

U.S. Department of Energy – FreedomCAR and Vehicle Technologies Program

Advanced Vehicle Testing Activity - Hybrids, Hydrogen, and Other Alternative Fuel Vehicle Activities

***Jim Francfort
2006 FedFleet***

Advanced Vehicle Testing Activity - Background

- **Part of the DOE's FreedomCAR and Vehicle Technologies Program**
- **Testing partner – Electric Transportation Applications**
- **AVTA Goal – Provide benchmark data for technology modeling, and research and development programs, as well as to help fleet managers and other vehicle purchasers make informed purchase and operations decisions**



Vehicle Testing Methods

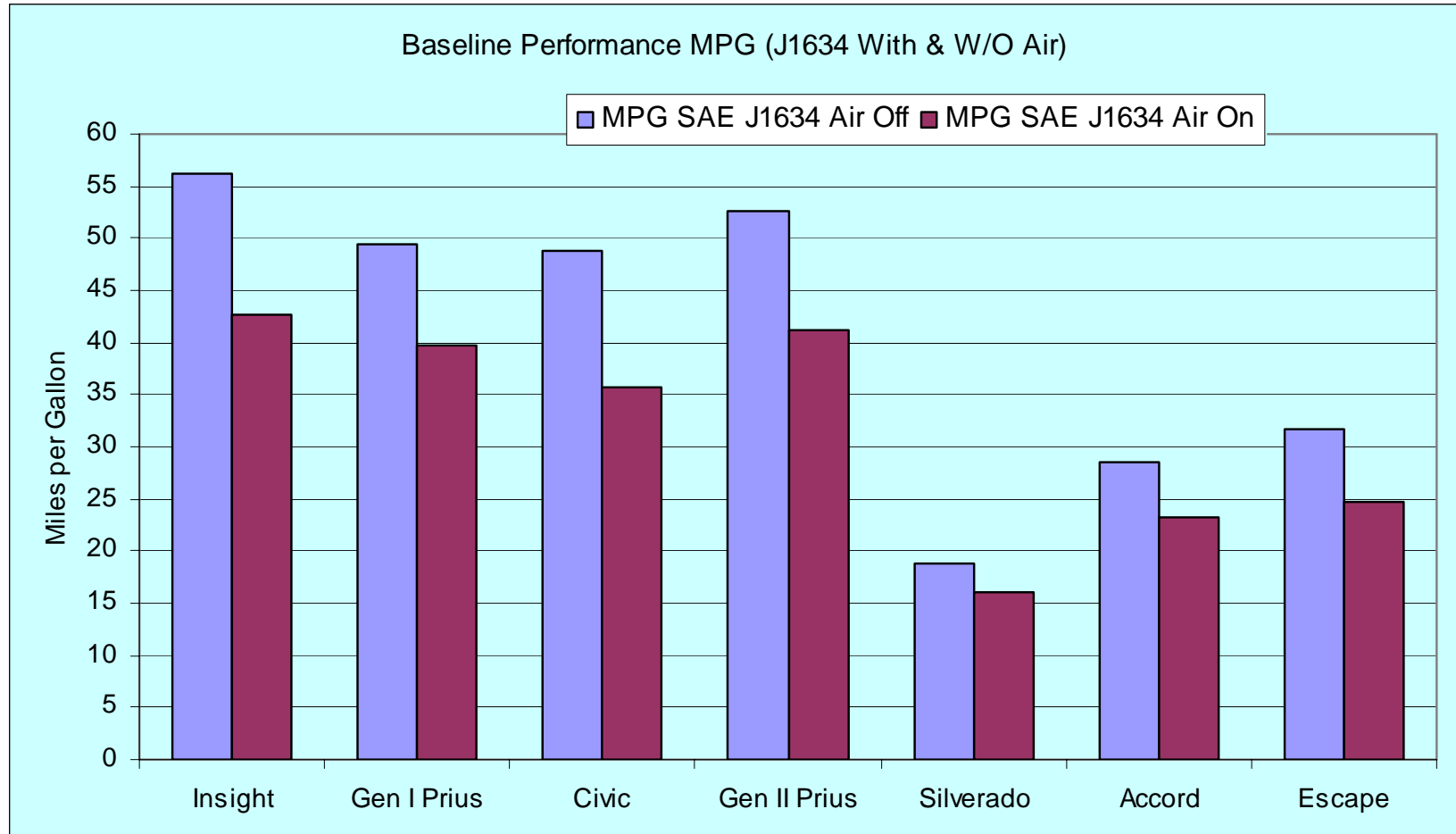
- **Baseline performance testing (dynamometer & closed track testing) – vehicle-to-vehicle comparisons of vehicle performance in controlled & repeatable environment**
- **Fleet (accelerated reliability) testing – vehicle performance in “real-world” fleet applications (HEVs 160,000 miles in 36 months)**
- **HEV end-of-life (at 160,000 miles) testing – conduct battery capacity & power testing**



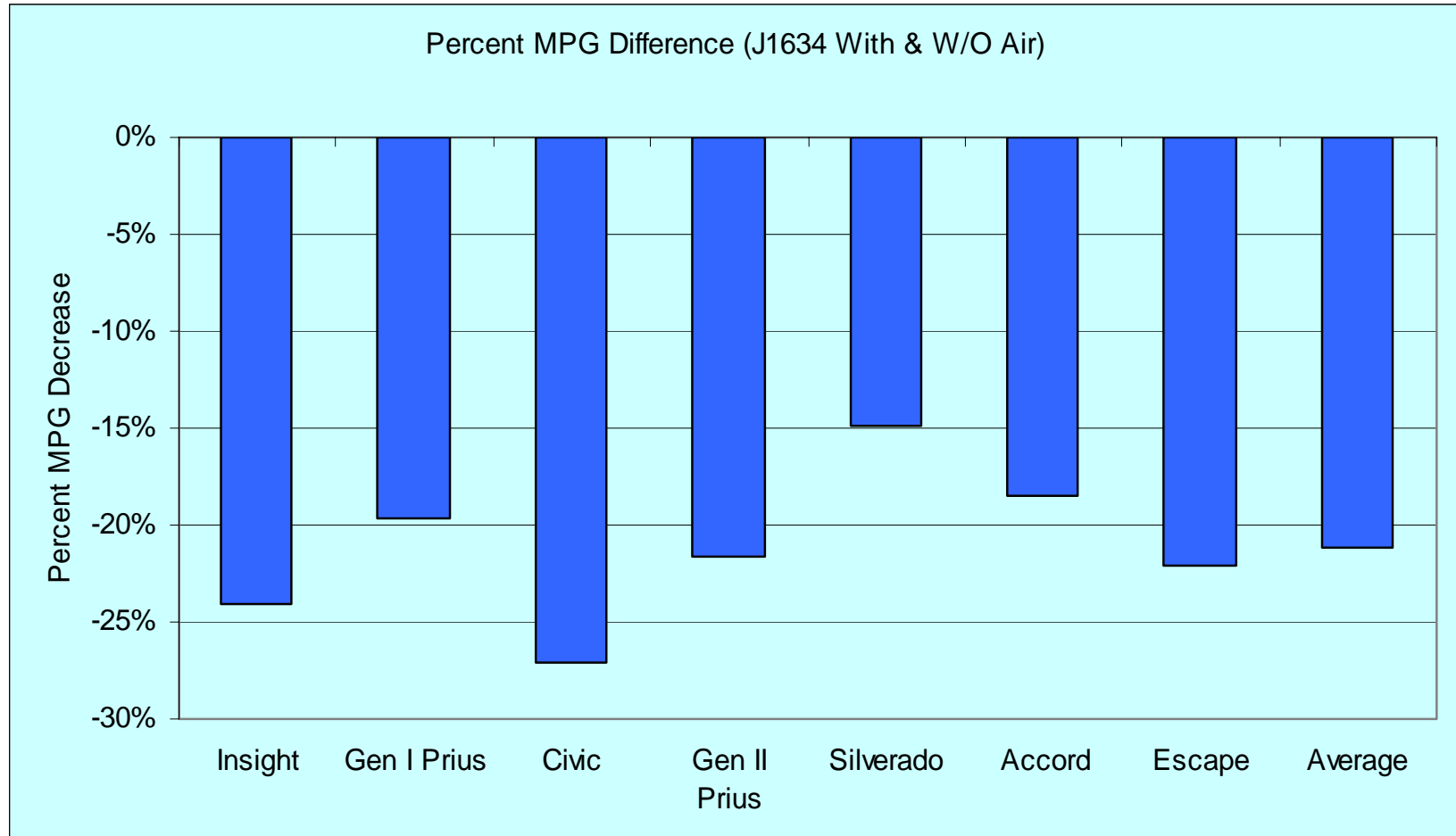
- **2002 Test Vehicles**
 - **Insight, Gen I Civic, Gen I Prius**
- **2005 Test Vehicles**
 - **Accord, Gen II Prius, Silverado (2WD), Escape (2WD)**
- **2006 Test Vehicles**
 - **Lexus RX400h, Toyota Highlander, Gen II Civic, Toyota Camry**



