Reducing Vehicle Petroleum-based Fuel Consumption: What are our options?

Presentation to Small Cities Council Steering Committee

Rexburg, ID
Aug 1, 2008

John Smart

INL/MIS-08-14599

Idaho National Laboratory

Idaho National Laboratory (INL)

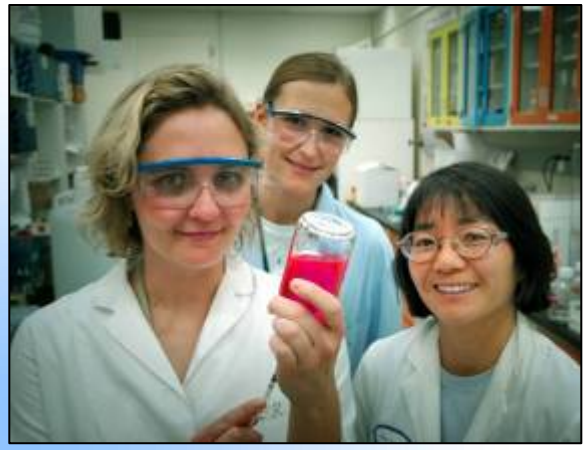
- **What is INL?**
  - **Laboratory owned by DOE and operated by Battelle Energy Alliance**

- **What Does INL Do?**
  - **Develop, demonstrate and promote technology solutions to our country's, region's and state's most difficult challenges in:**

✓ **Nuclear Energy**

✓ **National and Homeland Security**

✓ **Energy, Environment, and Infrastructure**



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U.S. DEPARTMENT OF ENERGY

The Role of National Laboratories in Improving Our Energy Future

- **The DOE systems of laboratories exists to do the work industry and universities *will not, should not, or cannot do.***

National Laboratories are the "crown jewels" of the nation for development of our nuclear science and technology capabilities; an American competitive advantage and an asset to their communities, states, and region.

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Energy Research Areas

- Nuclear
- Biomass
- Wind
- Hydro
- Geothermal
- Fossil
- Batteries
- Alternative Energy Vehicles
- Electric Grid Stability/Security

Advanced Vehicle Testing Activity (AVTA)

- Part of the U.S. Department of Energy's Vehicle Technologies Program
- INL and Electric Transportation Engineering Corporation (ETEC) conduct the AVTA's light-duty vehicle testing, with Argonne National Laboratory performing dynamometer testing

AVTA Goals

- Determine actual petroleum displacement and overall operating cost of advanced technology vehicles
- Provide benchmark data to industry and government research and development programs
- Assist consumers in making informed vehicle purchase, usage, and operating decisions

Outline

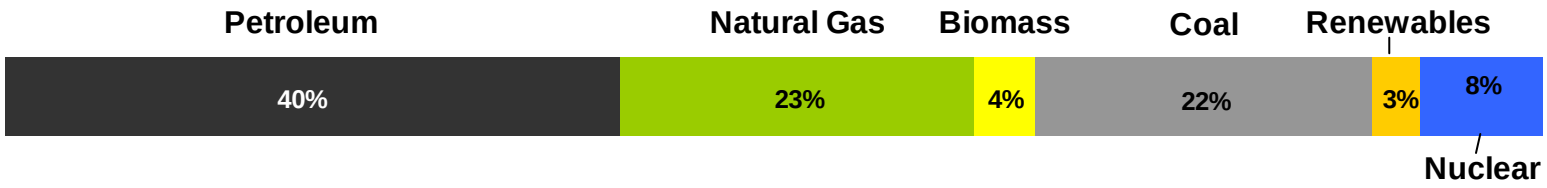
- US energy big picture
- Survey of vehicle technology
- AVTA test activities and results
- Trade-offs
- Broader picture (beyond technology)
- Discussion

US Energy Big Picture

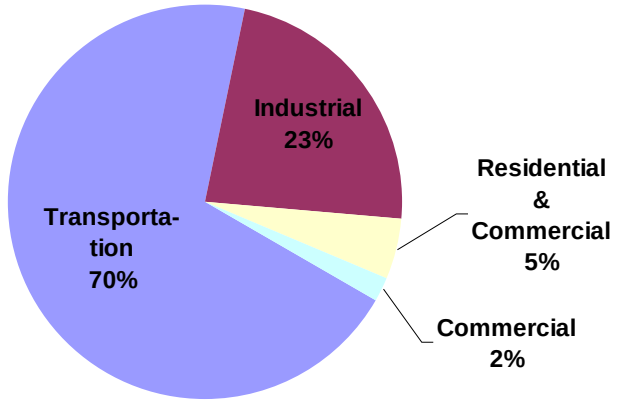
Areas of concern

- Energy security
  - Insufficient domestic supply forces us to import energy (oil)
- Global climate change
  - Tailpipe and smoke stack CO_2 emissions
- Economic stability
  - Your wallet (energy prices, food prices, other costs)
  - Your job security
  - Not just state of economy today, but worry about future

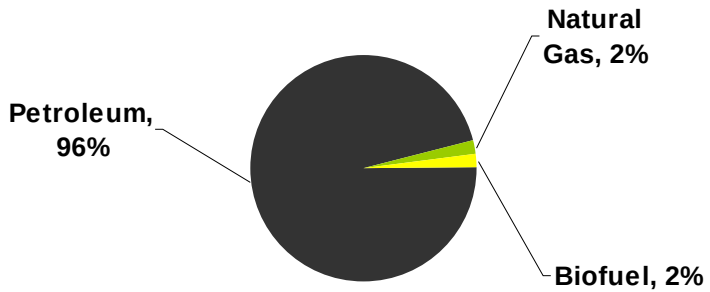
Sources and Uses of Energy in US



US Petroleum Usage



US Transportation Sector Energy Sources



Source: Energy Information Administration

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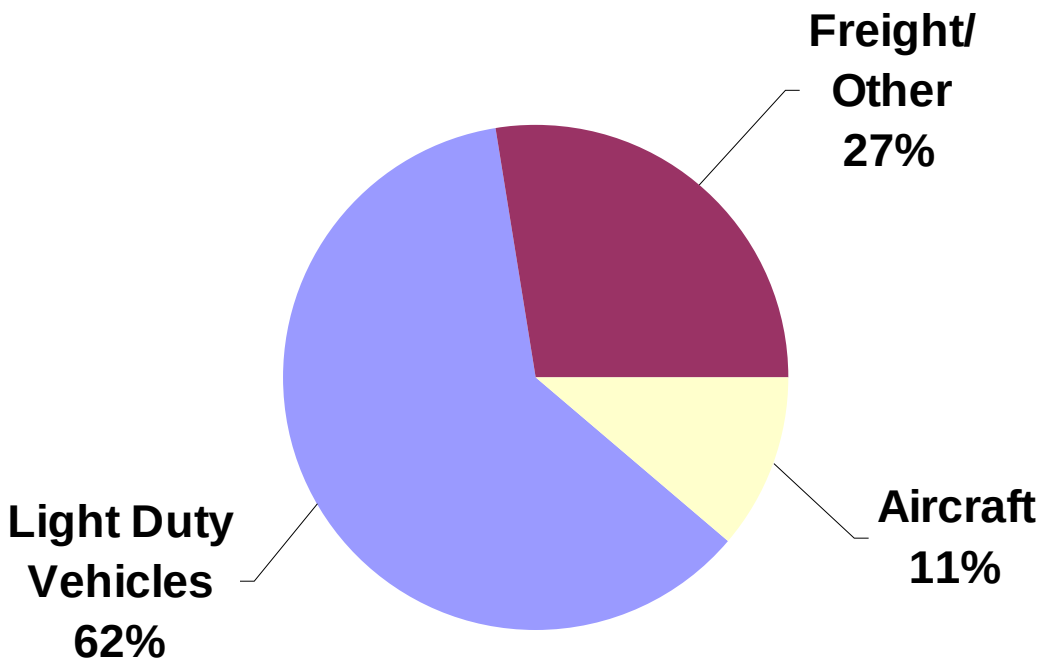
US Transportation Energy Usage



Source: Energy Information Administration

Reducing Petroleum Consumption of Light Duty Passenger Vehicles

- Reduce number of vehicles
  - Find other ways to get around, or share
- Increase vehicle efficiency
  - use less to do the same amount of work… or more work!
- Increase energy diversity
  - use another fuel source

Survey of Major Vehicle Technologies

- **Internal Combustion**
  - **Gasoline**
  - **Diesel**
  - **“Flex Fuel” gas + ethanol or methanol**
  - **Natural Gas**
  - **Biodiesel**
  - **Hydrogen**

- **Electric Drive**
  - **Small “neighborhood” battery electric vehicle (NEV)**
  - **Hybrid electric vehicle (HEV)**
  - **Plug-in hybrid electric vehicle (PHEV) or Extended range electric vehicle (EREV)**
  - **Full size battery electric vehicle (EV)**
  - **Fuel Cell Vehicle (FCV)**

Black = currently on market
Blue = entering market as aftermarket conversions
Red = under development, limited number of vehicles in market

What is the direction for the future?

