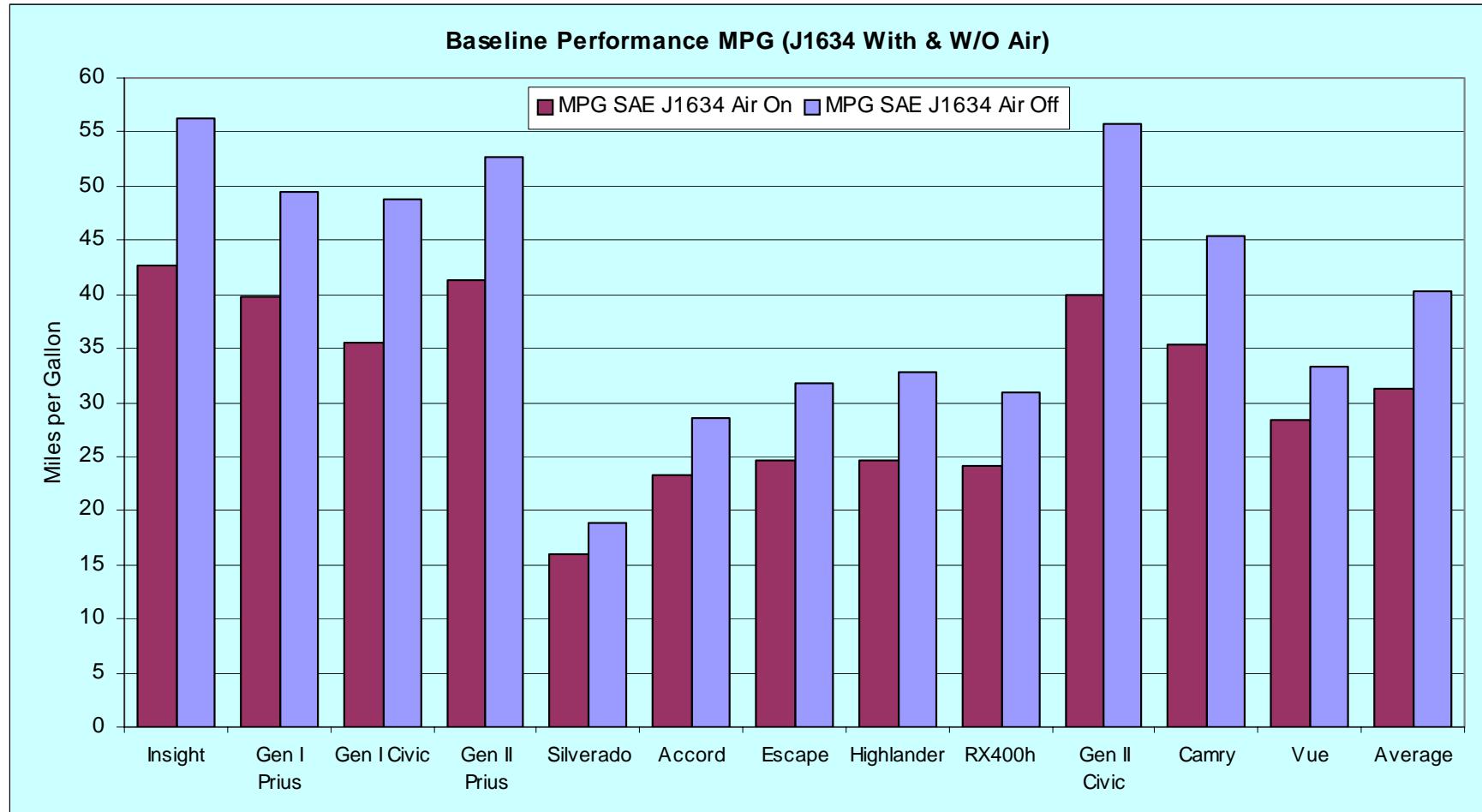
Fleet and Accelerated Testing

- Technology dependant
 - PHEVs are onroad tested in defined 10-mile city and highway loops for 4,240 miles
 - HEVs are tested for 160,000 miles and three years in high mileage fleets
 - HICEs in tested in private and utility fleets (hydrogen infrastructure fueling limited)