HEV Baseline Performance MPG



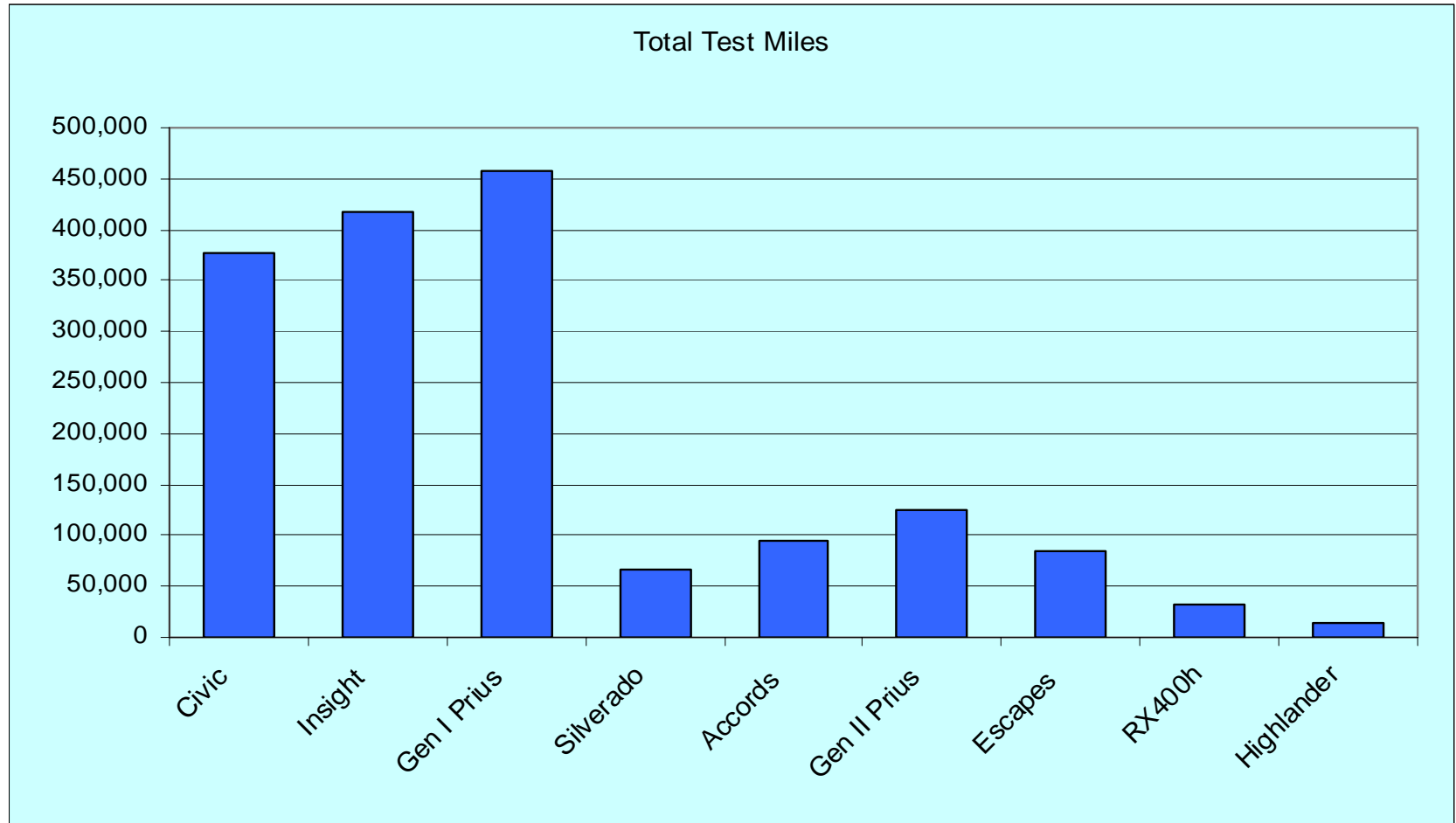
HEV MPG (J1634) - AC on/off Decrease



28 HEVs - Fleet Testing Status

- **6 - 2001 Honda Insights: Aug/01 – March/05**
- **6 - 2002 Gen I Toyota Prius: Nov/01 – April/05**
- **4 - 2003 Honda Civics: May/02 – April/05**
- **2 - 2004 Gen II Toyota Prius: Nov/03 – ongoing**
- **2 - 2004 Chevrolet Silverado: Sept/04 – ongoing**
- **2 - 2005 Honda Accord: Jan/05 – ongoing**
- **2 - 2005 Ford Escape: April/05 – ongoing**
- **2 - 2005 Lexus RX400h: May/05 – ongoing**
- **2 - 2006 Toyota Highlander: Oct/05 – ongoing**

1.7 Million HEV Fleet Test Miles



HEV Fleet Testing Fact Sheets

- Summarize real-world:
 - Vehicle use
 - Major maintenance & repair events
 - Mileage profile
 - Fuel use
 - Life cycle operating costs



HEV Maintenance / Repairs

- Date, mileage, description & cost/warranty

HEV Fleet Testing - Maintenance Sheet

2003 – Honda Civic Hybrid

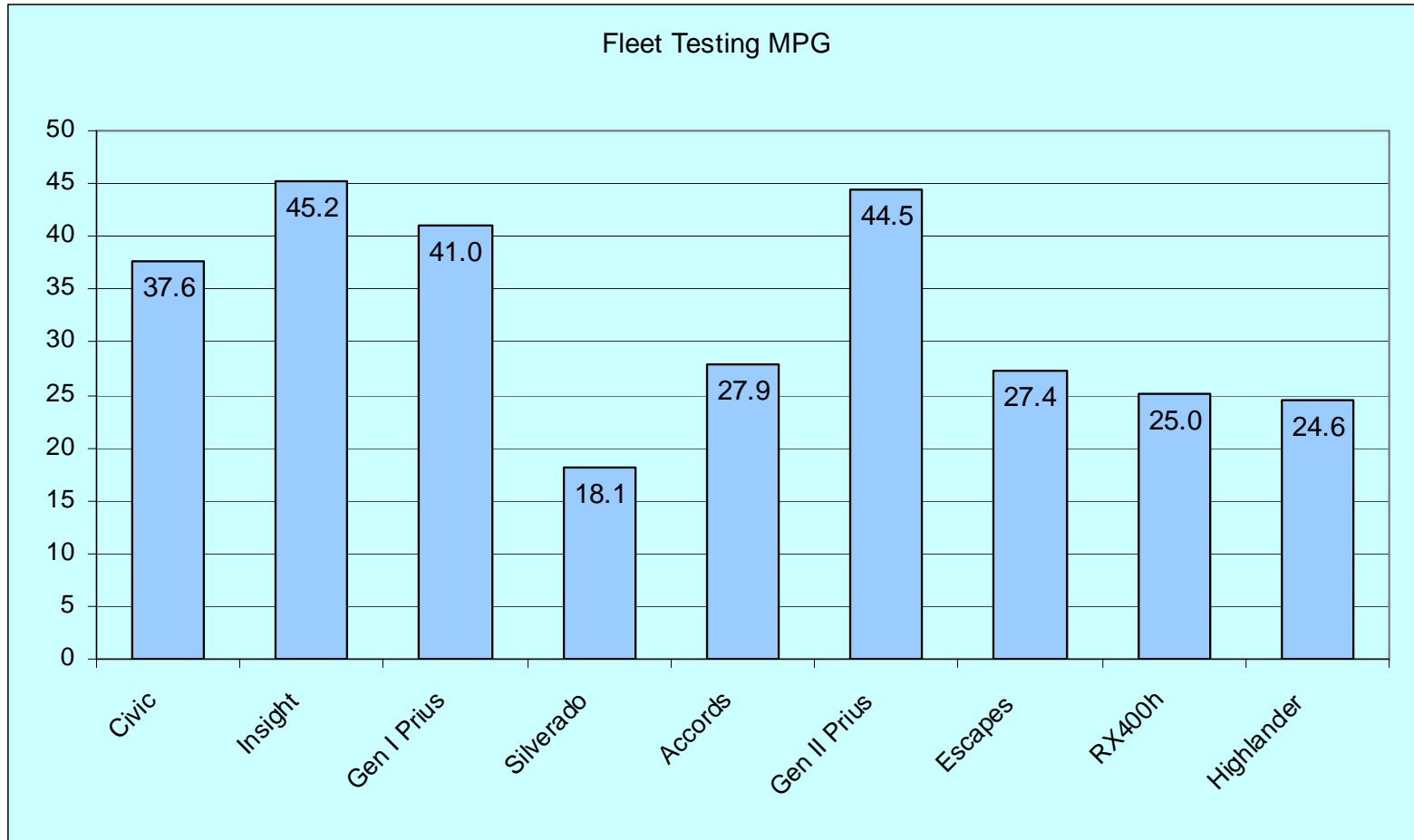
U.S. Department of Energy
Energy Efficiency
and Renewable Energy