- **Lots of possibilities, no “silver bullet”**
- **Complex technological and societal trade-offs with every path**
- **Consensus is that electrification will play key role in diversifying energy**

AVTA Testing History

- Plug-in hybrid electric vehicles
  - 6 models, ~75 vehicles in fleets
- Hybrid electric vehicles
  - 14 models, 3.7 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
  - 16 models, 200,000 test miles
- Urban electric vehicles
  - 3 models, 1 million test miles

Hybrid Electric Vehicles (HEV)

- Uses electric motor(s) and battery pack to provide power source in addition to internal combustion engine
- Charges battery pack by capturing energy normally wasted during braking and coasting
- Uses that energy to drive motor(s) for power during acceleration
- Does not plug in to electrical grid for recharging
- Manufactures can tune to improve fuel efficiency or performance

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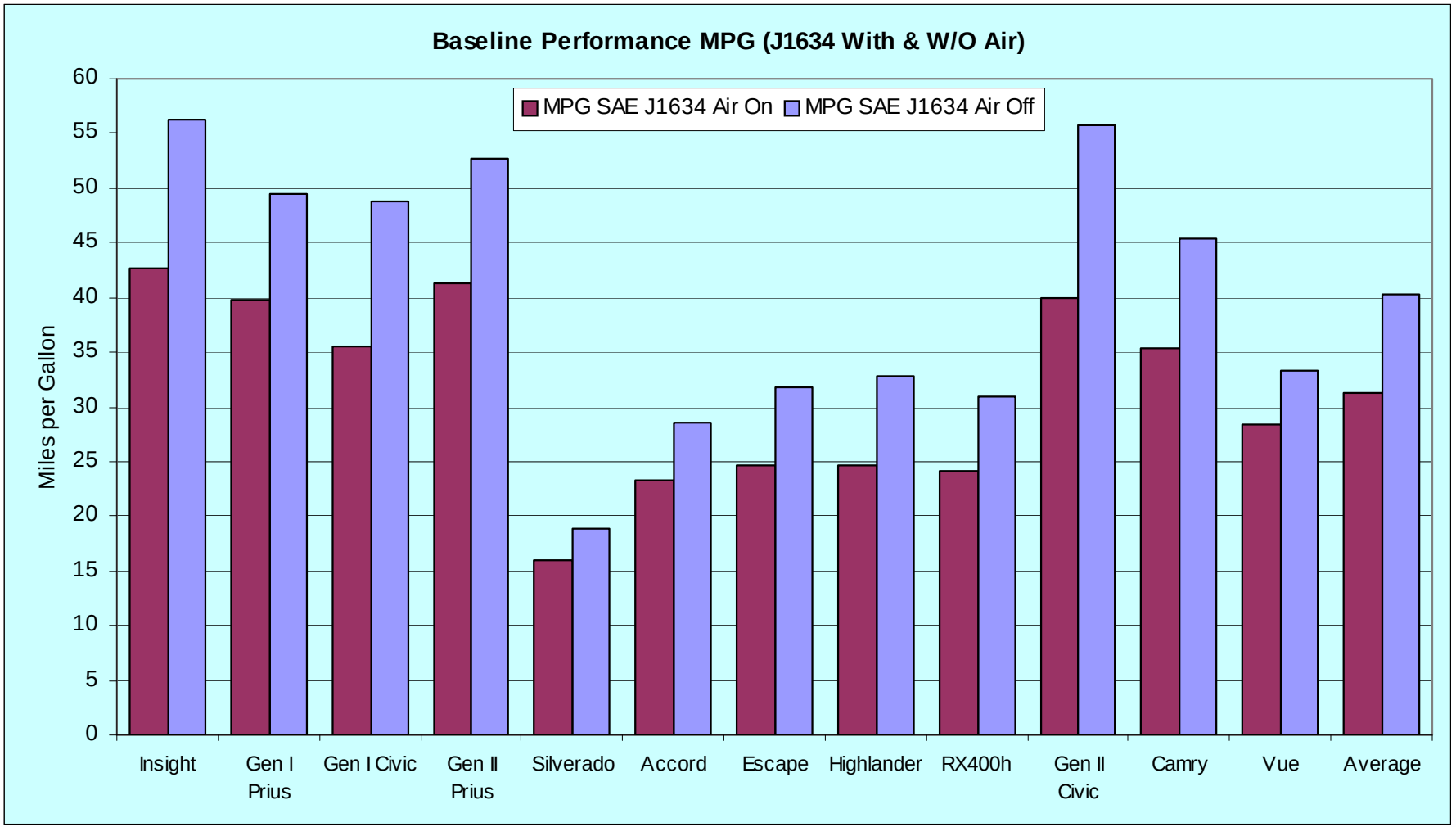
Hybrid Electric Vehicles (HEVs) in Testing

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	Completed
2005 Ford Escape (front & 4-WD)	2	Completed
2005 Honda Accord	2	Completed
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
2008 Nissan Altima	2	Ongoing
2008 GM 2-mode Tahoes	2	Ongoing
Total	39 to date	

HEVs Baseline Performance Testing



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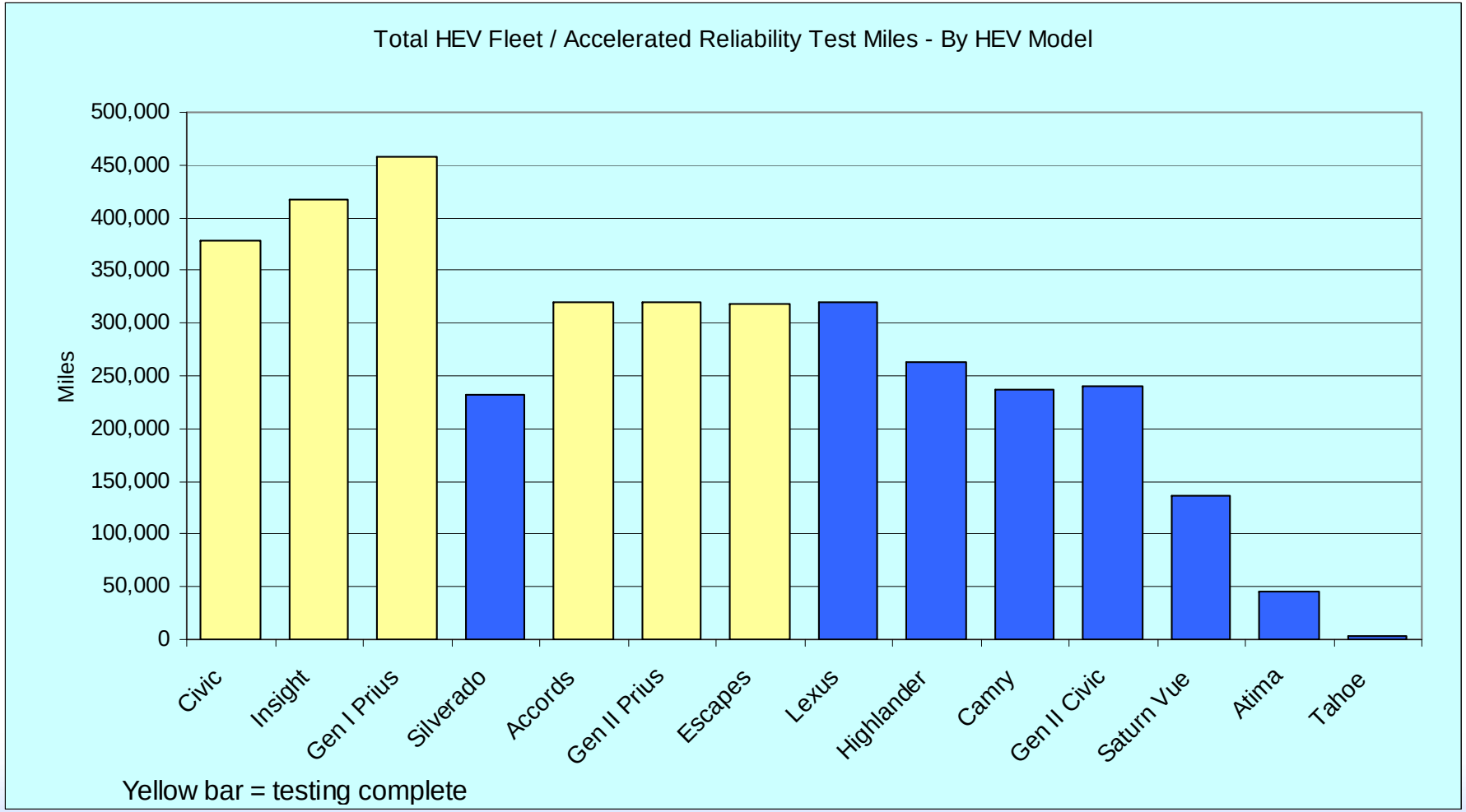
Onroad Test miles per HEV model