Hybrid Electric Vehicle (HEV) Testing

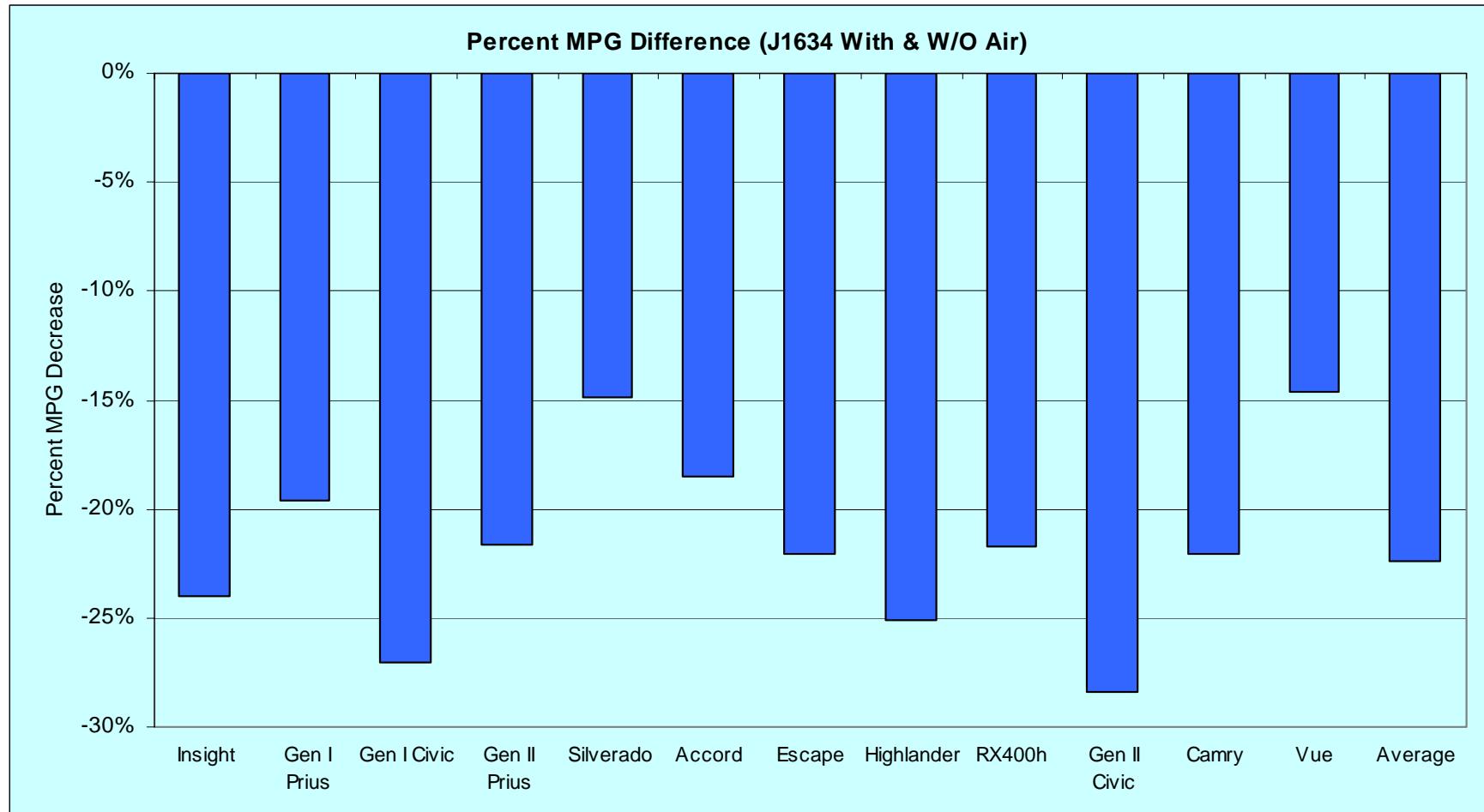
HEV Baseline Performance Testing

- 12 HEV models baseline performance tested to date



HEV Baseline Performance Testing

- Percentage mpg decrease with air conditioning on

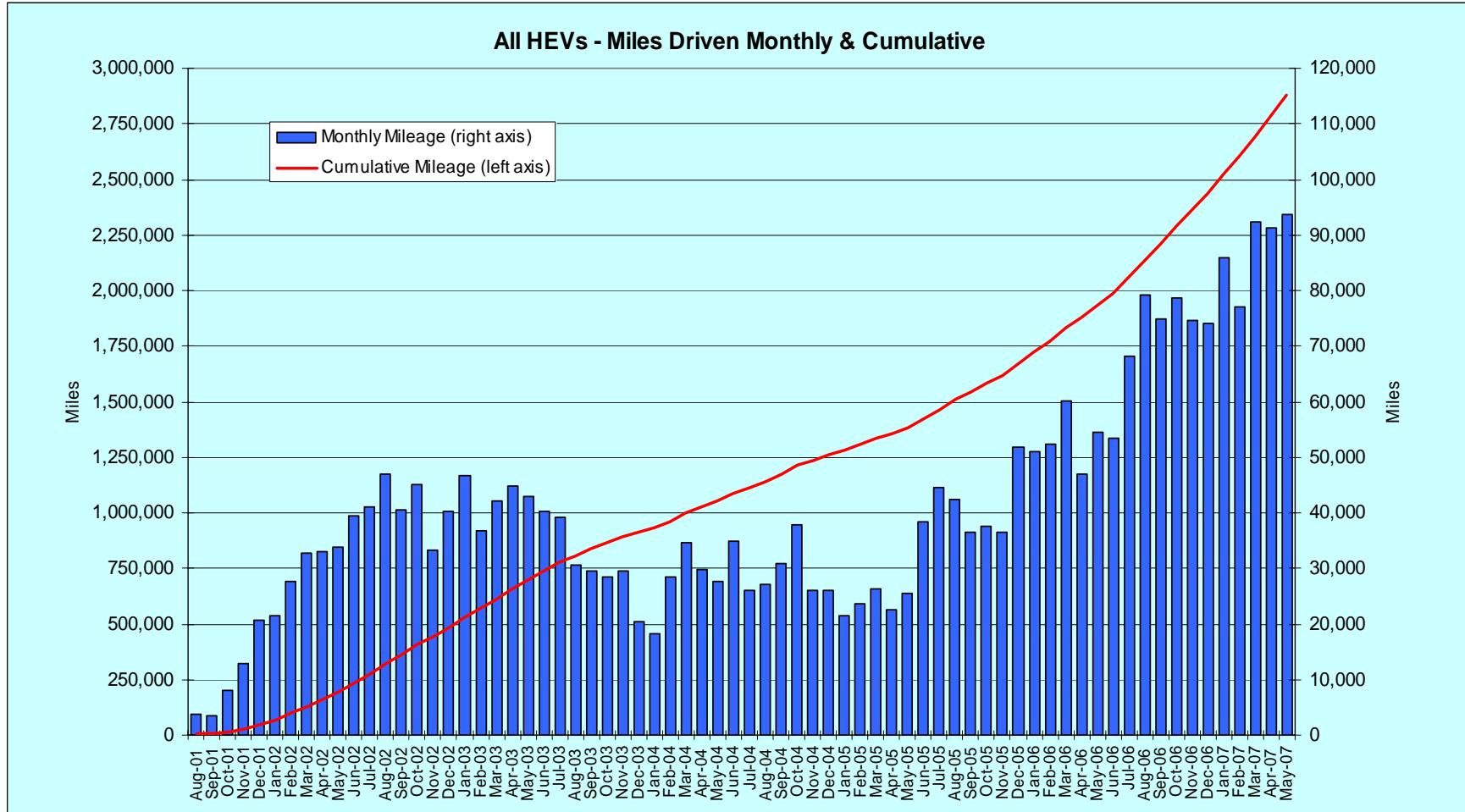


HEV Accelerated Testing

HEV Model	Number Accelerated Tested	Accelerated Testing Status
2001 Honda Insight	6	Completed
2002 Gen I Toyota Prius	6	Completed
2003 Gen I Honda Civic	4	Completed
2004 Chevrolet Silverado (2- & 4-WD)	2	Ongoing
2004 Gen II Toyota Prius	2	Completing
2005 Ford Escape (front & 4-WD)	2	Completing
2005 Honda Accord	2	Ongoing
2006 Lexus RX 400h (front & 2 AWD)	3	Ongoing
2006 Toyota Highlander (AWD)	2	Ongoing
2006 Gen II Honda Civic	2	Ongoing
2007 Saturn Vue	2	Ongoing
2007 Toyota Camry	2	Ongoing
200X Nissan Altima	?	Obtaining
200X GM 2-mode vehicles	?	?
Total	35 to date	