Advanced Vehicle Testing Activity

VIN #JHMES96663S003864

Date	Mileage	Description	Cost
7/10/2002	5,041	Change oil and rotate tires	\$ 27.00
8/6/2002	9,979	Change oil and rotate tires	\$ 28.62
9/5/2002	15,023	15,000 mile service	\$ 231.38
9/24/2002	18,706	Repair accident damage to left front (not included in maintenance costs)	\$ 1,222.34
10/8/2002	20,142	Change oil and rotate tires	\$ 28.99
10/29/2002	25,147	Change oil and rotate tires	\$ 30.87
12/20/2002	33,270	Change oil and rotate tires	\$ 31.07
2/10/2003	43,290	45,000 mile service	\$ 341.58
2/13/2003	43,500	Repair accident damage to rear bumper (not included in maintenance costs)	\$ 834.42
3/18/2003	53,381	Change oil and rotate tires	\$ 30.67
4/22/2003	62,573	Change oil and rotate tires	\$ 30.67
5/23/2003	69,932	Change oil and rotate tires	\$ 30.67
6/6/2003	74,353	30,000 mile service	\$ 324.18
6/24/2003	77,828	Replace four tires and align front wheels	\$ 185.33
6/19/2003	77,589	Check Engine trouble light illuminated. Dealer reset, no problem found.	warranty
7/7/2003	80,425	Change oil and rotate tires	\$ 31.09
7/8/2003	80,434	Check Engine light illuminated. Dealer repaired an intermittent problem with a valve sticking.	warranty
8/27/2003	89,304	90,000 mile service	\$ 324.13
8/4/2003	86,353	Change oil and rotate tires	\$ 31.09
9/12/2003	90,507	Check Engine trouble light illuminated. Updated PCM software installed by dealer.	\$ 50.00
10/14/2003	93,616	Ignition switch replaced	\$ 50.00
10/24/2003	93,912	Change oil and replace brake pads	\$ 146.22
11/20/2003	96,556	Check Engine light illuminated. Dealer replaced the Purge System pressure sensor	\$ 50.00
1/15/2004	96,802	Transmission shifting erratically. Transmission replaced	\$ 3,503.82
1/26/2004	97,750	Check Engine trouble light illuminated. Catalytic converters replaced.	\$ 1,124.38
2/24/2004	103,901	15,000 mile service	\$ 260.83
4/6/2004	113,685	30,000 miles service and accessory 12 volt battery replacement	\$ 464.09
4/15/2004	115,649	Replace front tires	\$ 112.38
5/3/2004	119,570	Change oil and rotate tires	\$ 31.92