- **Minimum 320,000 test miles per HEV model in 36 months**



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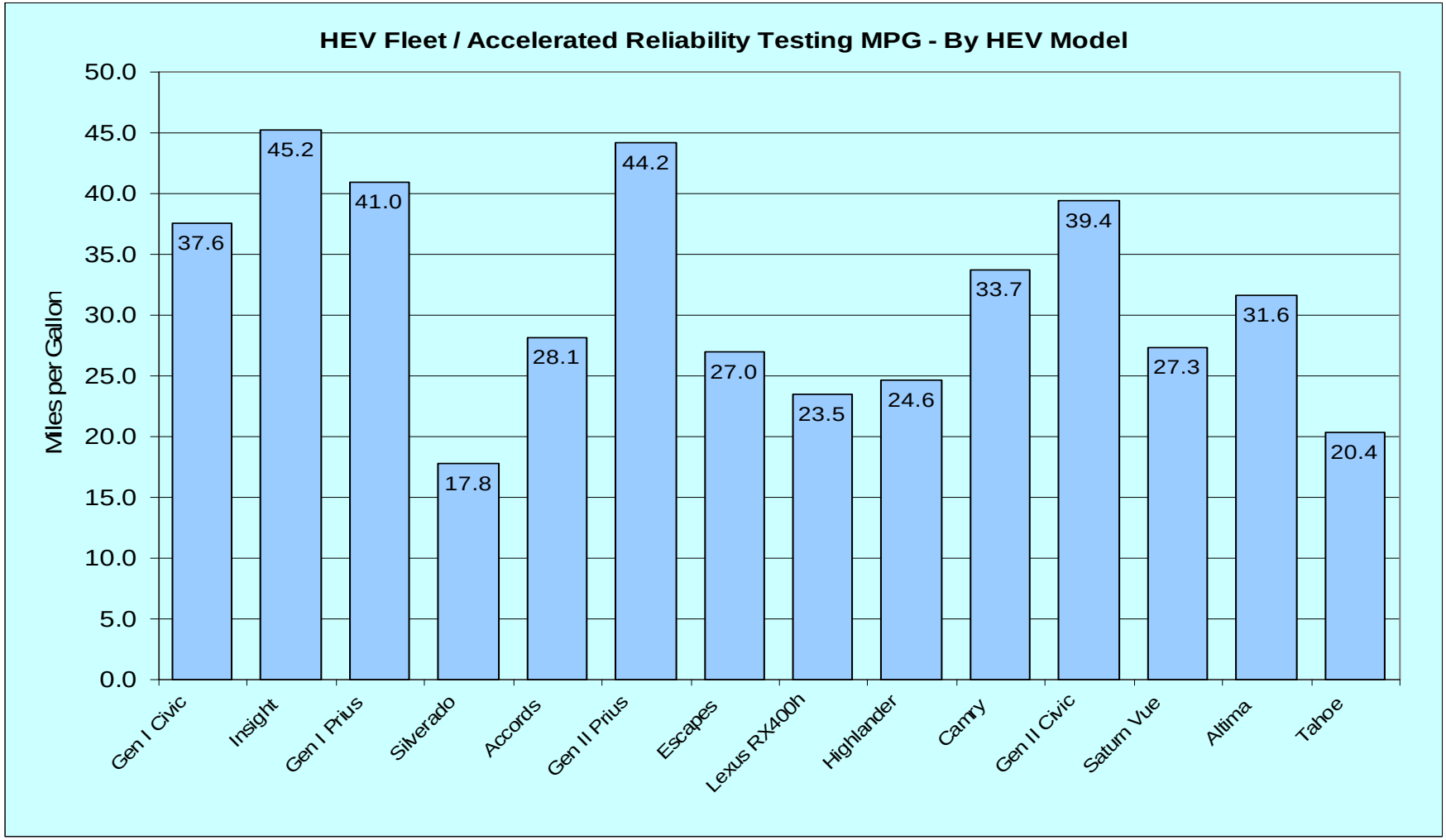
Onroad Miles per gallon by HEV model



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HEV Maintenance and Repairs

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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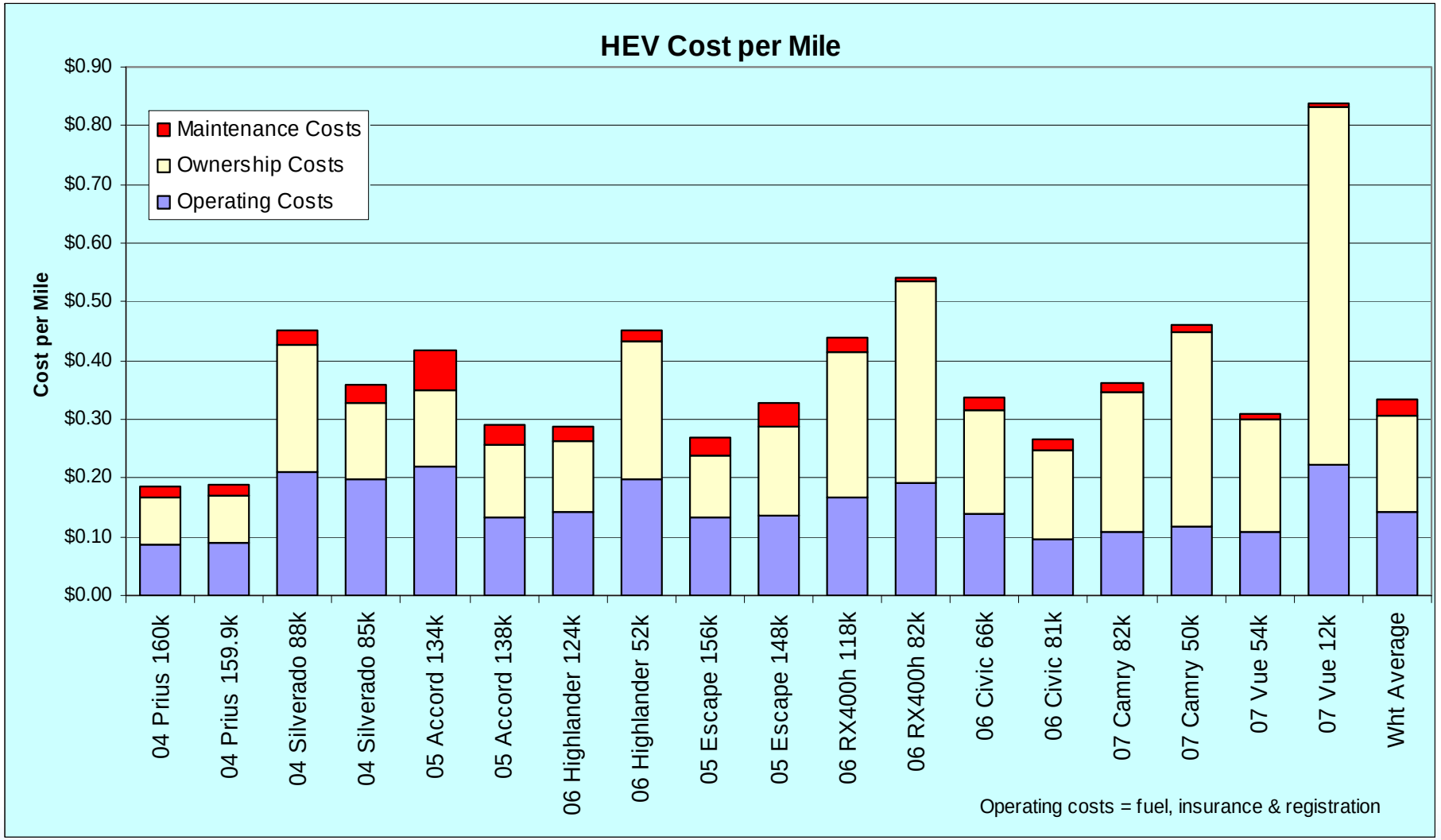
HEV Life-Cycle Costs per Mile



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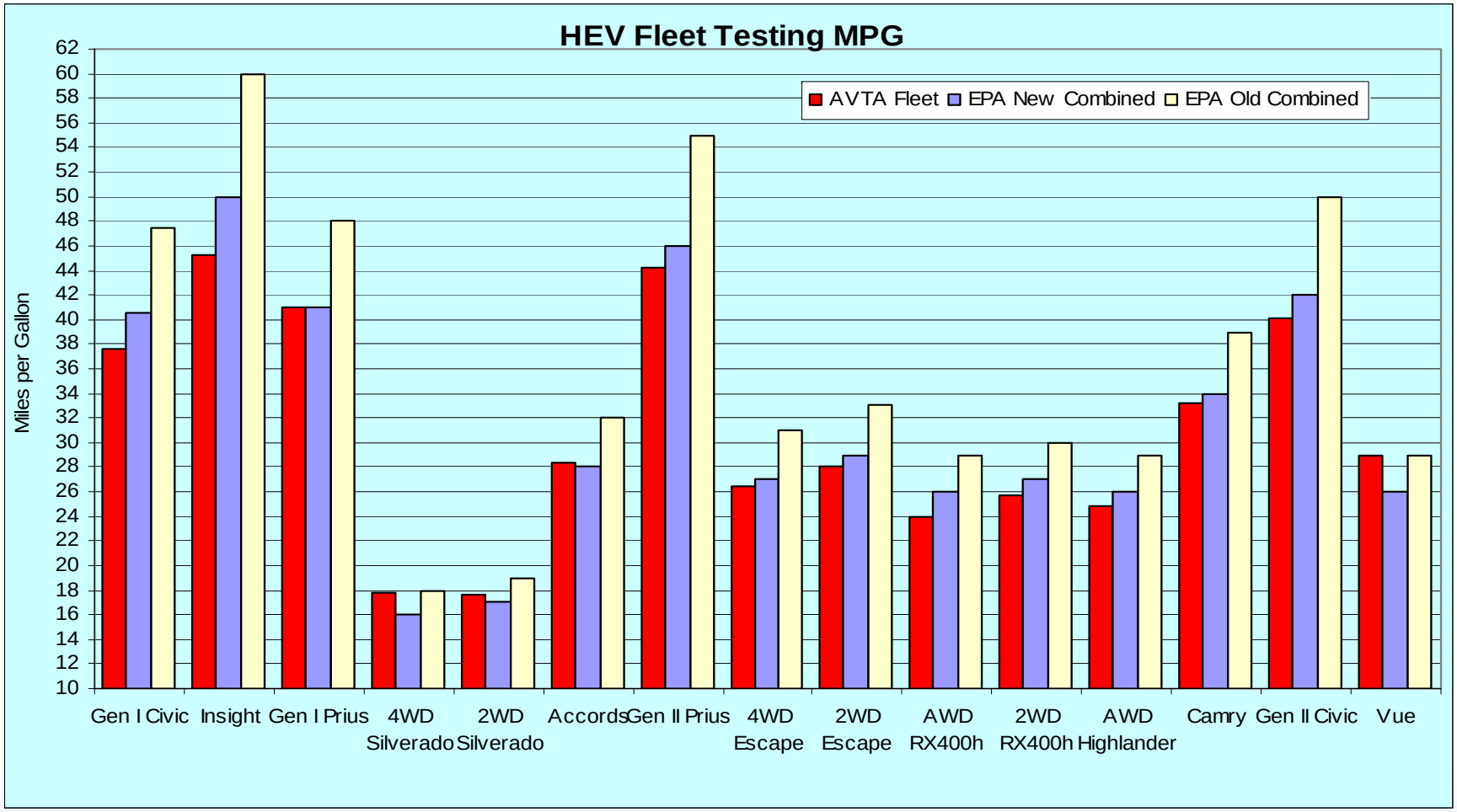
HEV Accelerated Testing Results