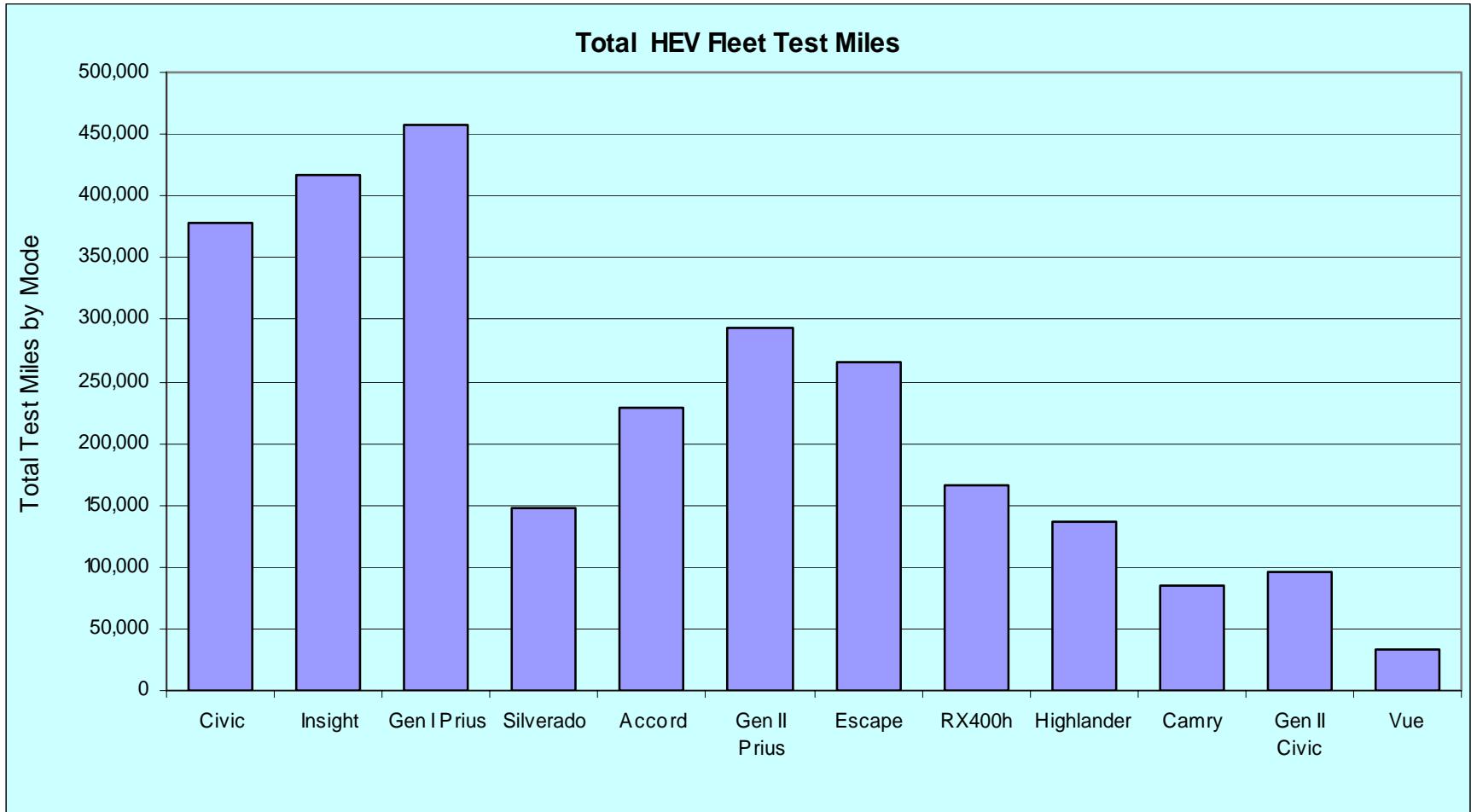
HEV Accelerated Testing

- 2.9 million total accelerated testing miles



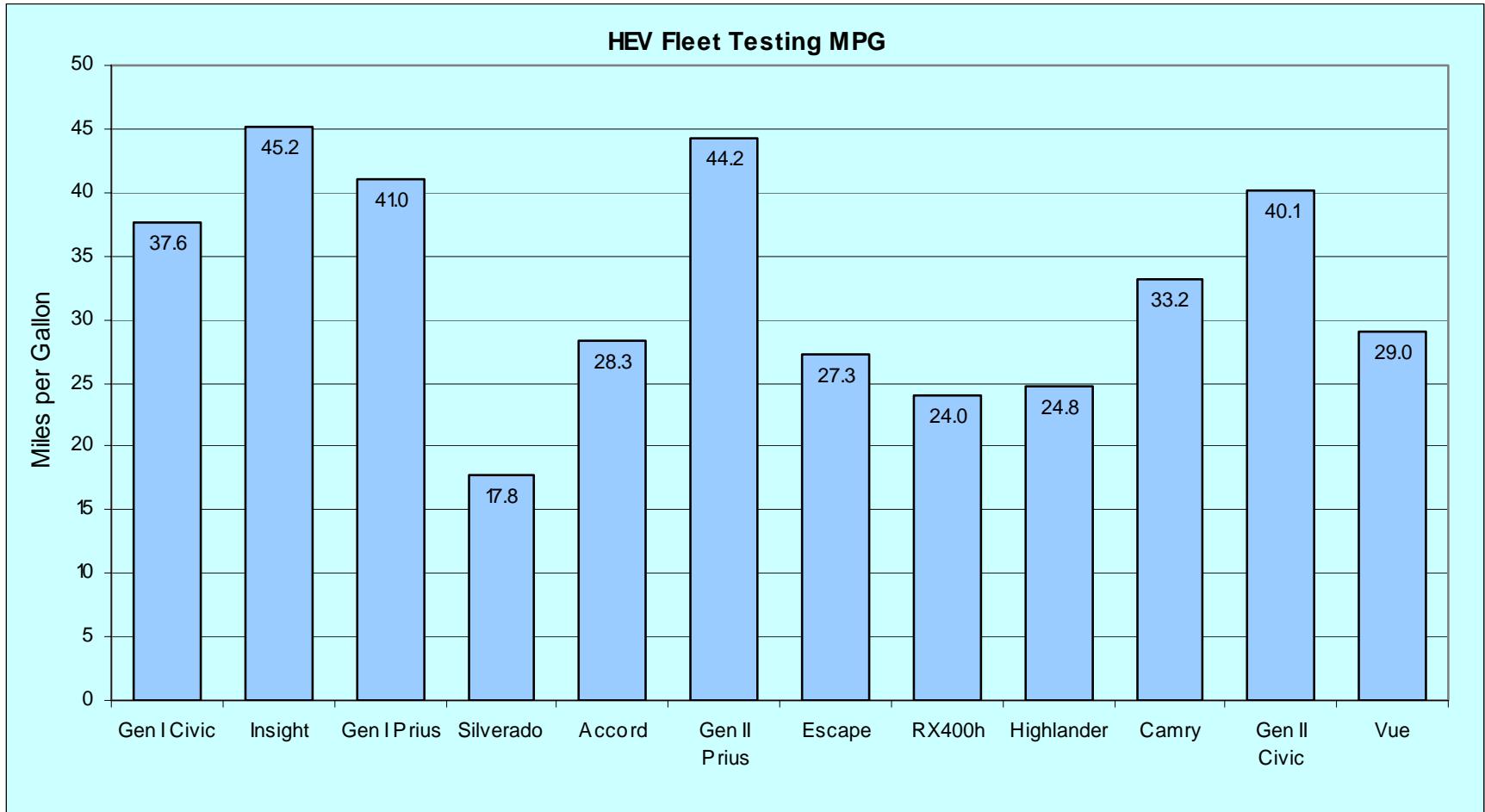
HEV Accelerated Testing

- Test miles per HEV model



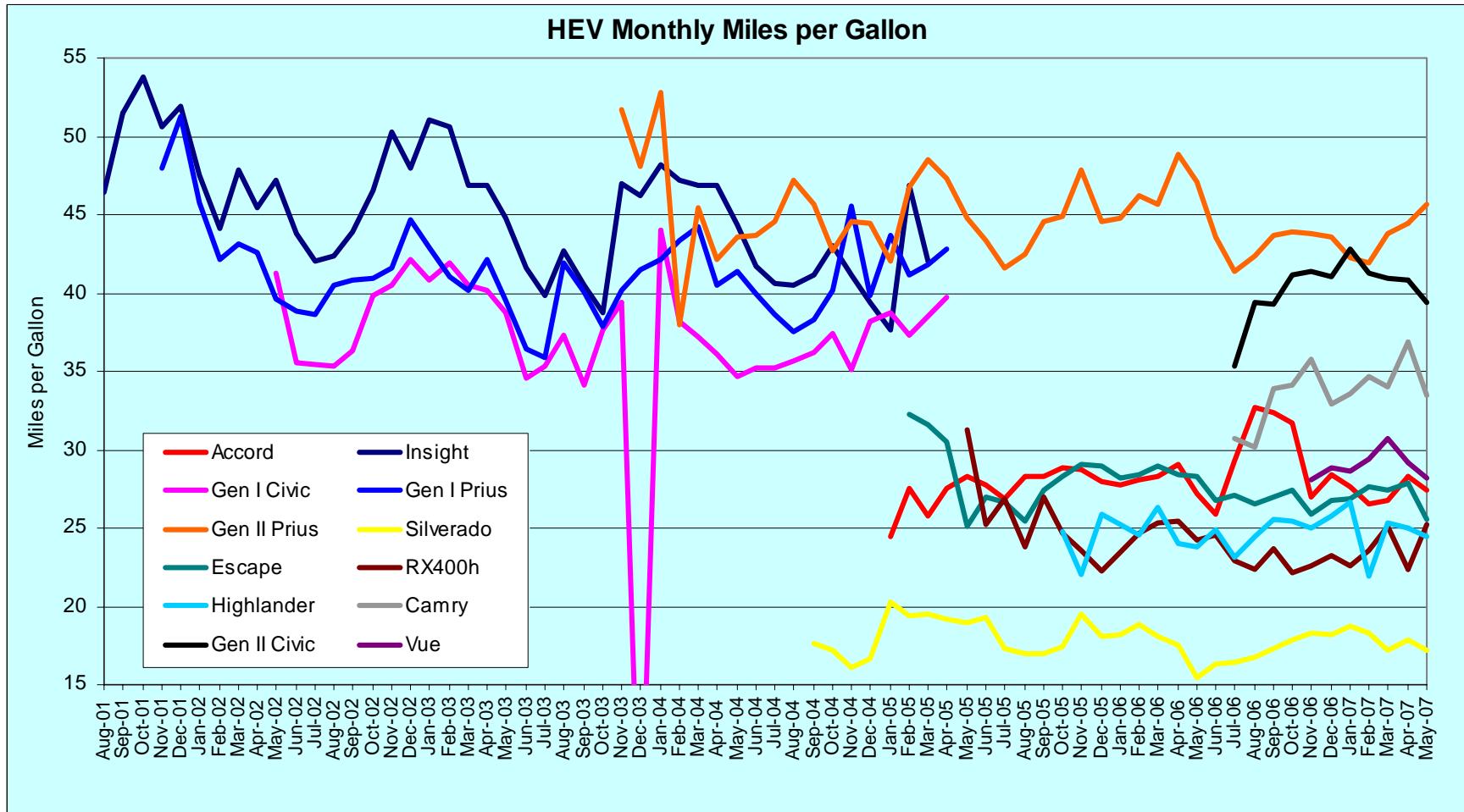
HEV Accelerated Testing

- Miles per gallon by HEV model



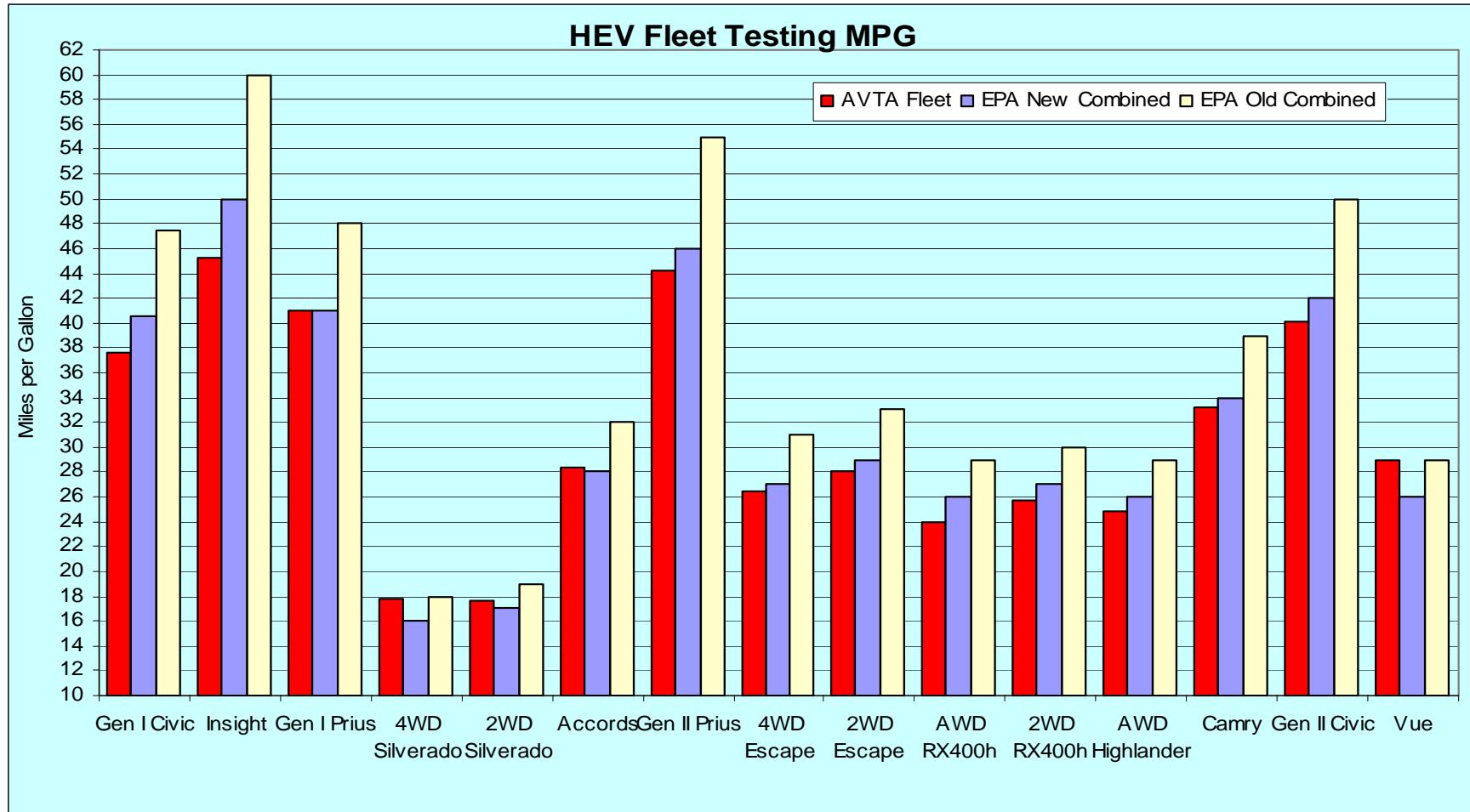
HEV Accelerated Testing

- Monthly miles per gallon



HEV Accelerated Testing

- AVTA accelerated testing and EPA miles per gallon



HEV Maintenance and Repairs Tracked

FREEDOMCAR & VEHICLE TECHNOLOGIES PROGRAM

HEV Fleet Testing

Advanced Vehicle Testing Activities

Maintenance Sheet for 2006 – Highlander



VIN # JTEDW21A160006395

Date	Mileage	Description	Cost
12/14/2005	4,855	Changed oil, rotated tires	\$31.99
1/5/2006	9,952	Changed oil, rotated tires	\$28.04
1/31/2006	15,749	15K service	\$187.05
2/22/2006	20,783	Changed oil, rotated tires	\$28.07
3/15/2006	26,197	Changed oil, rotated tires	\$28.10
4/17/2006	31,578	30K service	\$321.80
4/26/2006	36,682	Changed oil, rotated tires	\$28.99
5/18/2006	42,113	Changed oil, rotated tires	\$28.99
6/9/2006	47,475	15K interval service, 45K preventative maintenance	\$200.67
7/5/2006	53,711	Changed oil	\$38.44
7/26/2006	59,632	60K service	\$346.86
8/21/2006	65,947	Changed oil	\$38.31
9/12/2006	71,030	Changed oil, replaced wiper blades	\$57.20
9/14/2006	71,053	Check engine light on - Code PA93 Inverter cooling system malfunction inverter coolant low	warranty
9/29/2006	73,015	Replaced windshield	\$272.87
10/6/2006	75,949	75K service	\$200.67
12/6/2006	90,270	Changed oil	\$39.60



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Electric Transportation Applications