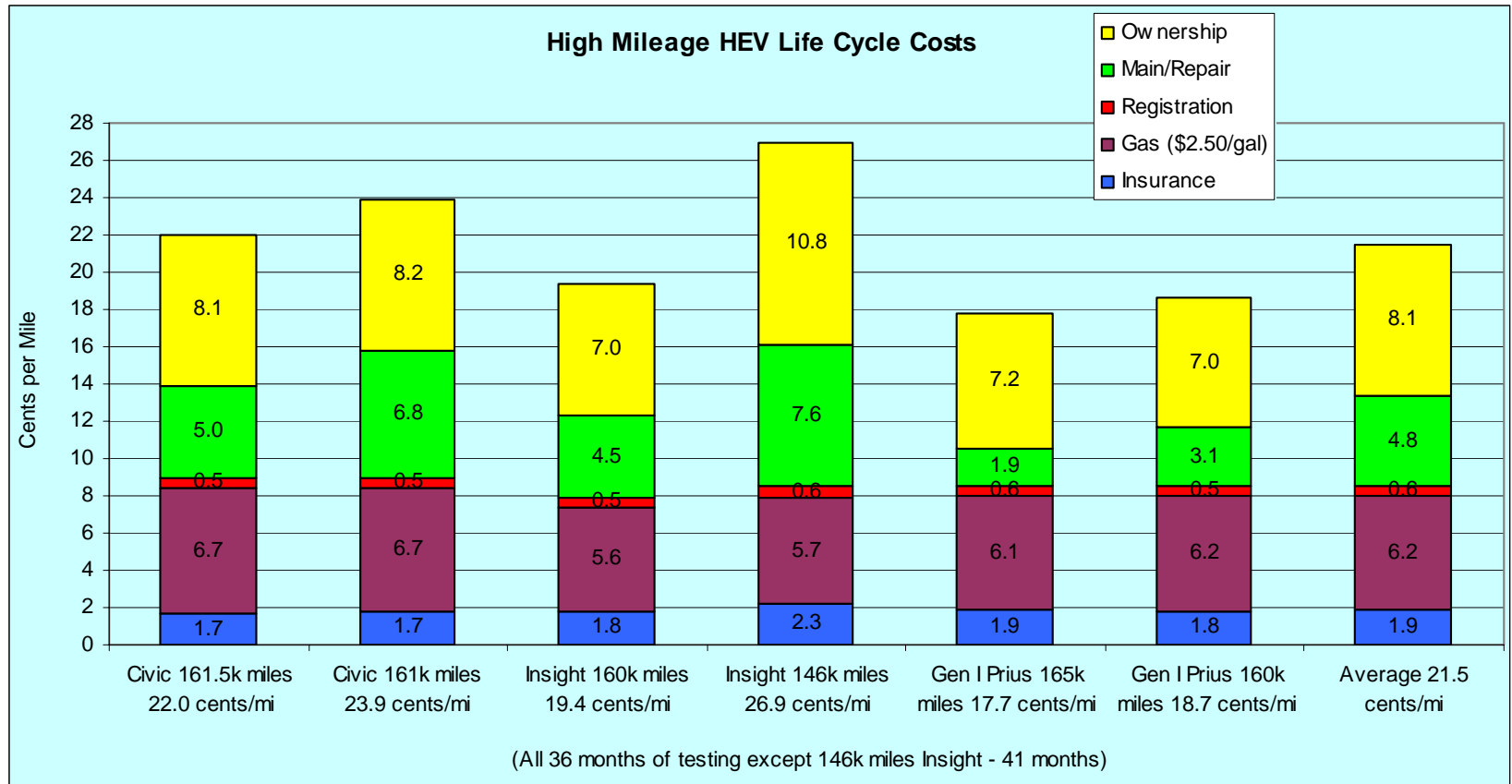
HEV Fleet Testing Average MPG



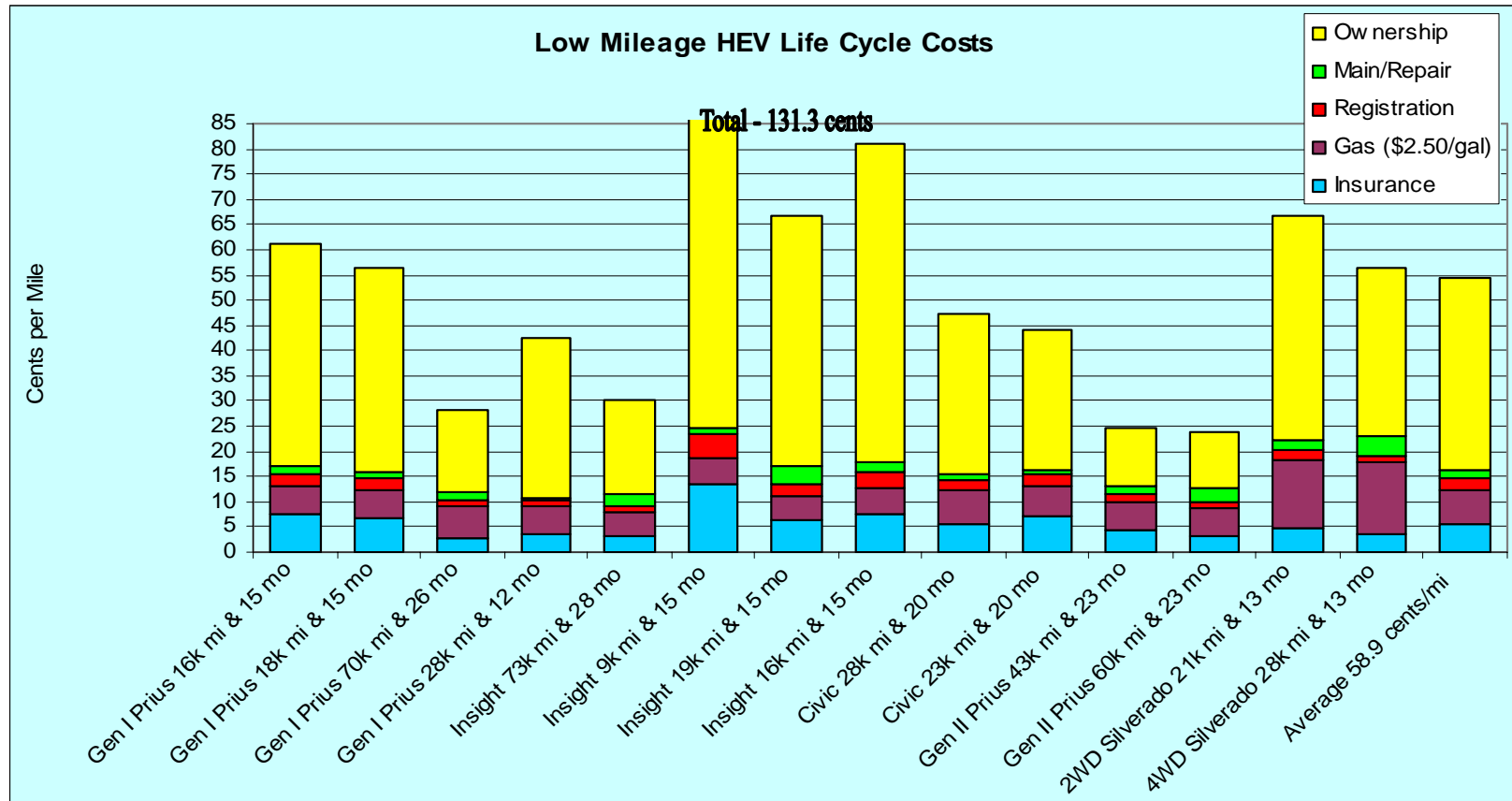
HEV Maintenance / Repairs Summary

- **Civic & Insight - 6 CVT failures in 4 units: 97k, 99k, 89k & 77k mi. Again: 157k & 146k mi.**
- **Insight battery control module & battery pack replaced: 72k miles**
- **Insight & Civic - 7 software upgrades & 3 catalytic converters replaced**
- **Gen I Prius - rack & pinion replacements 1st Prius: 106k, & 2nd Prius: 25k & 32k miles**
- **Silverado battery pack replaced: 36k miles**