- **AVTA accelerated testing and EPA miles per gallon**



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Plug-in Hybrid Electric Vehicles (PHEV)

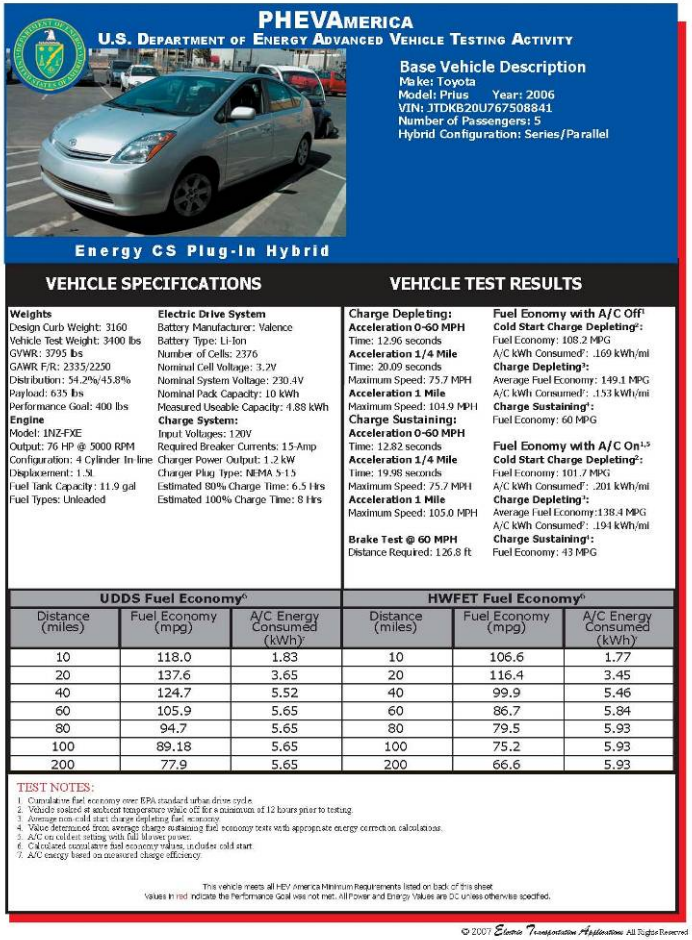
- **Like HEVs, PHEVs use motor(s) and battery pack in addition to IC engine**
- **Battery pack has much higher energy capacity for greater proportion of electric propulsion**
- **Vehicle must be plugged in to recharge battery pack; also captures braking energy**
- **Can plug into standard 110/120 VAC outlet**

Plug-in Hybrid Electric Vehicles (PHEV)

- **Aftermarket conversion companies installing battery packs in HEVs to convert to PHEVs**
- **Several auto makers have announced plans to produce PHEVs, including GM, Ford, Chrysler, and Toyota**
- **Many are promoting PHEVs as “100+ mpg” cars**

PHEV Baseline Performance Testing

- These and other test results at http://avt.inl.gov



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

Base Vehicle Description
Make: Toyota
Model: Prius Year: 2006
VIN: JTDKB20U767508841
Number of Passengers: 5
Hybrid Configuration: Series/Parallel

Energy CS Plug-In Hybrid

VEHICLE SPECIFICATIONS

Weights
Design Curb Weight: 3160
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

Electric Drive System
Battery Manufacturer: Valence
Battery Type: Li-Ion
Number of Cells: 2376
Nominal Cell Voltage: 3.2V
Nominal System Voltage: 230.4V
Nominal Pack Capacity: 10 kWh
Measured Useable Capacity: 4.88 kWh

Charge System:
Input Voltages: 120V
Required Breaker Currents: 15-Amp
Charger Power Output: 1.2 kW
Charger Plug Type: NEMA 5-15
Estimated 80% Charge Time: 6.5 Hrs
Estimated 100% Charge Time: 8 Hrs

VEHICLE TEST RESULTS

Charge Depleting:
Acceleration 0-60 MPH
Time: 12.96 seconds
Acceleration 1/4 Mile
Time: 20.09 seconds
Maximum Speed: 75.7 MPH
Acceleration 1 Mile
Maximum Speed: 104.9 MPH

Charge Sustaining:
Acceleration 0-60 MPH
Time: 12.82 seconds
Acceleration 1/4 Mile
Time: 19.98 seconds
Maximum Speed: 75.7 MPH
Acceleration 1 Mile
Maximum Speed: 105.0 MPH

Brake Test @ 60 MPH
Distance Required: 126.8 ft

Fuel Economy with A/C Off[1]
Cold Start Charge Depleting[2]:
Fuel Economy: 108.2 MPG
A/C kWh Consumed[7]: .169 kWh/mi
Charge Depleting[3]:
Average Fuel Economy: 149.1 MPG
A/C kWh Consumed[7]: .153 kWh/mi
Charge Sustaining[4]:
Fuel Economy: 60 MPG

Fuel Economy with A/C On[1,5]
Cold Start Charge Depleting[2]:
Fuel Economy: 101.7 MPG
A/C kWh Consumed[7]: .201 kWh/mi
Charge Depleting[3]:
Average Fuel Economy:138.4 MPG
A/C kWh Consumed[7]: .194 kWh/mi
Charge Sustaining[4]:
Fuel Economy: 43 MPG

UDDS Fuel Economy[6]

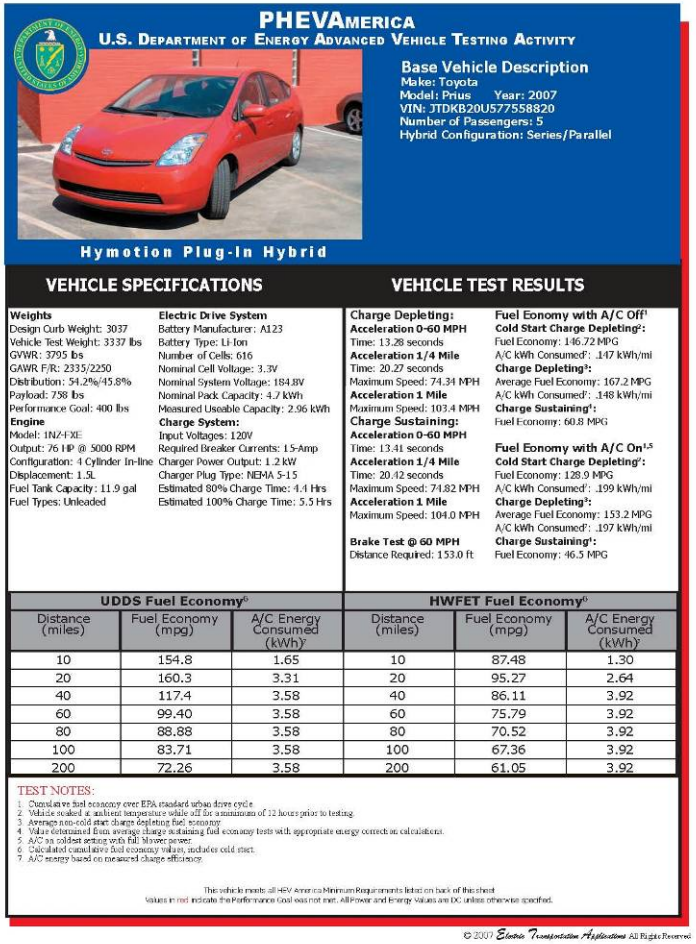
Distance (miles)	Fuel Economy (mpg)	A/C Energy Consumed (kWh)[7]
10	118.0	1.83
20	137.6	3.65
40	124.7	5.52
60	105.9	5.65
80	94.7	5.65
100	89.18	5.65
200	77.9	5.65

HWFET Fuel Economy[6]

Distance (miles)	Fuel Economy (mpg)	A/C Energy Consumed (kWh)[7]
10	106.6	1.77
20	116.4	3.45
40	99.9	5.46
60	86.7	5.84
80	79.5	5.93
100	75.2	5.93
200	66.6	5.93

TEST NOTES:
1. Cumulative fuel economy over EPA standard urban drive cycle.
2. Vehicle soaked 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 coldest 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: JTDKB20U577558820
Number of Passengers: 5
Hybrid Configuration: Series/Parallel

Hymotion Plug-In Hybrid

VEHICLE SPECIFICATIONS

Weights
Design Curb Weight: 3037
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

Electric Drive System
Battery Manufacturer: A123
Battery Type: Li-Ion
Number of Cells: 616
Nominal Cell Voltage: 3.3V
Nominal System Voltage: 184.8V
Nominal Pack Capacity: 4.7 kWh
Measured Useable Capacity: 2.96 kWh

Charge System:
Input Voltages: 120V
Required Breaker Currents: 15-Amp
Charger Power Output: 1.2 kW
Charger Plug Type: NEMA 5-15
Estimated 80% Charge Time: 4.1 Hrs
Estimated 100% Charge Time: 5.5 Hrs

VEHICLE TEST RESULTS

Charge Depleting:
Acceleration 0-60 MPH
Time: 13.28 seconds
Acceleration 1/4 Mile
Time: 20.27 seconds
Maximum Speed: 74.34 MPH
Acceleration 1 Mile
Maximum Speed: 103.4 MPH

Charge Sustaining:
Acceleration 0-60 MPH
Time: 13.41 seconds
Acceleration 1/4 Mile
Time: 20.42 seconds
Maximum Speed: 74.82 MPH
Acceleration 1 Mile
Maximum Speed: 104.0 MPH

Brake Test @ 60 MPH
Distance Required: 153.0 ft

Fuel Economy with A/C Off[1]
Cold Start Charge Depleting[2]:
Fuel Economy: 146.72 MPG
A/C kWh Consumed[7]: .147 kWh/mi
Charge Depleting[3]:
Average Fuel Economy: 167.2 MPG
A/C kWh Consumed[7]: .148 kWh/mi
Charge Sustaining[4]:
Fuel Economy: 60.8 MPG