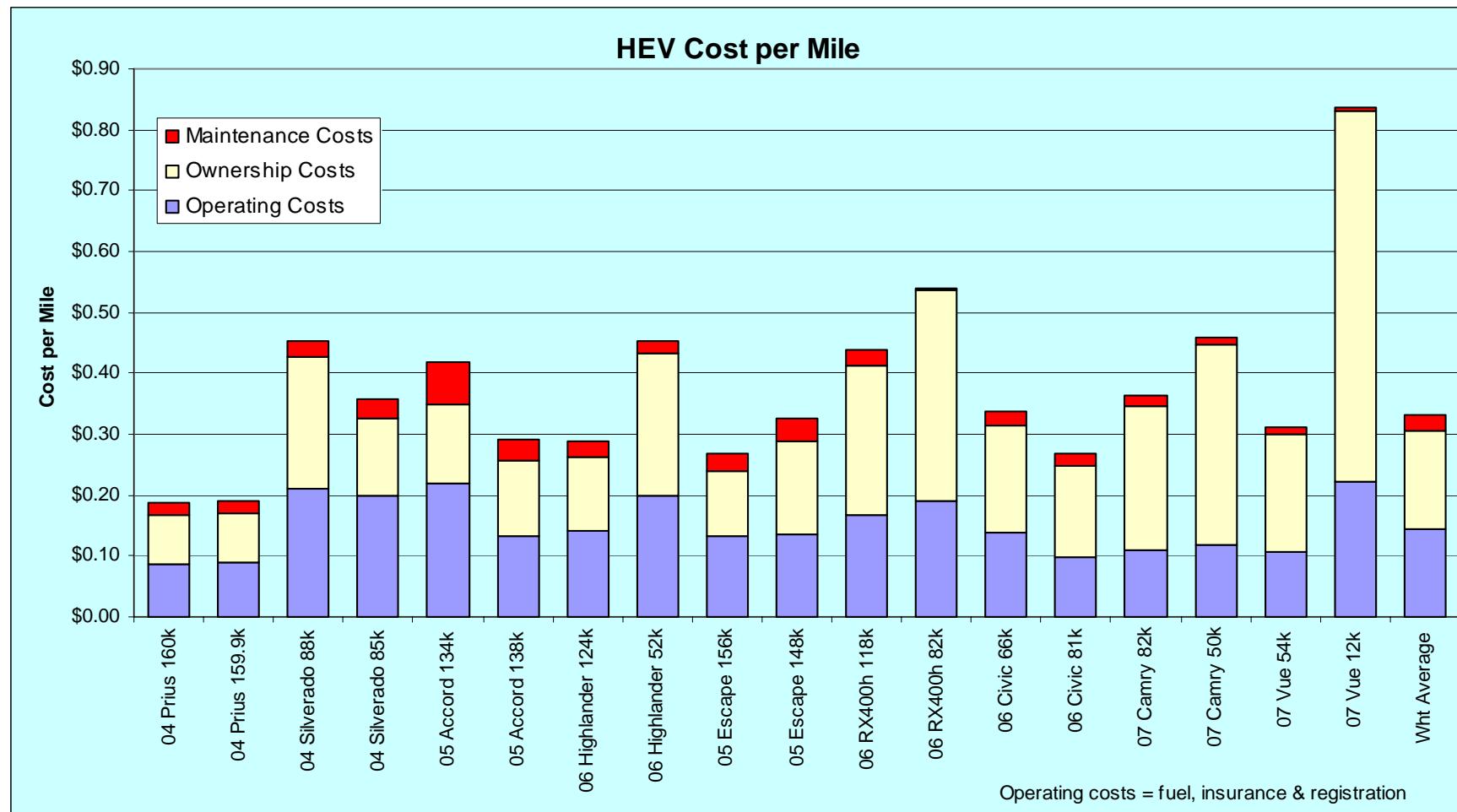
Idaho National Laboratory

FreedomCAR
& Fuel Partnership

U.S. DEPARTMENT OF ENERGY

HEV Life-cycle Costs

- Ownership, operating, and maintenance costs per mile



Plug-in Hybrid Electric Vehicle (PHEV) Testing

PHEV Status and Brief Description

- Can be a currently available HEV that has been converted to a PHEV by adding a second battery pack or using a larger replacement battery pack. Vehicle converters and OEMs are using both methods in series and parallel configurations
- Several OEMs have also announced future products
- Different from HEVs in that PHEVs must be plugged into the electric grid to charge, usually via a 110 volt, 15 amp circuit, the larger PHEV battery packs



PHEV Baseline Performance Testing

PHEVAMERICA
U.S. DEPARTMENT OF ENERGY ADVANCED VEHICLE TESTING ACTIVITY



Base Vehicle Description
 Make: Toyota
 Model: Prius Year: 2006
 VIN: JTDXKB20U767508841
 Number of Passengers: 5
 Hybrid Configuration: Series/Parallel

Energy CS Plug-in Hybrid

VEHICLE SPECIFICATIONS			VEHICLE TEST RESULTS		
Weights Design Curb Weight: 3160 lbs Vehicle Test Weight: 3400 lbs GVWR: 3795 lbs GAWR F/R: 2335/2250 Distribution: 54.2%/45.8% Payload: 635 lbs Performance Goal: 400 lbs Engine Model: 1NZ-FXE Output: 76 HP @ 5000 RPM Configuration: 4 Cylinder In-line Displacement: 1.5L Fuel Tank Capacity: 11.9 gal Fuel Types: Unleaded			Charge Depleting: Acceleration 0-60 MPH: Time: 12.96 seconds Acceleration 1/4 Mile : A/C kWh Consumed: .169 kWh/mi Charge Depleting: Maximum Speed: 75.7 MPH Acceleration 1 Mile : Average Fuel Economy: 149.1 MPG Charge Sustaining: Maximum Speed: 104.9 MPH Charge System: Acceleration 0-60 MPH: Time: 12.82 seconds Cold Start Charge Depleting: Fuel Economy: 108.2 MPG Acceleration 1/4 Mile : Time: 20.09 seconds Charge Depleting: Nominal Cell Voltage: 3.2V Acceleration 1 Mile : Nominal System Voltage: 10 kWh Charge Sustaining: Measured Useable Capacity: 4.88 kWh Charge System: Input Voltages: 120V Required Breaker Currents: 1.5-Amp Charger Power Output: 1.2 kW Charger Plug Type: NEMA 5-15 Displacement: 1.5L Fuel Tank Capacity: 11.9 gal Fuel Types: Unleaded		
UDDS Fuel Economy^a			HWFET Fuel Economy^a		
Distance (miles)	Fuel Economy (mpg)	A/C Energy Consumed (kWh)	Distance (miles)	Fuel Economy (mpg)	A/C Energy Consumed (kWh)
10	118.0	1.83	10	106.6	1.77
20	137.6	3.65	20	116.4	3.45
40	124.7	5.52	40	99.9	5.46
60	105.9	5.65	60	86.7	5.84
80	94.7	5.65	80	79.5	5.93
100	89.18	5.65	100	75.2	5.93
200	77.9	5.65	200	66.6	5.93

TEST NOTES:

1. Cumulative fuel economy over EPA standard urban drive cycle.
2. Vehicle tested at ambient temperature while off for a minimum of 12 hours prior to testing.
3. Average non-cold start charge depleting fuel economy
4. Value determined from average charge sustaining fuel economy tests with appropriate energy correction calculations.
5. A/C on cold setting with full blower power.
6. Calculated cumulative fuel economy values, includes cold start.
7. A/C energy based on measured charge efficiency.

This vehicle meets all HEV America Minimum Requirements listed on back of this sheet.
 Values in red indicate the Performance Goal was not met. All Power and Energy Values are DC unless otherwise specified.

PHEVAMERICA
U.S. DEPARTMENT OF ENERGY ADVANCED VEHICLE TESTING ACTIVITY



Base Vehicle Description
 Make: Toyota
 Model: Prius Year: 2007
 VIN: JTDXKB20U577558820
 Number of Passengers: 5
 Hybrid Configuration: Series/Parallel

Hymotion Plug-In Hybrid

VEHICLE SPECIFICATIONS			VEHICLE TEST RESULTS		
Weights Design Curb Weight: 3037 lbs Vehicle Test Weight: 3337 lbs GVWR: 3795 lbs GAWR F/R: 2335/2250 Distribution: 54.2%/45.8% Payload: 738 lbs Performance Goal: 400 lbs Engine Model: 1NZ-FXE Output: 76 HP @ 5000 RPM Configuration: 4 Cylinder In-line Displacement: 1.5L Fuel Tank Capacity: 11.9 gal Fuel Types: Unleaded			Charge Depleting: Acceleration 0-60 MPH: Time: 13.28 seconds Acceleration 1/4 Mile : A/C kWh Consumed: .147 kWh/mi Charge Depleting: Nominal Cell Voltage: 3.3V Acceleration 1 Mile : Nominal System Voltage: 194.8V Charge Sustaining: Maximum Speed: 4.7 kWh Charge System: Input Voltages: 120V Required Breaker Currents: 1.5-Amp Charger Power Output: 1.2 kW Charger Plug Type: NEMA 5-15 Displacement: 1.5L Fuel Tank Capacity: 11.9 gal Fuel Types: Unleaded		
UDDS Fuel Economy^a			HWFET Fuel Economy^a		
Distance (miles)	Fuel Economy (mpg)	A/C Energy Consumed (kWh)	Distance (miles)	Fuel Economy (mpg)	A/C Energy Consumed (kWh)
10	154.8	1.65	10	87.48	1.30
20	160.3	3.31	20	95.27	2.64
40	117.4	3.58	40	86.11	3.92
60	99.40	3.58	60	75.79	3.92
80	88.88	3.58	80	70.52	3.92
100	83.71	3.58	100	67.36	3.92
200	72.26	3.58	200	61.05	3.92