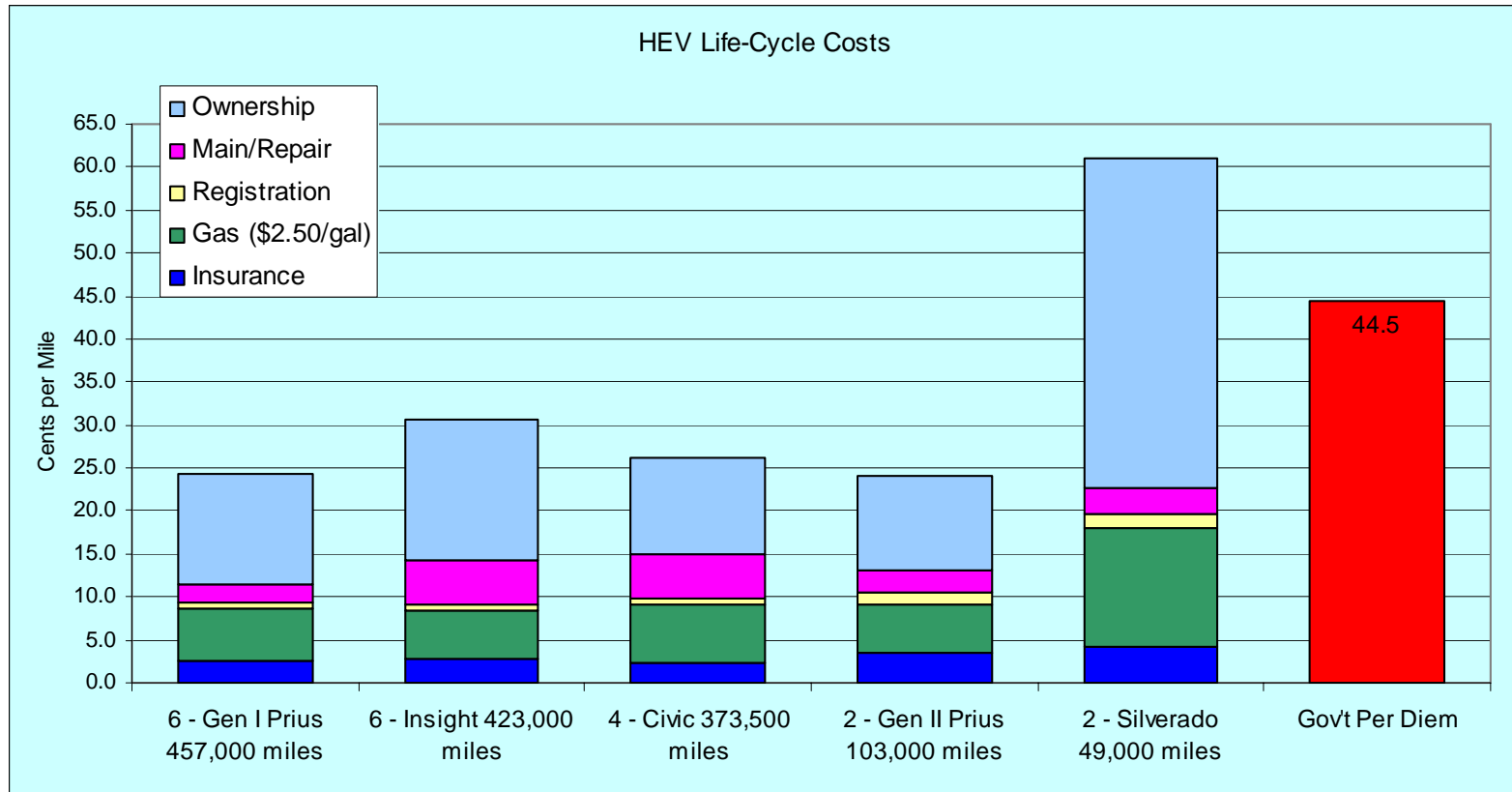
Life Cycle Costs - High Mileage HEVs



Life Cycle Costs - Low Mileage HEVs

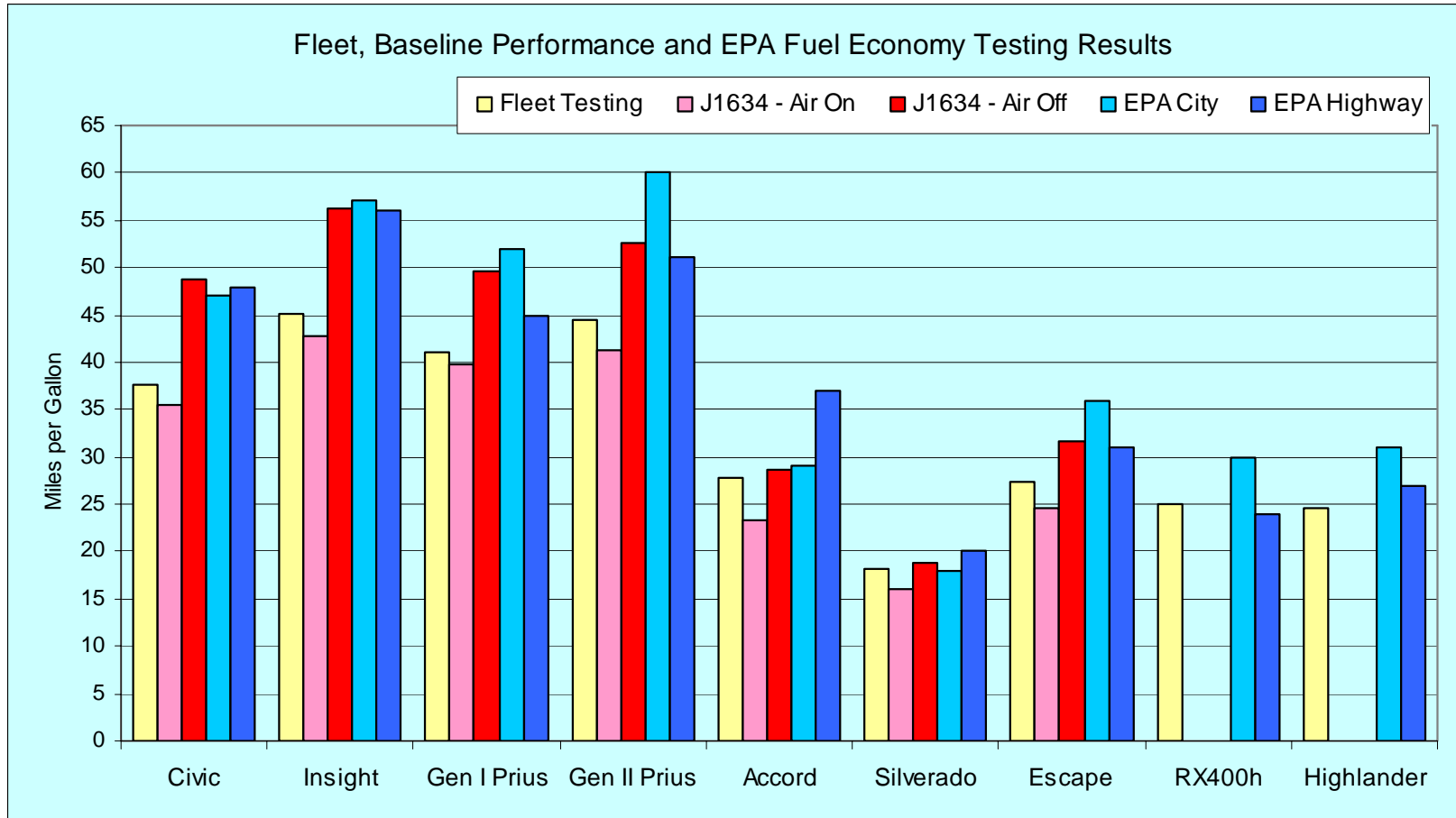


Life Cycle Costs - By HEV Model

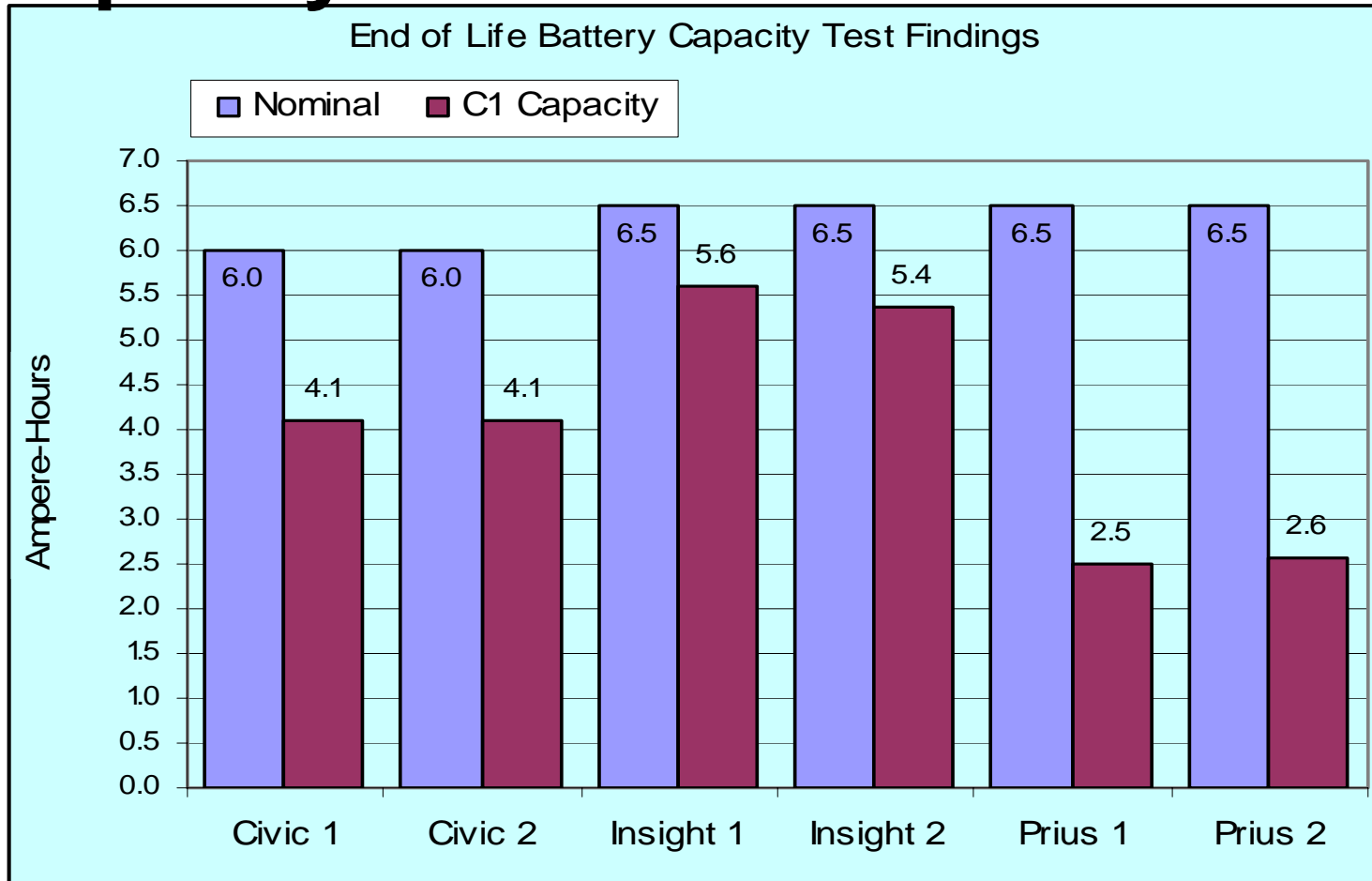


Costs include: Insurance, maintenance & repairs (excludes any collision costs), fuel @ \$2.50 gallon, registration, and purchase – sales cost (or lease cost for Silverado)

HEV MPG: Fleet SAE J1634 & EPA



HEV End-of-Life (160K miles) Battery Capacity



*Gen I Prius

HEV End-of-Life Phase II (J1634) vs. Onboard Vehicle Computer MPG

End-of-life Phase II MPG Testing	Onboard computer mpg percentage above Phase II SAE J1634 mpg
Civic 1 AC off	+21.7%
Civic 1 AC on	+21.0%
Insight 1 AC off	+11.0%
Insight 1 AC on	+11.7%
Gen I Prius AC off	+15.7%
Gen I Prius AC on	+14.7%