Fuel Economy with A/C On[1,5]
Cold Start Charge Depleting[2]:
Fuel Economy: 128.9 MPG
A/C kWh Consumed[7]: .199 kWh/mi
Charge Depleting[3]:
Average Fuel Economy: 153.2 MPG
A/C kWh Consumed[7]: .197 kWh/mi
Charge Sustaining[4]:
Fuel Economy: 46.5 MPG

UDDS Fuel Economy[6]

Distance (miles)	Fuel Economy (mpg)	A/C Energy Consumed (kWh)[7]
10	154.8	1.65
20	160.3	3.31
40	117.4	3.58
60	99.40	3.58
80	88.88	3.58
100	83.71	3.58
200	72.26	3.58

HWFET Fuel Economy[6]

Distance (miles)	Fuel Economy (mpg)	A/C Energy Consumed (kWh)[7]
10	87.48	1.30
20	95.27	2.64
40	86.11	3.92
60	75.79	3.92
80	70.52	3.92
100	67.36	3.92
200	61.05	3.92

TEST NOTES:
1. Cumulative fuel economy over EPA standard urban drive cycle.
2. Vehicle soaked 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.
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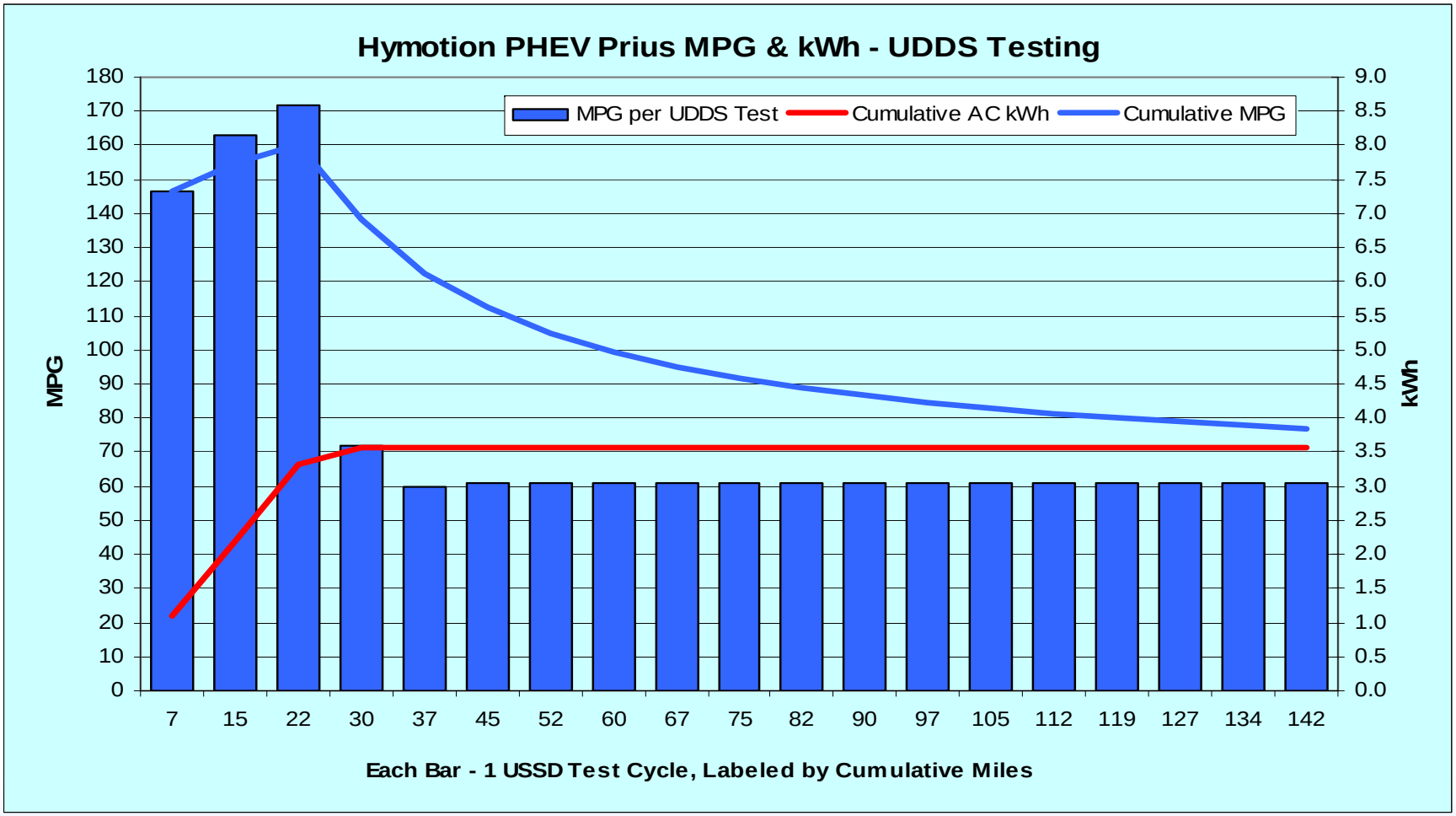
Toyota Prius with Hymotion PHEV conversion – EPA City Test



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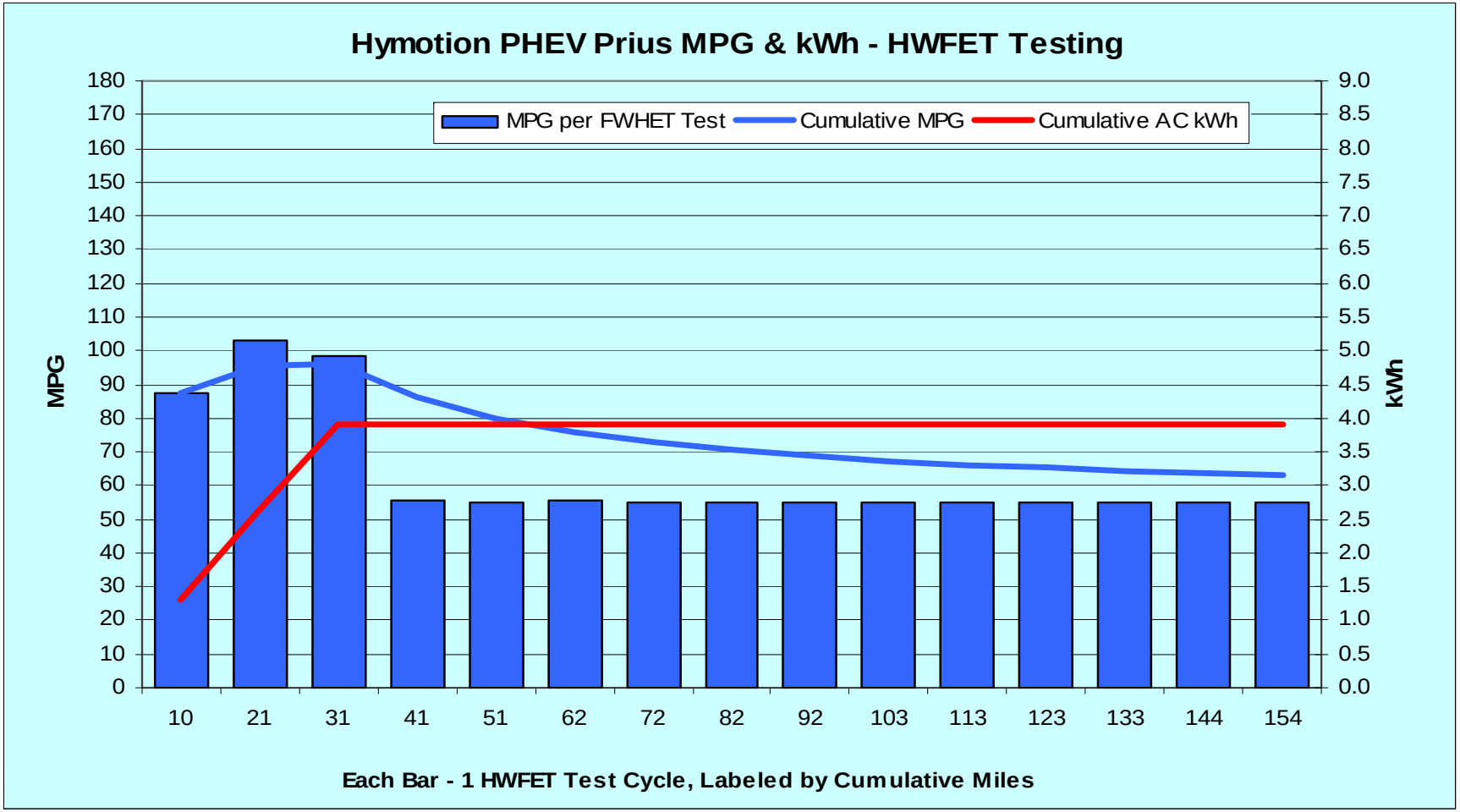
Toyota Prius with Hymotion PHEV conversion – EPA Highway Test