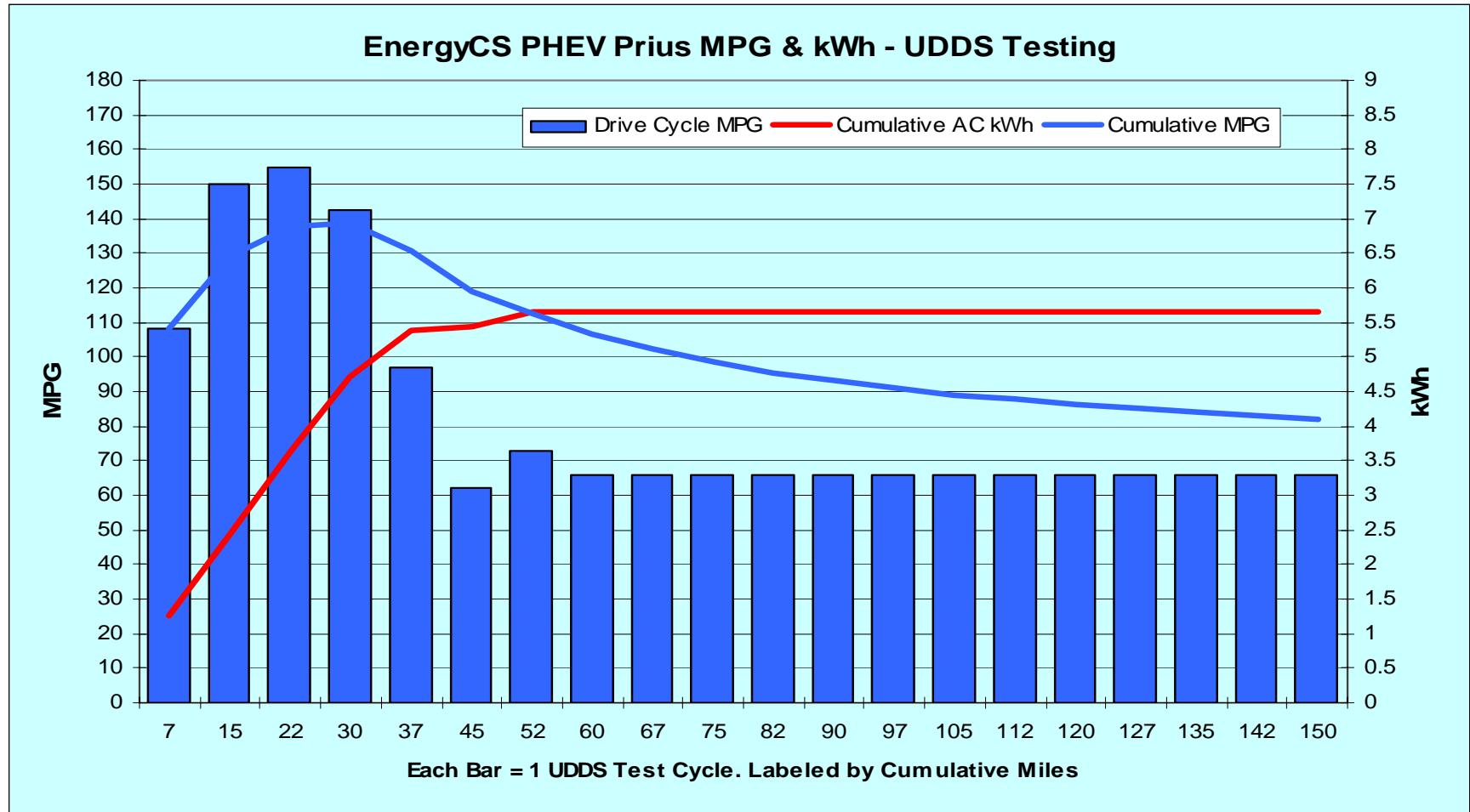
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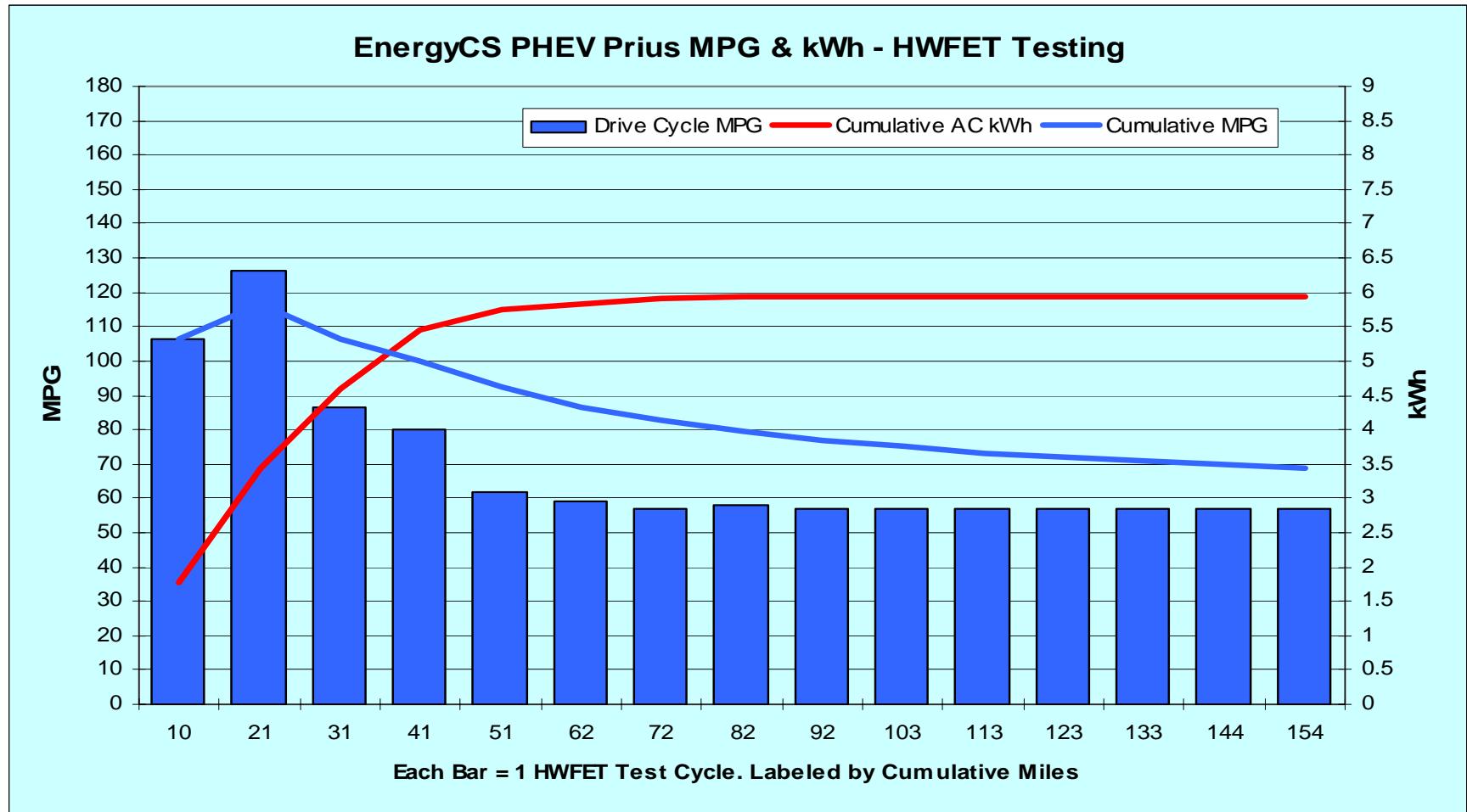
EnergyCS Prius – UDDS Fuel Use