Additional HEV Testing

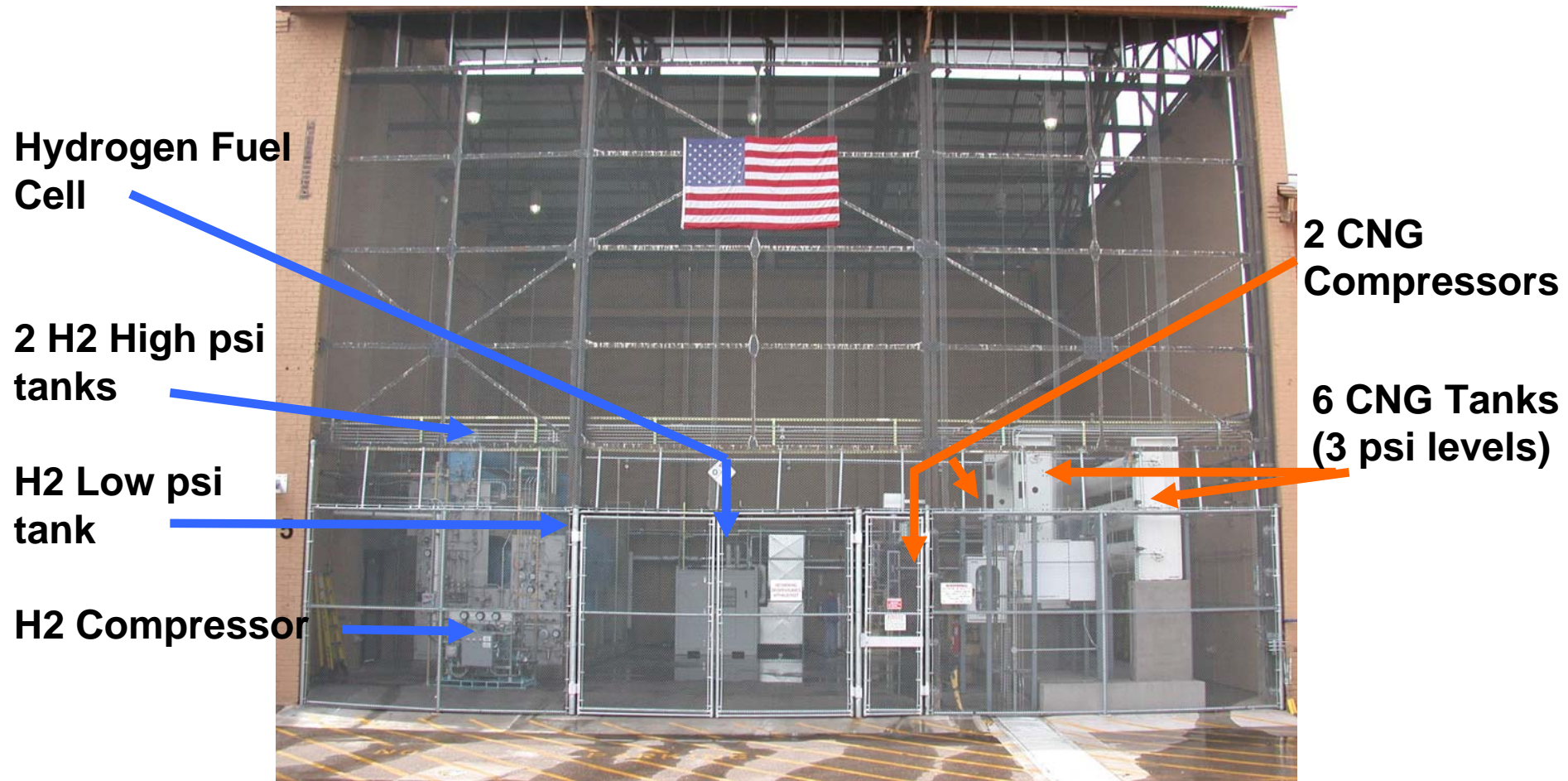
- **Hydrogen ICE HEV Hydrogen Prius from SCAQMD/Quantum**
- **Plug-in HEV Dodge Sprinter (lithium)**
- **Plug-in HEV Escape (lithium or lead) from Energy CS**
- **Plug-in Prius (lithium) from Energy CS**
- **Other OEM HEVs &/or Plug-ins (Gen II Civic & Toyota Camry)**

APS Alternative Fuel (Hydrogen) Pilot Plant

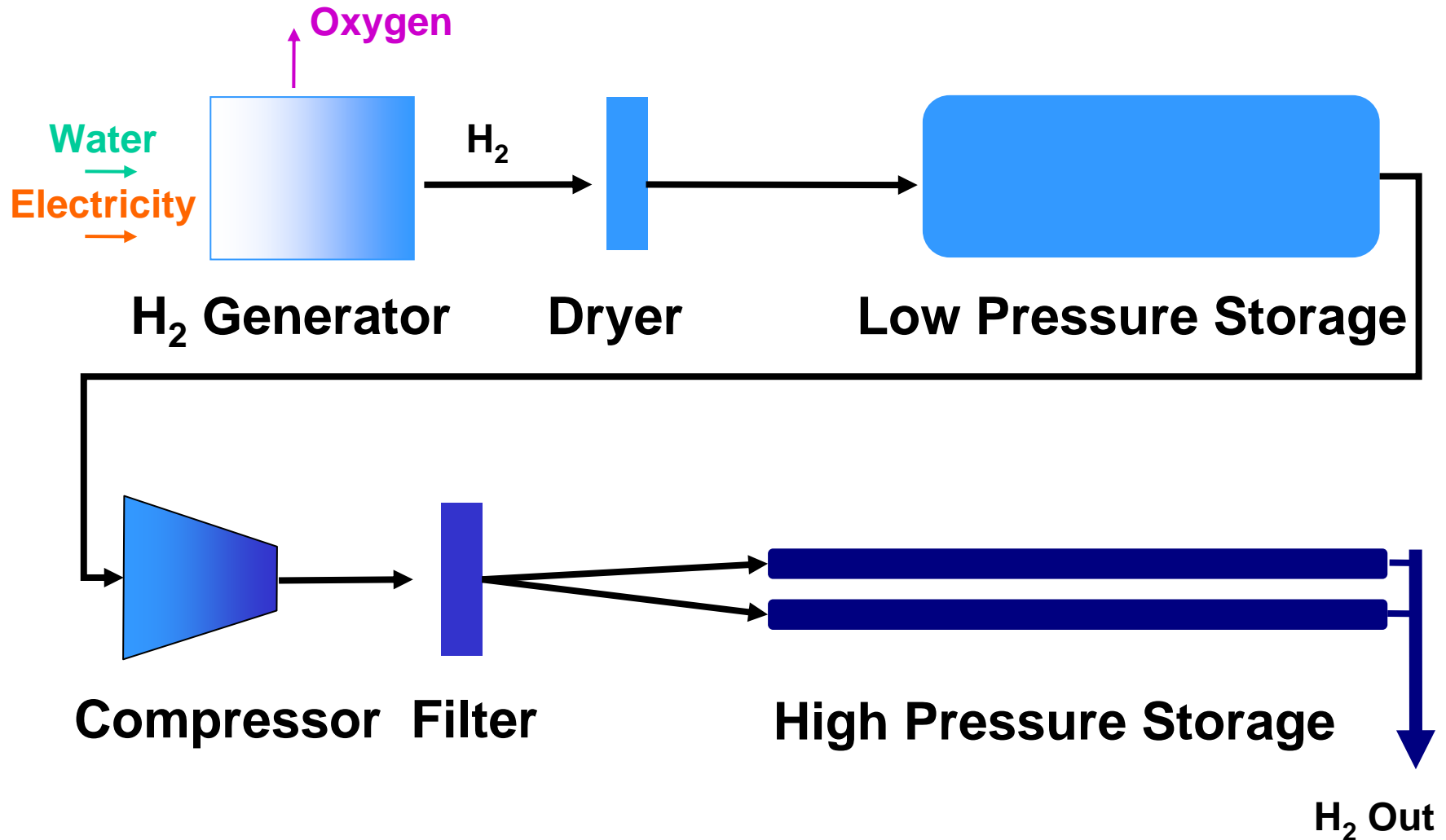
- First U.S. H₂ station in operation (June 2002)
- Partners: Arizona Public Service (APS), Electric Transportation Applications (ETA), U.S. Department of Energy, & Idaho National Laboratory (INL)



Pilot Plant Layout



Pilot Plant - Hydrogen Subsystem



Pilot Plant - Hydrogen Subsystem

- Proton Energy Systems' HOGEN PEM stationary fuel cell operating in reverse
- 9 Norman hydrogen filters
- Hydrogen Lector dryer
- Hydrogen compressor
- Hydrogen - 99.9997% purity