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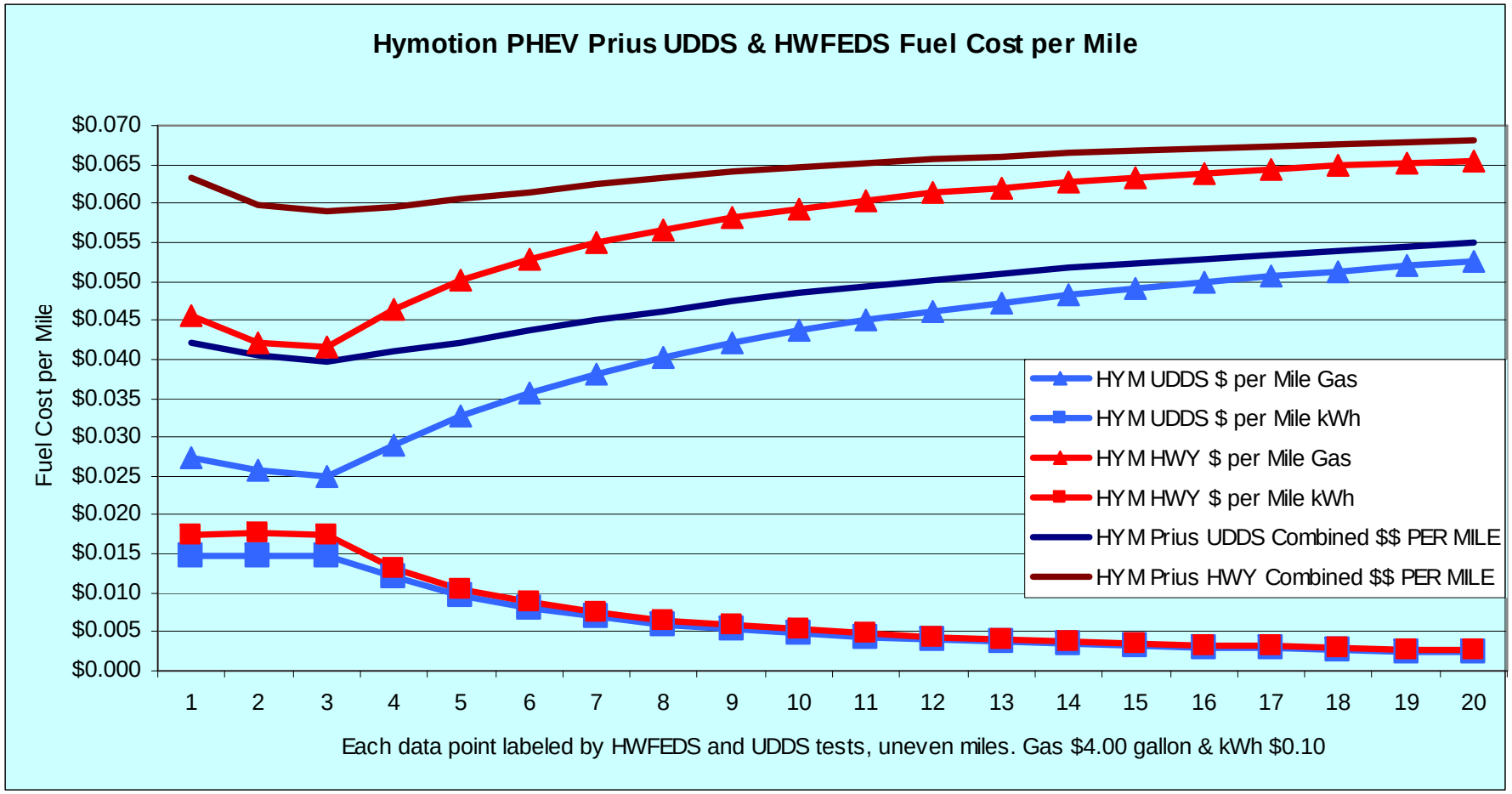
Hymotion Prius – Fuel Costs



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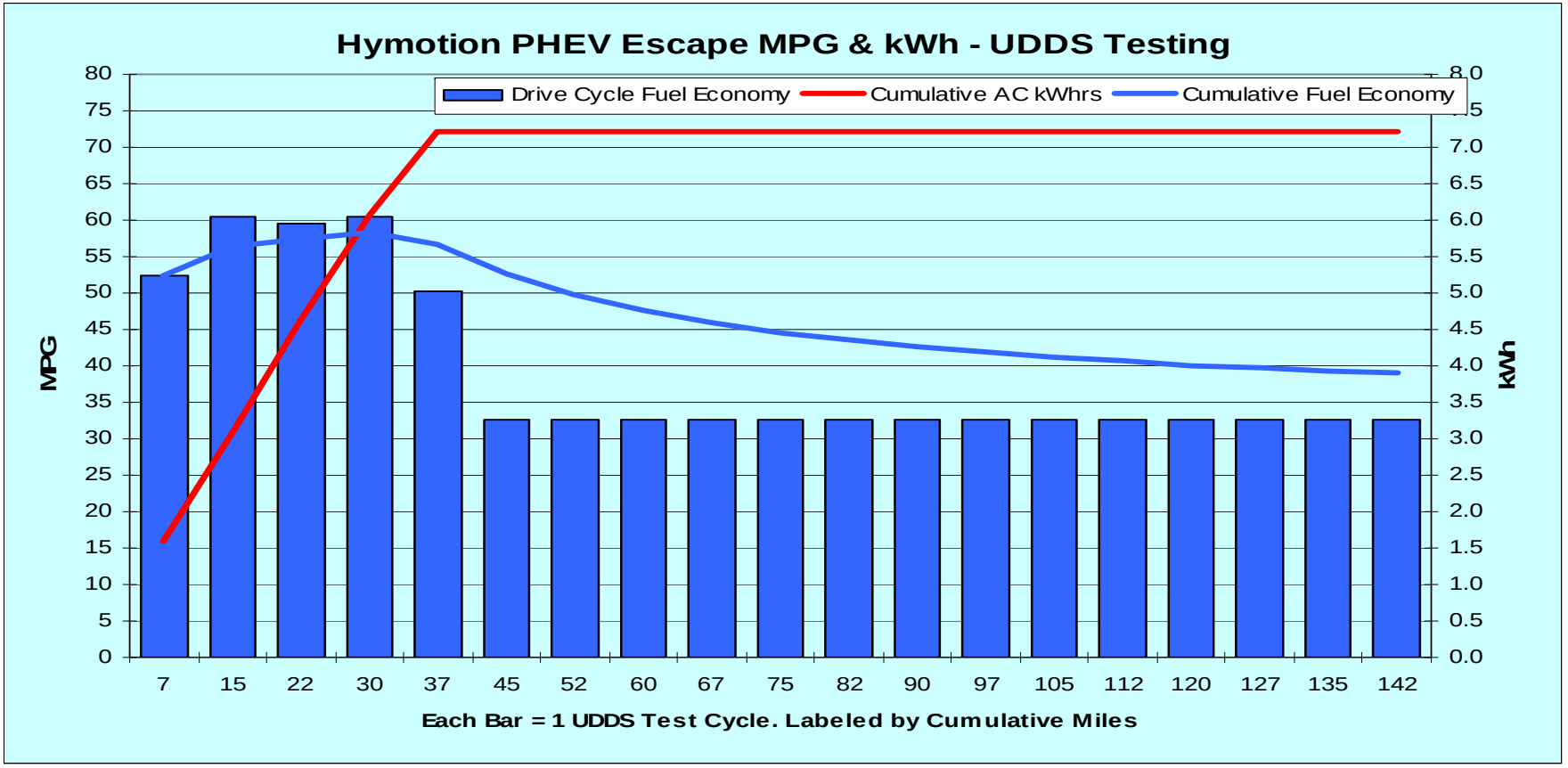
Hymotion Prius – On-road Accelerated Testing

Cycle	Urban	Highway	Charge	Reps	Total	Electricity	Gasoline	
(mi)	(10 mi)	(10 mi)	(hr)	(N)	(mi)	kWh	Gals	MPG
10	1	0	4	60	600	136.33	4.81	127.2
20	1	1	8	30	600	122.02	5.37	115.9
40	4	0	12	15	600	84.10	6.05	101.1
40	2	2	12	15	600	87.22	5.78	106.9
40	0	4	12	15	600	79.82	8.54	73.1
60	2	4	12	10	600	55.33	8.98	68.9
80	2	6	12	8	640	43.99	11.36	58.3
100	2	8	12	6	600	35.98	8.43	73.2
200	2	18	12	3	600	15.0	11.02	54.8
Total	2540	3100	1404	167	5,440	Weighted Average		79.5

Each total distance slightly greater than 600 and 640 miles. HEV version = 44 mpg