- 9 kWh Valence lithium pack – A/C kWh



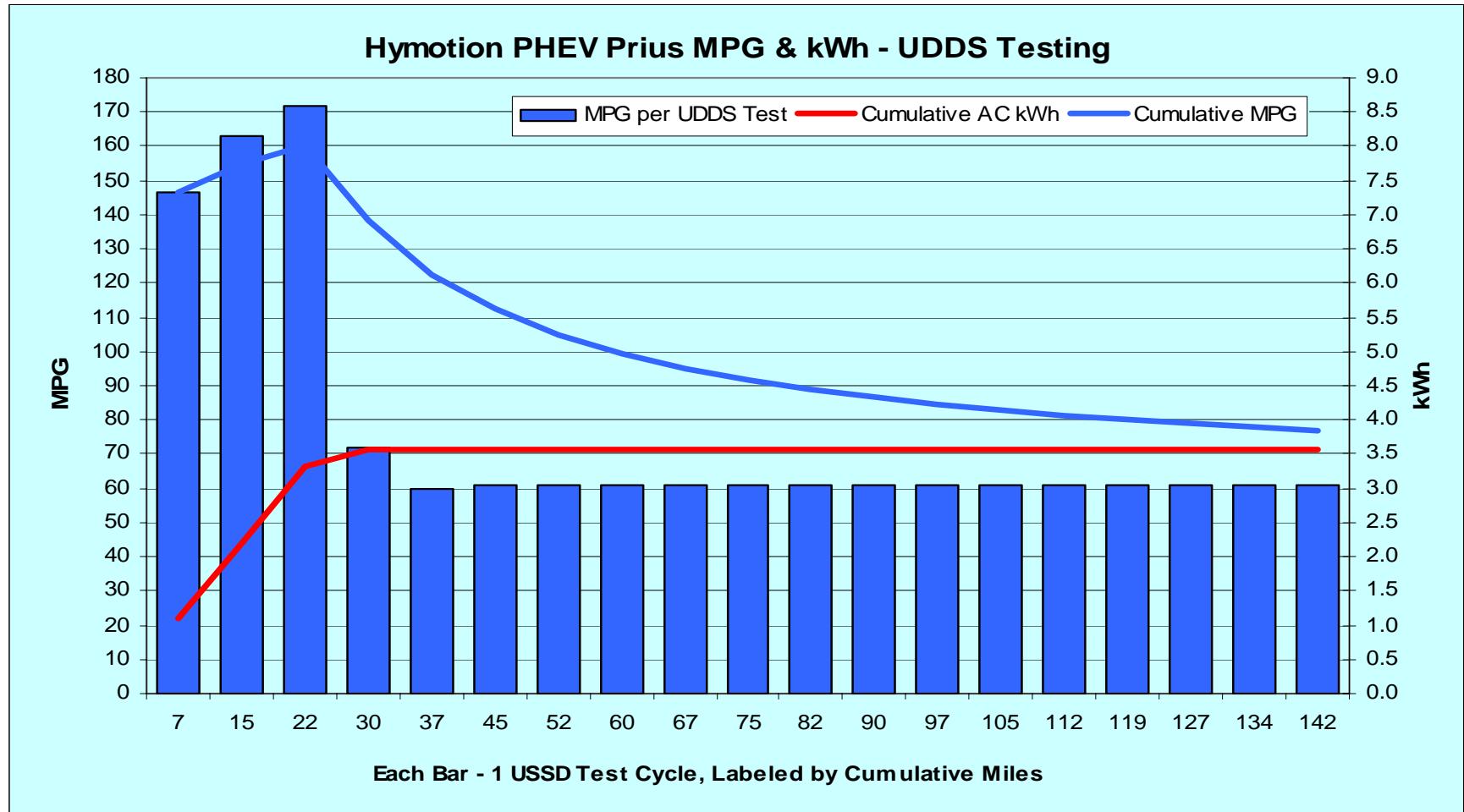
EnergyCS Prius – HWFET Fuel Use

- 9 kWh Valence lithium pack – A/C kWh



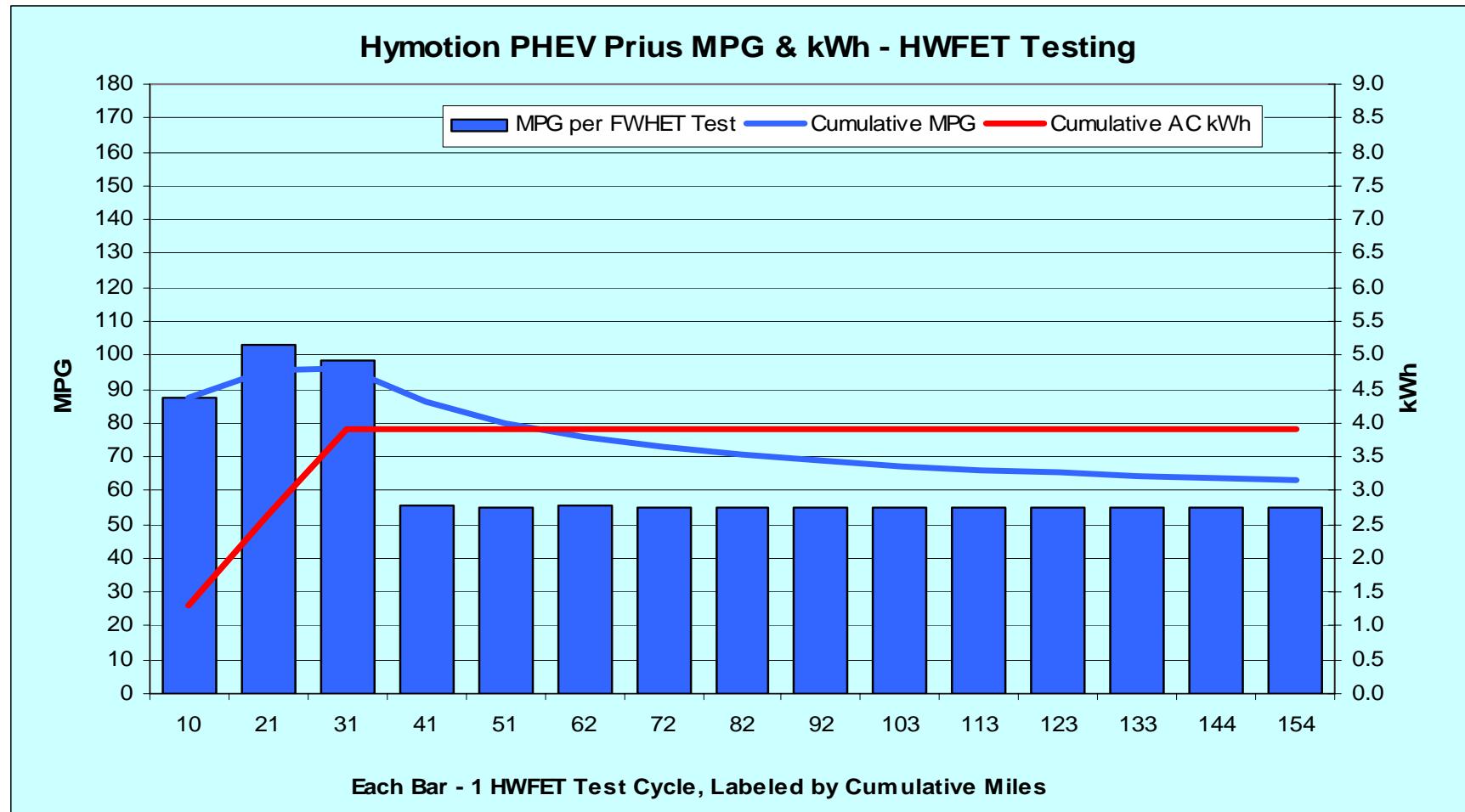
Hymotion Prius – UDDS Fuel Use

- 5 kWh A123 lithium and Prius packs – A/C kWh

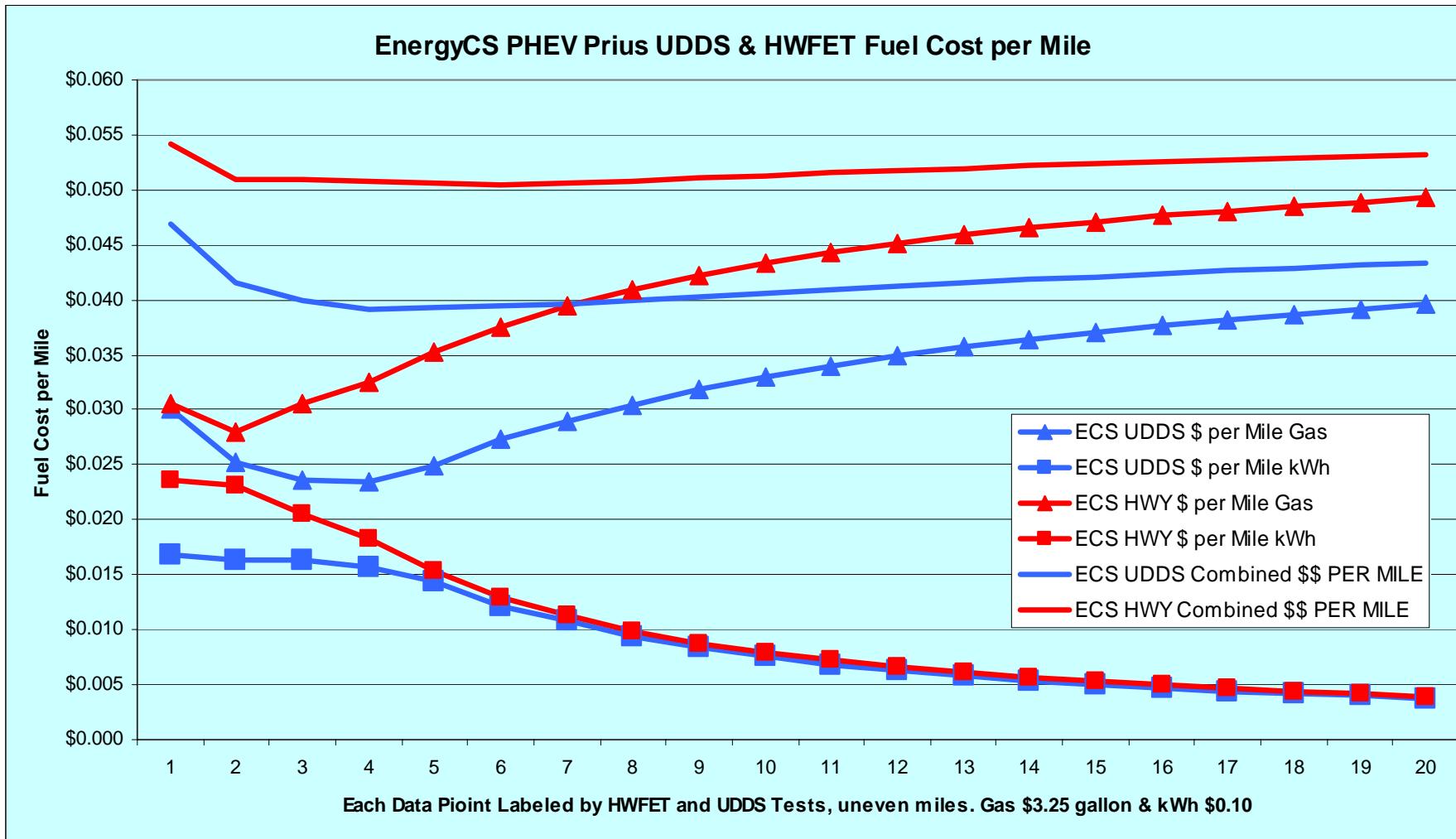


Hymotion Prius – HWFET Fuel Use

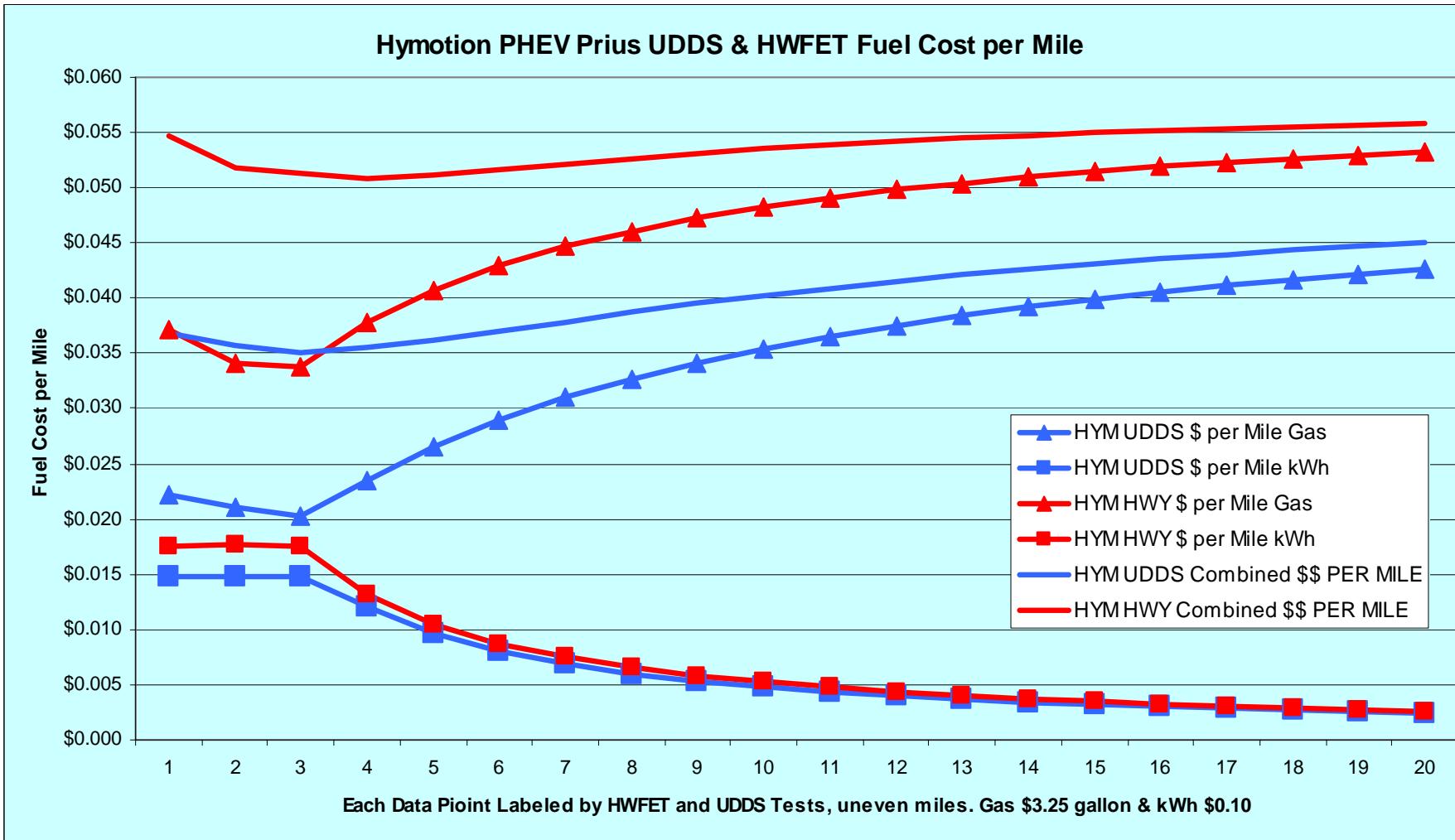
- 5 kWh A123 lithium and Prius packs – A/C kWh