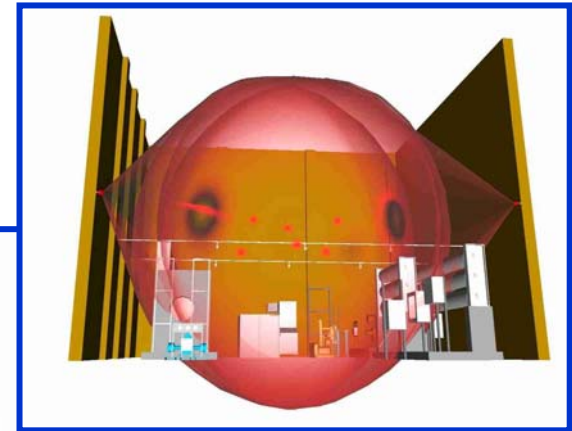
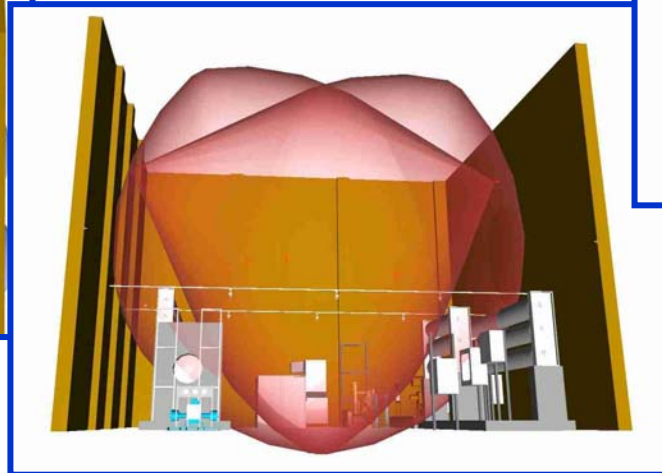
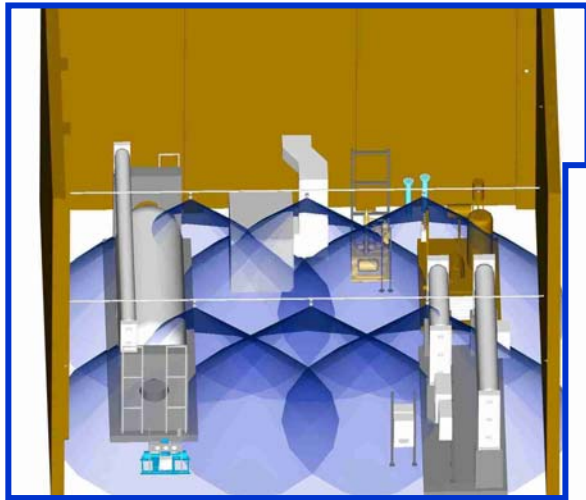
Pilot Plant - Hydrogen Storage

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

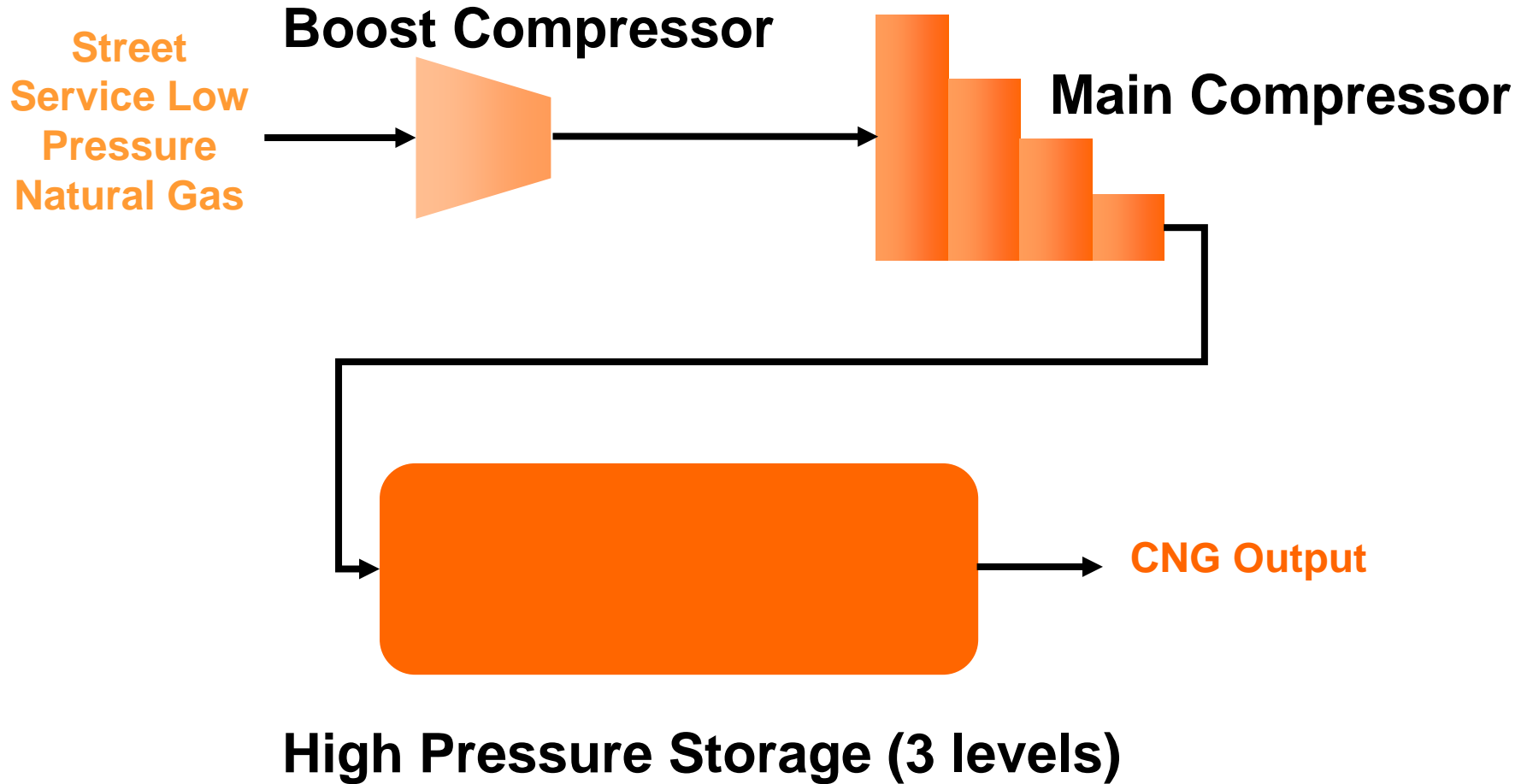


Hydrogen Gas & Flame Detectors

- Six combustible H₂ detectors
- Six IR/UV flame detectors (1 more at dispensing island)
- Tied to automated shutdown system



Pilot Plant - CNG Subsystem



CNG Subsystem

- Boost Compressor: 60 psi
- CNG Main Compressor: 5,000 psi
- CNG Storage/Pressure: 6 tanks, 22,500 scf
- 3 Low: 3,600 psi
- 2 Medium: 4,500 psi
- 1 High: 5,000 psi



H2 & HCNG Fueling Dispensers

- Metering & electronic billing interface
- Fully permitted for hydrogen, CNG, & H/CNG motor fuel dispensing
- Public access

City of Phoenix
Fire Department

150 South 12th Street
Phoenix, Arizona 85034
General Information (602)262-7462

POST THIS PERMIT ON JOB SITE

FIRE PERMIT

Permit # F203 0200731 Issue Date 05-MAR-2002 Expires 02-MAR-2012
Permit Description FUEL DISPENSING @ 435 S. 2ND AVE.
Project 99-22738 APS
Address NOT FOUND Zoning

Description/Scope of Work: MOTOR VEHICLE FUEL DISPENSING STATION
Operate.