Ford Hybrid Escape with Hymotion PHEV conversion – EPA City Test



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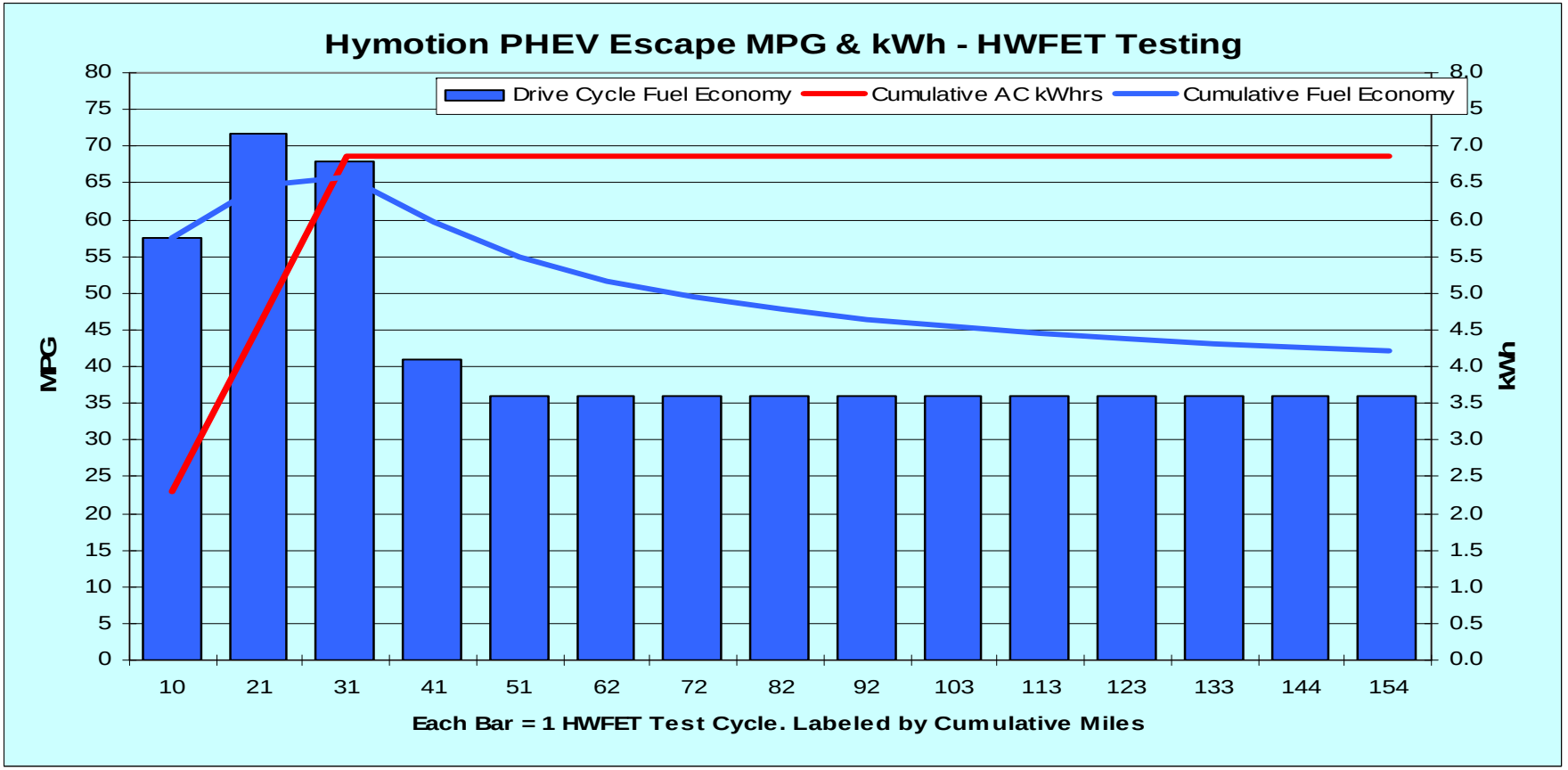
Ford Hybrid Escape with Hymotion PHEV conversion – EPA Hwy Test



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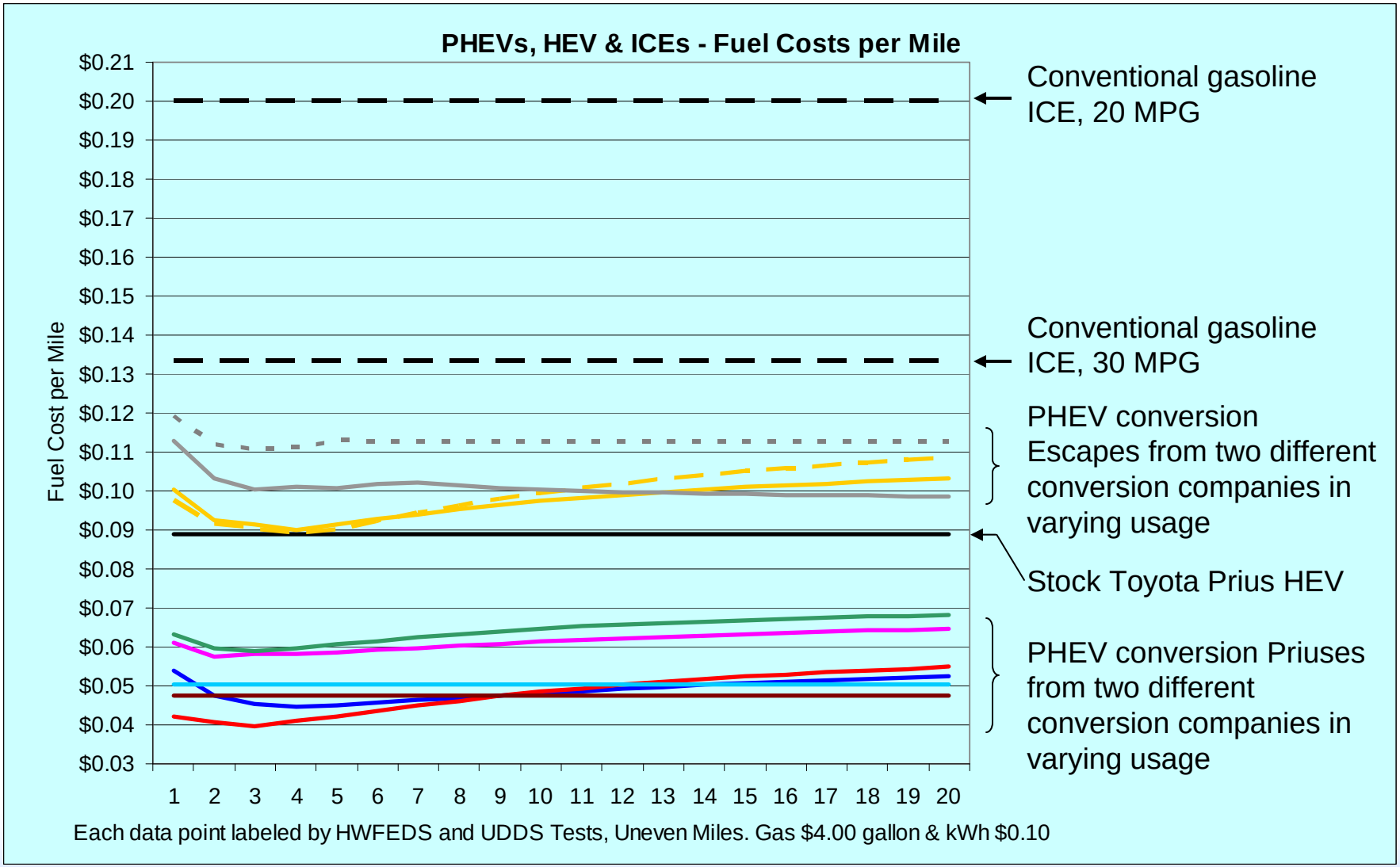
Hymotion Escape – On-road Accelerated Testing

Cycle	Urban	Highway	Charge	Reps	Total	Electricity	Gasoline	
(mi)	(10 mi)	(10 mi)	(hr)	(N)	(mi)	kWh	Gals	MPG
10	1	0	4	60	600			
20	1	1	8	30	600			
40	4	0	12	15	600			
40	2	2	12	15	600	Ongoing		
40	0	4	12	15	600	114.14	11.92	51.5
60	2	4	12	10	600	97.18	13.70	45.3
80	2	6	12	8	640	77.69	16.05	41.3
100	2	8	12	6	600	58.64	15.69	39.8
200	2	18	12	3	600			
Total	2340	3100	1344	162	5440	Weighted Average		

Each total distance slightly greater than 600 miles. HEV version = 27 mpg

Comparing Fuel Cost



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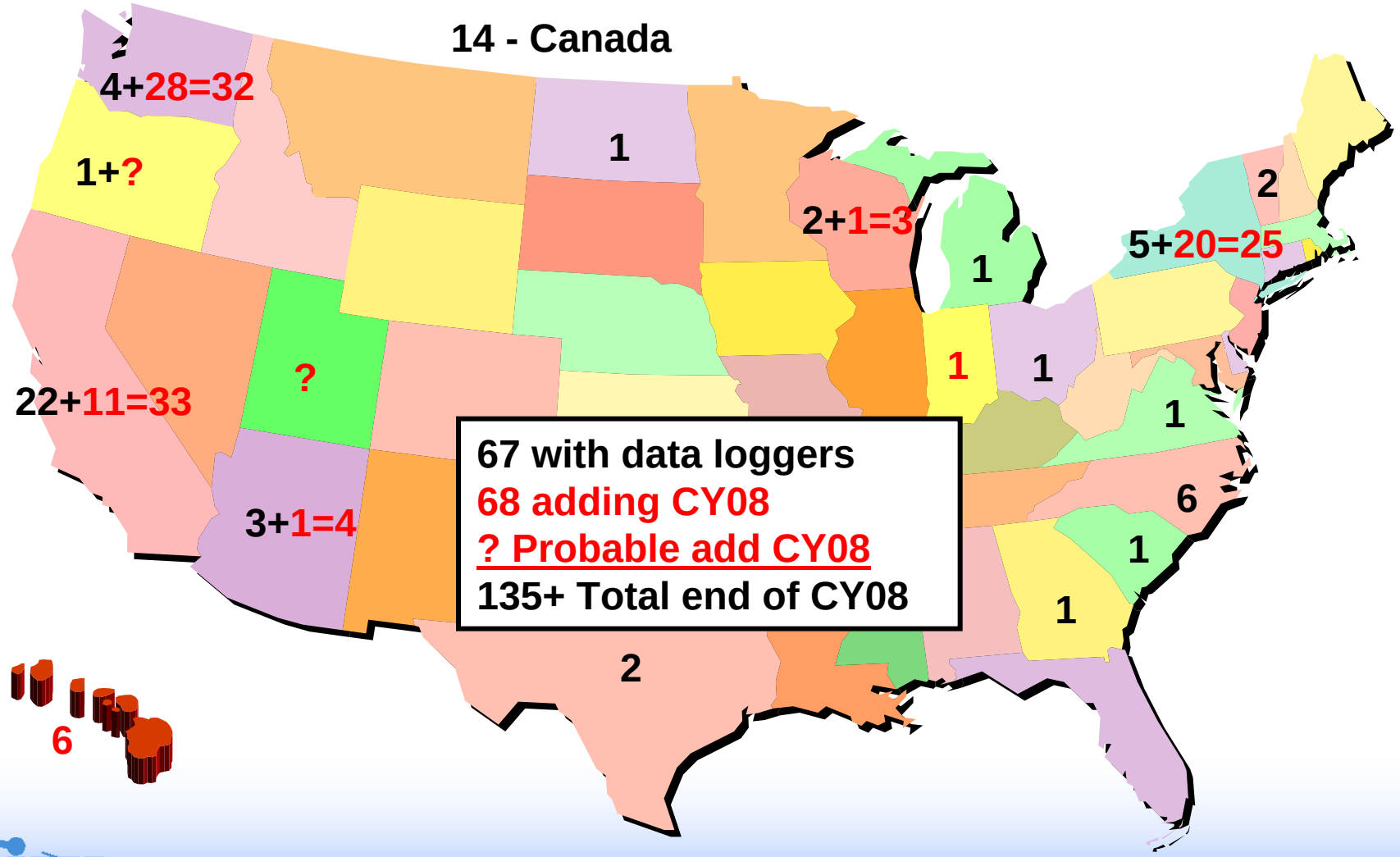
PHEV Demonstration Fleet