EnergyCS Prius – Fuel Costs



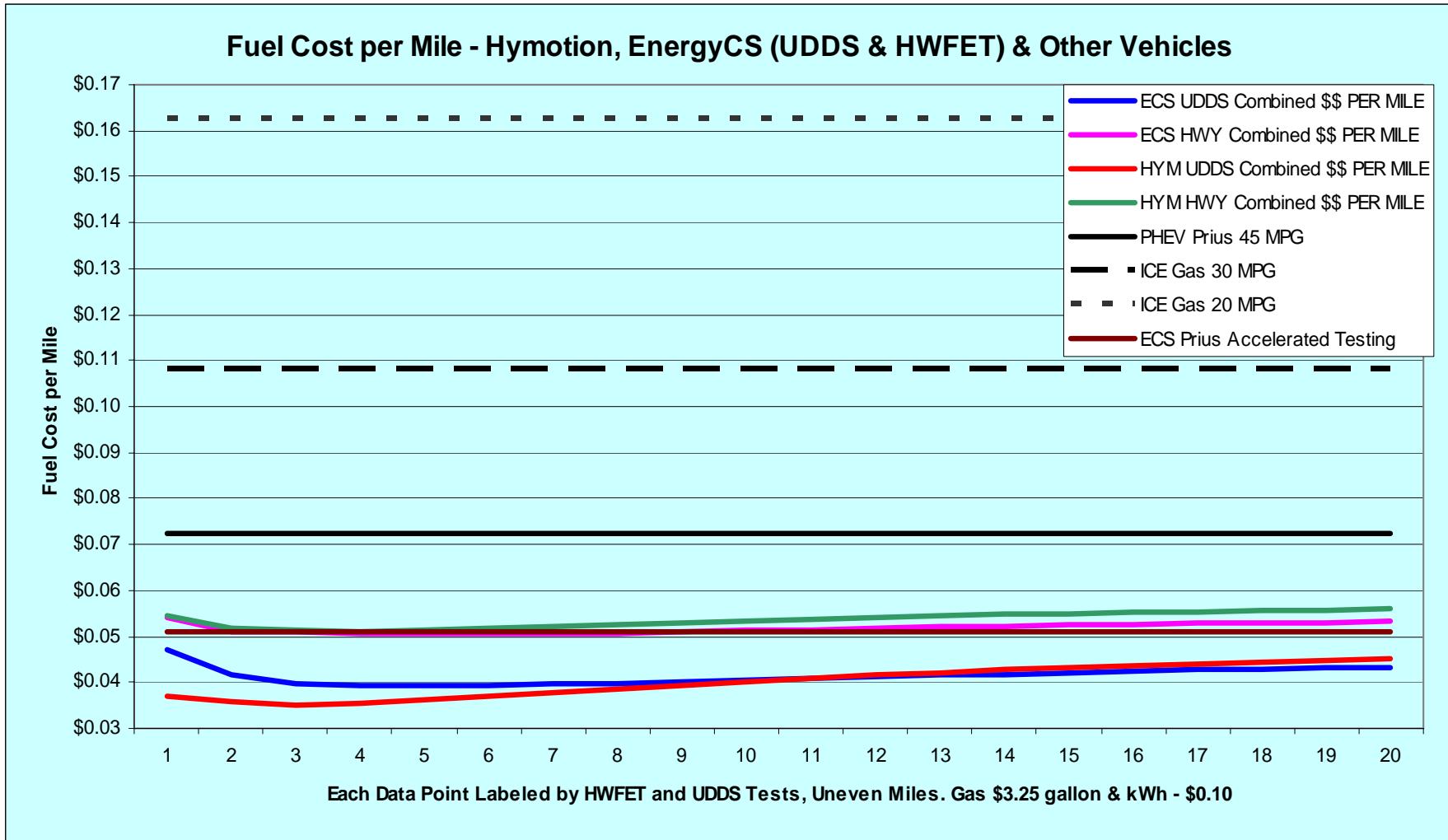
Hymotion Prius – Fuel Costs



EnergyCS Prius PHEV Accelerated Testing

Cycle	Urban (mi)	Highway (10 mi)	Charge (hr)	Reps (N)	Total (mi)	Electricity kWh	Gasoline	
	(10 mi)	(10 mi)	(hr)	(N)	(mi)		Gals	MPG
10	1	0	4	60	600			
20	1	1	8	30	600	86.21	7.95	75.5
40	4	0	12	5	200	17.37	1.61	124.2
40	2	2	12	5	200	29.00	1.42	140.8
40	0	4	12	5	200	30.00	2.43	82.3
60	2	4	12	10	600	65.00	5.90	101.7
80	2	6	12	8	640	39.04	10.09	63.4
100	2	8	12	6	600	22.67	8.81	68.1
200	2	18	12	3	600	12.98	10.46	57.4
Total	1740	2500	984	132	4240			

Combined ECS and Hymotion Fuel Costs



Other PHEV Test Vehicles and Partners

- PHEVs to be tested
 - Electrovaya Escape, Hymotion Civic and Escape, and HybridsPlus Escape (all lithium batteries)
- PHEV demonstration and testing partners
 - NYSERDA (New York State Energy Research and Development Agency)
 - Seattle area: City of Seattle, Seattle City Light, King County, Port of Seattle, Puget Sound Clean Air Agency
 - Tacoma Public Utilities
 - Southern California Edison
 - State of Hawaii



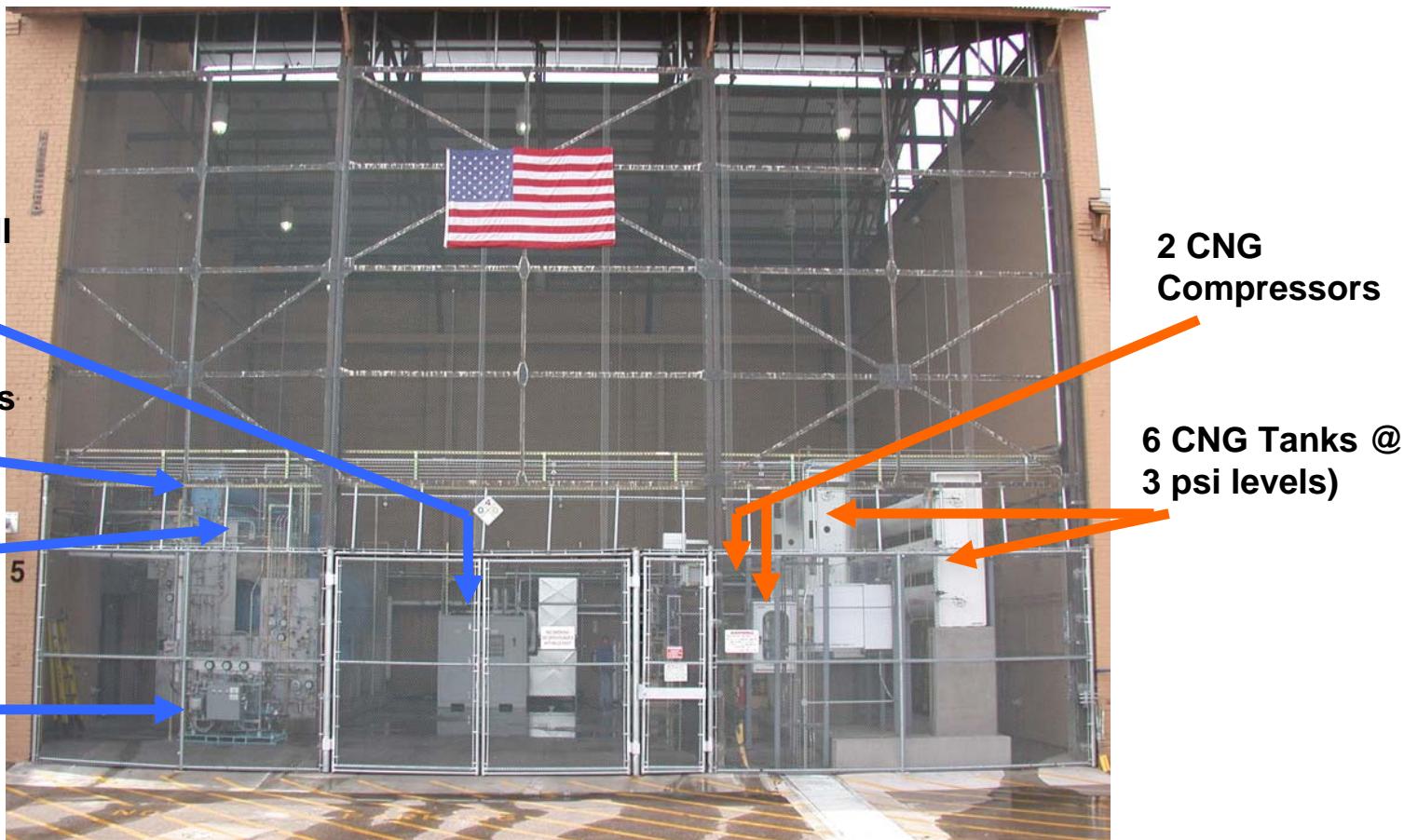
Hydrogen Internal Combustion Engine (HICE) Vehicle Testing

APS Alternative Fuel (Hydrogen) Pilot Plant

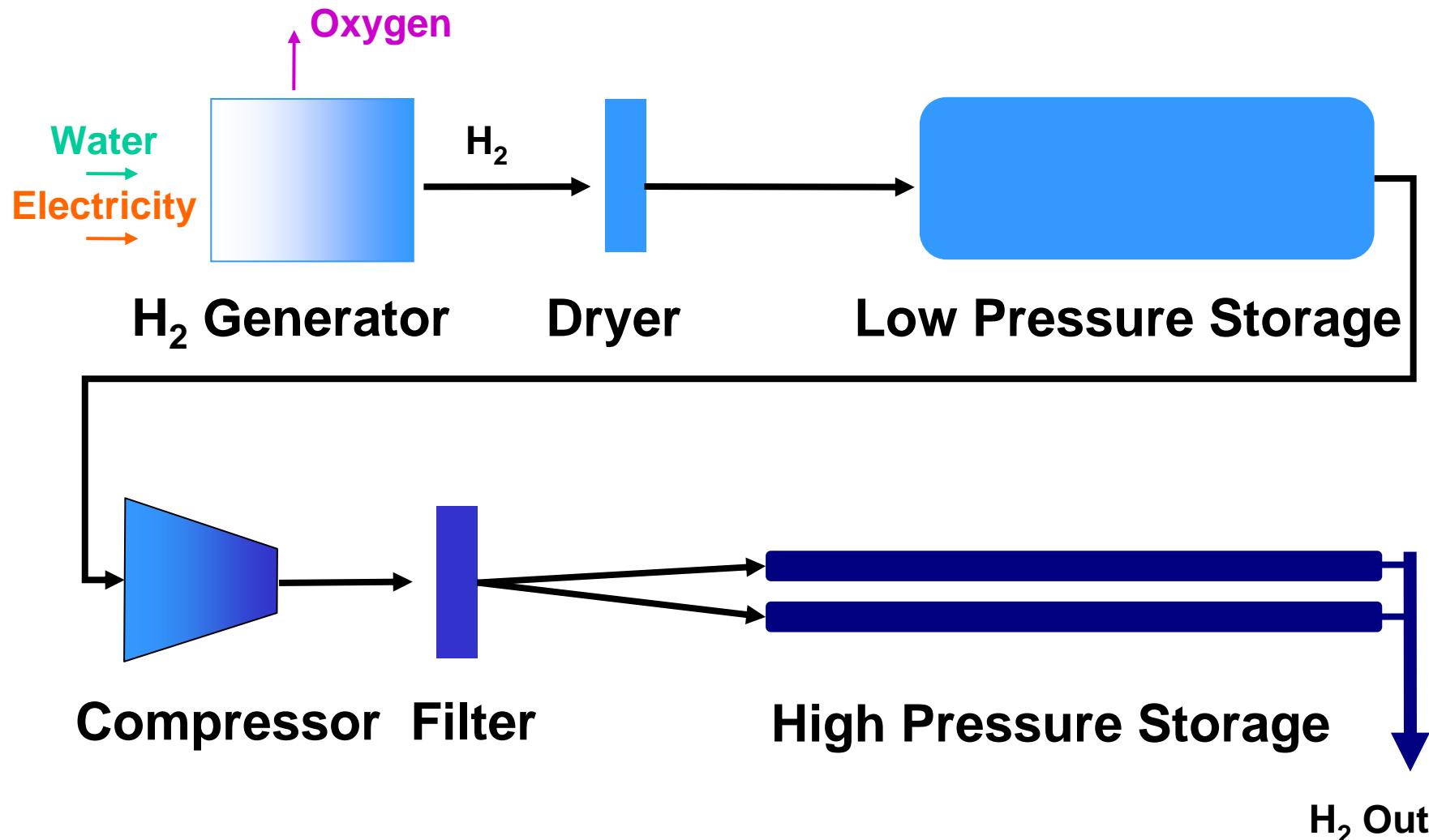
- Partners - Arizona Public Service (APS), Electric Transportation Applications (ETA), INL, & DOE
- First & longest operating hydrogen station in the U.S. – since June 2002
- Hydrogen produced onsite
- Hydrogen & CNG fueling