PERMITTEE:
APS/Phoenix West

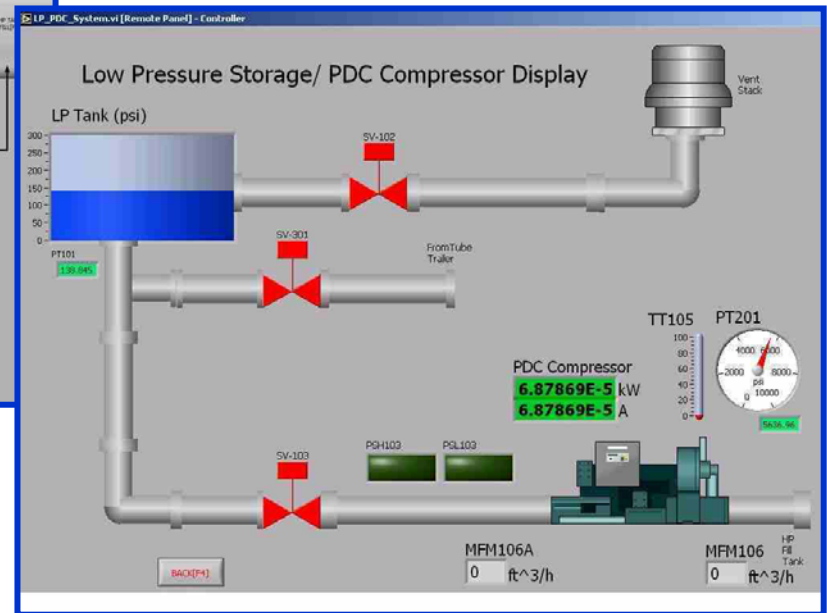
THIS PERMIT IS NOT TRANSFERABLE

COPY RECEIVED BY: [Signature] DATE: 3/22/02
FIRE CAPTAIN: [Signature] DATE: 3/22/02

CUSTOMER COPY



- **7,200 kg of H2 produced at 6,000 psi**
- **6,000 fueling events**
- **300,000+ hydrogen test miles**



Initial H2 & HCNG vehicle testing

- Dodge van on 15% HCNG (continues)
- Ford F150 up to 30% HCNG (continues)
- Ford F150 up to 50% HCNG (completed)
- 100% H2 Mercedes Benz van (completed)



15% HCNG Dodge Van

- 5.2 L CNG V8 (no modifications)
- 71k HCNG test miles: no problems
- 15% HCNG, 27k data miles: 15.5 miles/GGE



Percentage change in 15% HCNG emissions compared to 100% CNG	
Total hydrocarbons	-34.7%
Carbon monoxide	-55.4%
Oxides of nitrogen	+92.1%
Carbon dioxide	-11.3%

30% HCNG F150

- 5.4 L V8 CNG engine, added supercharger, ignition mods & exhaust gas recirculator
- 54k 30% HCNG miles: 17.5 miles/GGE



Fuel Blend	0 to 60 mph (secs.)	Miles/ GGE	Range (miles)
100% CNG	10.10	23.3	122
15% HCNG	10.97	22.6	110
30% HCNG	12.68	23.5	102



30% HCNG F150 Emissions

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

NO_x=Oxides of Nitrogen

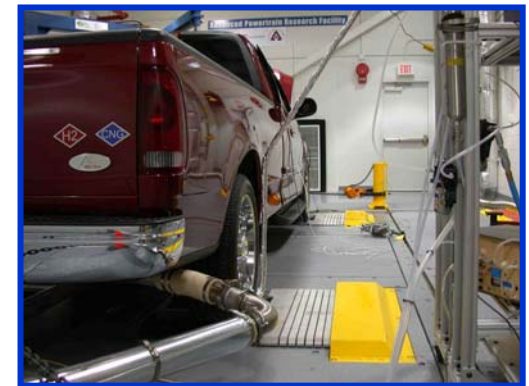
CO₂=Carbon Dioxide



50% HCNG F150

- **Modifications: SVO heads, supercharger, exhaust intercooler, ignition system, & exhaust gas recirculator**
- **Three 3,600 psi tanks with 3 kg H₂ 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%



HCNG ICE Vehicle Testing

- APS meter reader fleet 12 Bifuel vehicles
- 1,600 fueling events, 190k miles using 10,600 GGE of 15% HCNG
- Public Fleet - private Bifuel conversions
- 350 fueling events, 36k miles (estimated), 1,800 GGE of HCNG blends (mostly 15%)



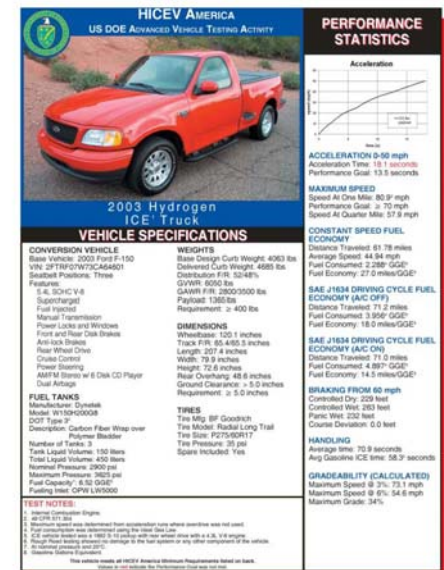
5.4L 16-Valve 100% H2 ICE Pickup

- 5.4L V-8, 100% H2, 16V, converted by ETEC
- 5 spd manual, supercharged (3 psi boost), H2 fuel injectors, & air-to-water intercooler
- Hardened valves & seats, & forged pistons (12:1 compression), lean-burn mode
- 3 Dynetek tanks (aluminum vessel & fiberglass wrap)
3,000 psi – 6.5 kg onboard



5.4L 16-Valve 100% H2 ICE Pickup

- Max speed 1 mile: 81 mph ¼ mile: 58 mph
- Acceleration (0 to 50 mph): 18.1 seconds
- SAE J1634 (AC on): 14.5 miles/GGE
- SAE J1634 (AC off): 18.0 miles/GGE
- 45 mph constant speed: 27.0 miles/GGE
- Range - 95 to 175 miles (14.5 to 27 mi/GGE)
- Fleet testing (3.5K miles) results: 17.0 miles/GGE = 110 miles range



5.4L 32-Valve 100% H2 ICE Pickup

- 5.4L V-8, 100% H2 32-valve, converted by ETEC
- Automatic transmission, H2 fuel injectors, 12 lbs supercharger boost, & air-to-air intercooler
- Hardened valves & seats, & forged pistons 11.5:1 compression, lean-burn mode
- 15.3 kg onboard H2 storage
- 3 Dynetek tanks 5,000 psi, 15.3 kg H2 onboard
- Fleet testing (7.5k miles): 15.3 miles/GGE & 230 miles range



6L V-8 100% H2 ICE Pickup

- **Base vehicle: Chevrolet 1500HD crew cab (4 door) with 6L V8 CNG engine**
- **Converted by ETEC/Roush**
- **4-speed automatic, supercharger, electronic port fuel injection, liquid-to-air intercooler**
- **Integration of powertrain control module & development of H2 lean-burn control strategies**



6L V-8 100% H2 ICE Pickup

- Implementation of J1850 communications to maintain seamless integration with existing OEM equipment
- 10.5 kg onboard H2 storage @ 5,000 psi
- 180 Horsepower & 260 lb-ft torque
- Anticipated 15 miles/GGE = 155 miles range



6L V-8 100% H2 ICE Pickup

- Targeted to meet NOx requirements for 2007 Tier II, Bin 7 standards
- HC<10 ppm & NOx<25 ppm on engine dynamometer
- Nine vehicles being produced in 1st run
- To be baseline performance tested
- Track 8 unit fleet in Vancouver



INL Oil Bypass Filter Evaluation

- Examine oil bypass filter effectiveness, & quantify engine oil use reductions
- 1.3 million miles on 11 buses & 6 Tahoes
- Test oil quality for 28 variables - total base number, oxidation & nitration levels, contaminants (metals, water, soot, & fuel), & track makeup oil use
- Buses 90% & Tahoes 80% of oil changes avoided



318 INL Alternative Fuel Vehicles

- 79 B20 motor coach buses
- 7 Dedicated LNG motor coach buses
- 154 Bi-fuel light-duty CNG vehicles
- 52 Bi-fuel E85 (85% ethanol) pickups/SUVs
- 22 Bi-fuel LNG pickups
- 2 CNG vans
- 2 Propane vans



INL Alternative Fuel Infrastructure

- **LNG / CNG station at site**
- **CNG station in Idaho Falls**
- **E85 (85% ethanol / 15% gasoline) station at site**
- **B20 (20% biodiesel / 80% diesel) station at site**
- **Adding E85 fueling in Idaho Falls**



Acknowledgement

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FreedomCAR and Vehicle Technologies Program

Vehicle Systems Team Leader, Tien Duong

Project Leader and VSATT Lead, Lee Slezak

<http://avt.inl.gov>

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