Pilot Plant - Layout



Pilot Plant - Hydrogen Subsystems



Pilot Plant – Hydrogen Subsystems cont'd

- Proton Energy Systems' Hogen PEM stationary fuel cell operating in reverse
- Hydrogen Lectrodryer
- Hydrogen compressor
- Norman hydrogen filters
- Hydrogen - 99.9997% purity

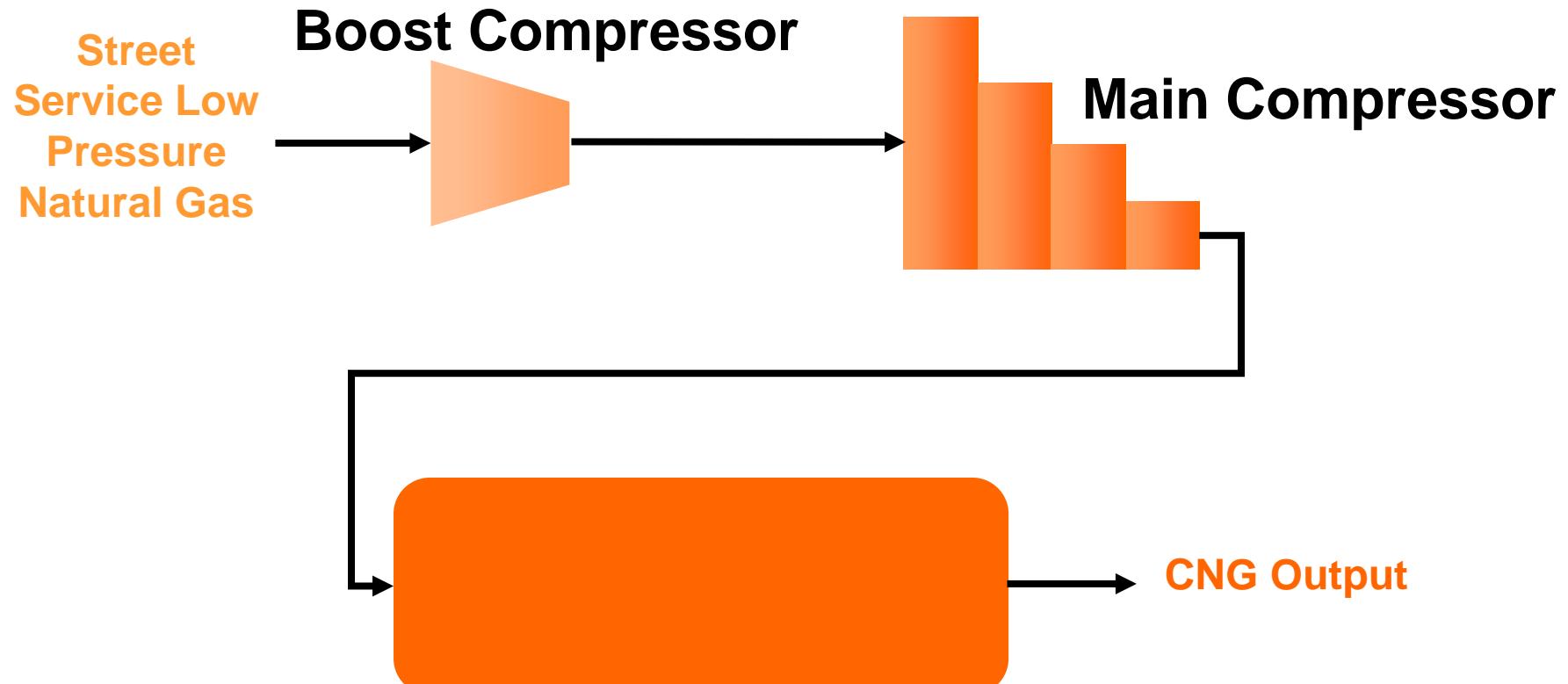


Pilot Plant - Hydrogen Subsystems cont'd

- Low pressure hydrogen storage (lower tank)
 - 8,955 SCF @ 150 psi
- High pressure hydrogen storage (upper 2 tanks)
 - 17,386 SCF @ 6,000 psi (total both tanks)



Pilot Plant - CNG Subsystem



Pilot Plant - CNG Subsystem cont'd

- CNG Boost Compressor
 - 300 scfm @ 60 psi
- CNG Main Compressor
 - 350 scfm @ 5,000 psi
- CNG Storage/Pressure – 6 tanks
 - 3 Low: 11,079 scf @ 3,600 psi
 - 2 Medium: 5,711 scf @ 4,500 psi
 - 1 High: 5,711 scf @ 5,000 psi



Pilot Plant - Fueling Dispensers

- Includes metering & electronic billing interface
- Fully permitted for motor fuel dispensing
- Public access



15% HCNG Dodge Van Emissions Testing

- 5.2 L CNG V8 (no modifications) with 71,000 HCNG test miles - no problems - 15.5 miles/GGE

Percentage change in 15% HCNG emissions compared to 100% CNG emissions

Total hydrocarbons	-34.7%
Carbon monoxide	-55.4%
Oxides of nitrogen	+92.1%
Carbon dioxide	-11.3%



30% HCNG F150 Testing

- 5.4 L V8 CNG base engine – added supercharger, ignition modifications & exhaust gas recirculator
- Fleet testing HCNG miles: 17.3 miles/GGE

Fuel Blend	0 to 60 mph (secs.)	Miles/GGE	Range (miles)
CNG	10.10	23.3	122
15% HCNG	10.97	22.6	110
30% HCNG	12.68	23.5	102



30% HCNG F150 Emissions Testing

Fuel Type	Percentage Change in Emissions Testing					
	NMHC	CH ₄	HC	CO	NO _x	CO ₂
Gasoline	Base	Base	Base	Base	Base	Base
CNG	-80	+967	+35	-63	-34	-24
15% HCNG	-78	+1000	+40	-70	-26	-27
30% HCNG	-89	+1050	+37	-73	-25	-28

NMHC=Non-Methane Hydrocarbons

CH₄=Methane

HC=Total Hydrocarbons

CO=Carbon Monoxide

NOx=Oxides of Nitrogen

CO₂=Carbon Dioxide



50% HCNG F150 Emissions Testing

- Modifications
 - SVO heads, exhaust intercooler & supercharger
 - Exhaust gas recirculator & ignition modification
 - Equipped with 3 Quantum hydrogen 3,600 psi tanks with 9 kg total storage

Percent reduction in emissions (HCNG versus gasoline-fueled F-150)

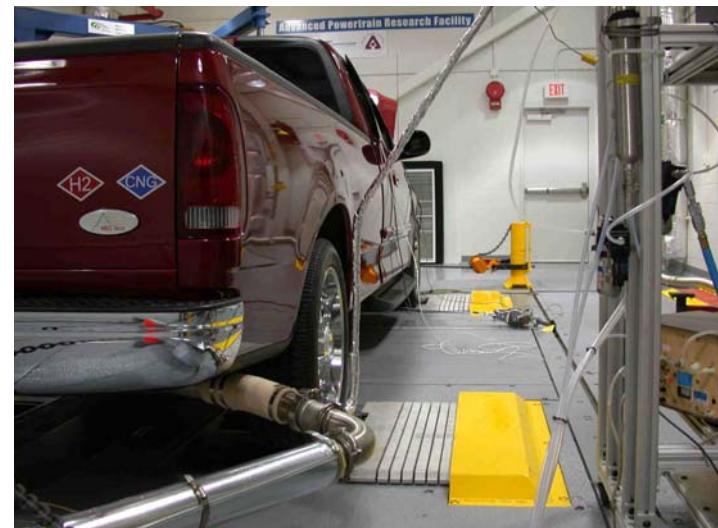
HC	CO	NO _x	CO ₂
-3.5%	-43.3%	-97.0%	-16.7%

HC = total hydrocarbons

CO = carbon monoxide

CO₂ = carbon dioxide

NOx = oxides of nitrogen



5.4L 16-valve 100% Hydrogen ICE Vehicle

- 5.4L V-8, 100% hydrogen 16-valve Ford/ETEC pickup
- 5 speed transmission, supercharged (3 psi), lean-burn
- Onboard hydrogen storage 3 Dynetek tanks @ 3,000 psi, 6.5 kg, aluminum vessel & fiberglass wrap
- SAE J1634 fuel economy (AC on): 14.5 miles/GGE
- SAE J1634 fuel economy (AC off): 18.0 miles/GGE
- Fleet testing – 18.5 miles per GGE (120 miles range)



5.4L 32-valve 100% Hydrogen ICE Vehicle

- 5.4L V-8, 100% hydrogen 32-valve Ford/ETEC pickup
- 12 pounds supercharger boost, with hardened valves & seats, and forged pistons with 11.5:1 compression
- 13.0 miles per GGE in fleet testing
- Onboard hydrogen storage 3 Dynetek tanks @ 5,000 psi, 15.3 kg (200-mile range)



6L V-8 100% Hydrogen ICE Vehicle

- Base vehicle: Chevrolet 1500HD crew cab (4 door) with 6L V8 CNG engine, converted by ETEC/Roush to 100% hydrogen
- 10.5 kg 100% hydrogen storage onboard @ 5,000 psi
- 200 Horsepower & 260 lb-ft torque
- 14 city & 20 highway miles per GGE - range of 140 to 200 miles
- Eight vehicles in fleet testing in Vancouver B.C.



Acknowledgement

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FreedomCAR and Vehicle Technologies Program
Vehicle Systems Team Leader, Tien Duong
AVTA DOE Lead, Lee Slezak

Additional Information

<http://avt.inl.gov>

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