Current and Future Vehicle Locations



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26 Hymotion Prius - January thru May 2008

- **Below averages do NOT tell the whole PHEV energy-use potential – see following May-only slides**

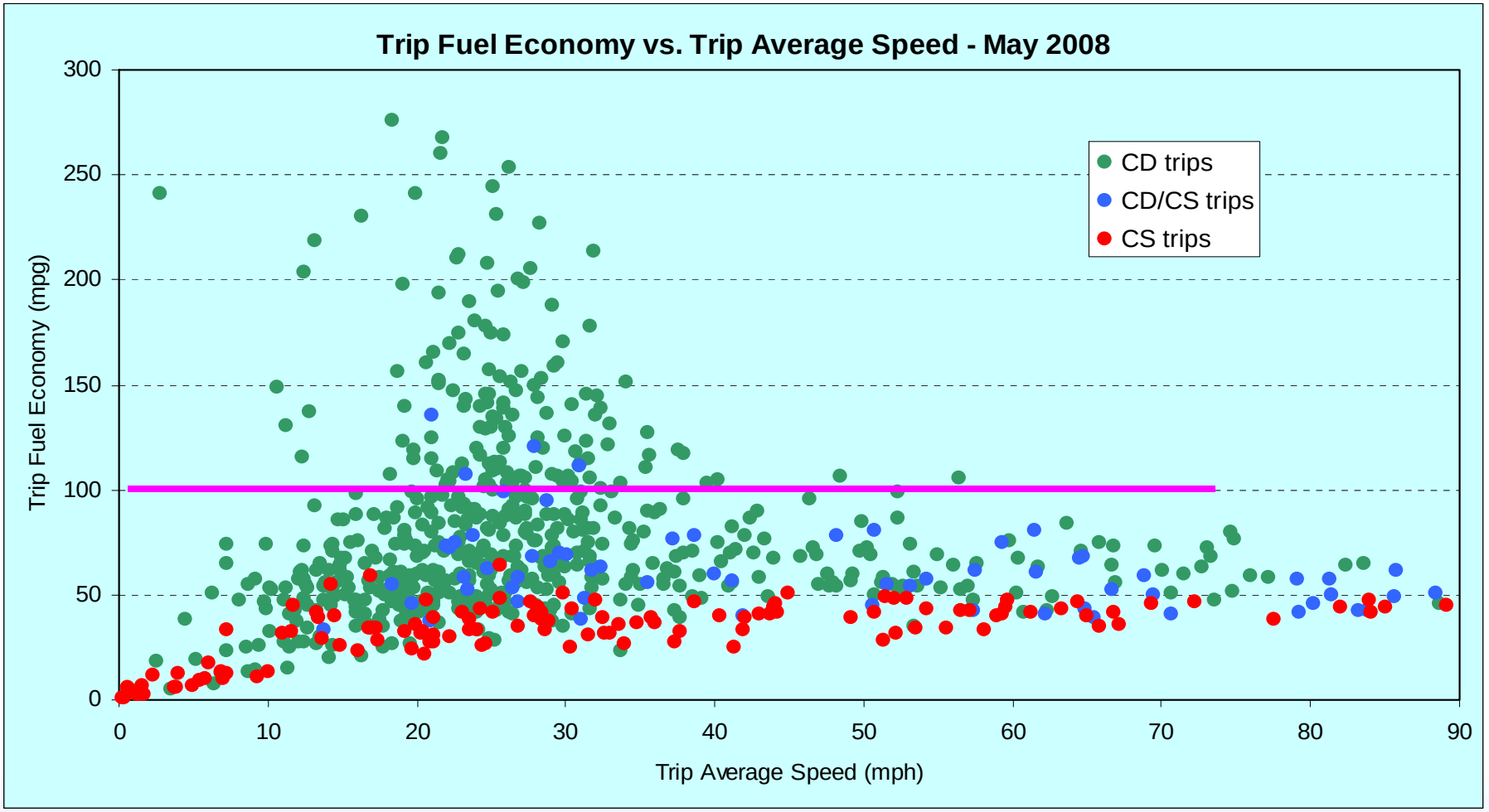
Charge / Operating Mode	Number of Trips	Distance Traveled (Miles)	Miles per Gallon
Charge Depleting (CD)	3,073	14,820	59
Mixed CD / CS	404	11,121	49
Charge Sustaining (CS)	1,358	16,059	40
All trips combined	4,835	42,000	48

13 Hymotion Prius in May 2008 - MPG

- **Below averages do NOT tell the whole PHEV energy use potential – see next 3 slides**

Charge / Operating Mode	Number of Trips	Total Distance (Miles)	Average Trip Distance (miles)	MPG	DC kWh per Mile
Charge Depleting (CD)	575	3,040	5.3	72.0	0.138
Mixed CD / CS	67	1,840	27.5	52.1	0.050
Charge Sustaining (CS)	133	1,411	10.6	40.2	
Electric vehicle only (EV)	137	127	0.9		0.236
Total	912	6,417	7.0		
CD, CS, CD/CS results (excludes EV results)	775	6,291	8.1	55.9	

13 Hymotion Prius MPG Vs. Speed



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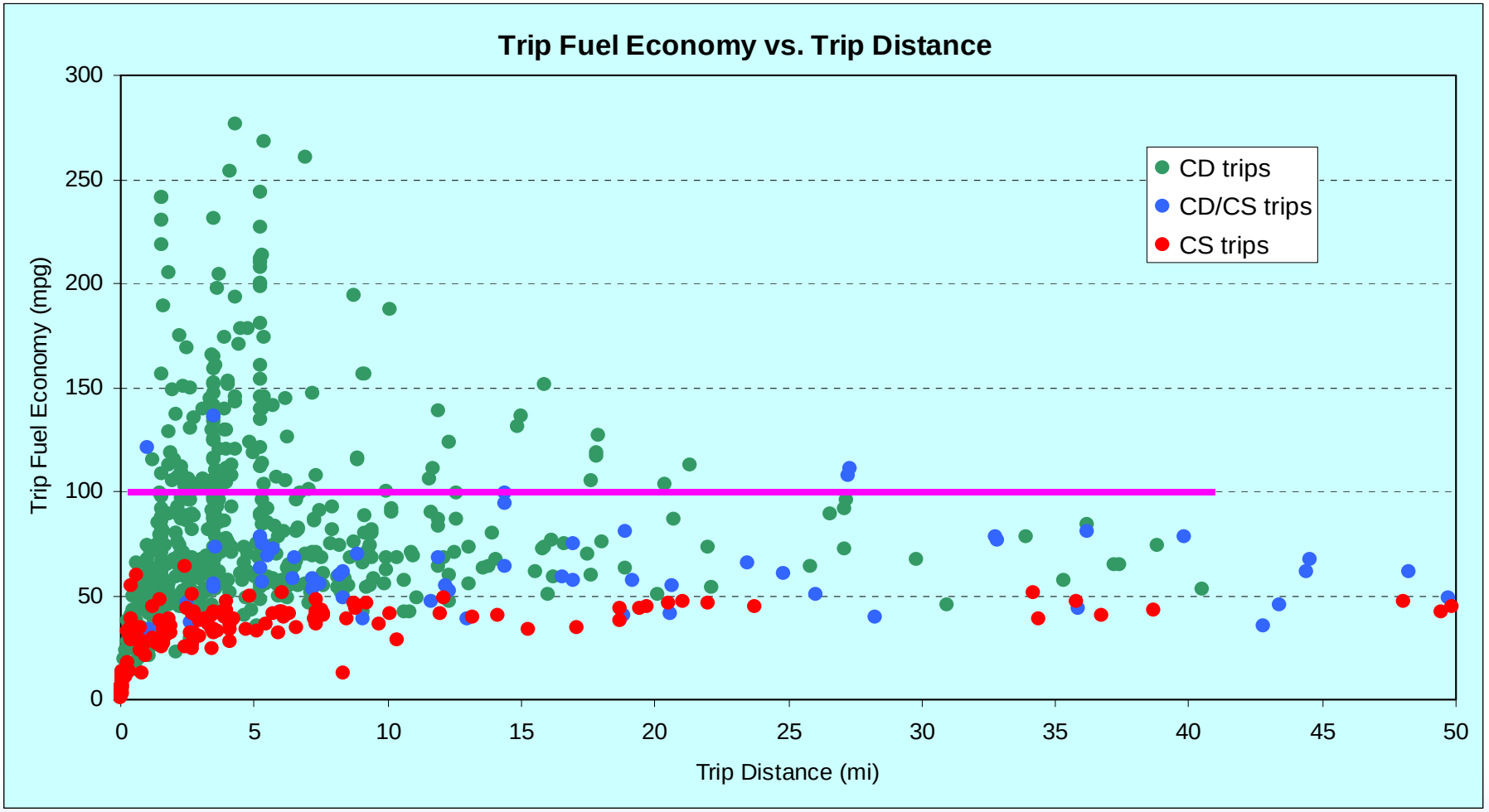
13 Hymotion Prius MPG Vs. Distance



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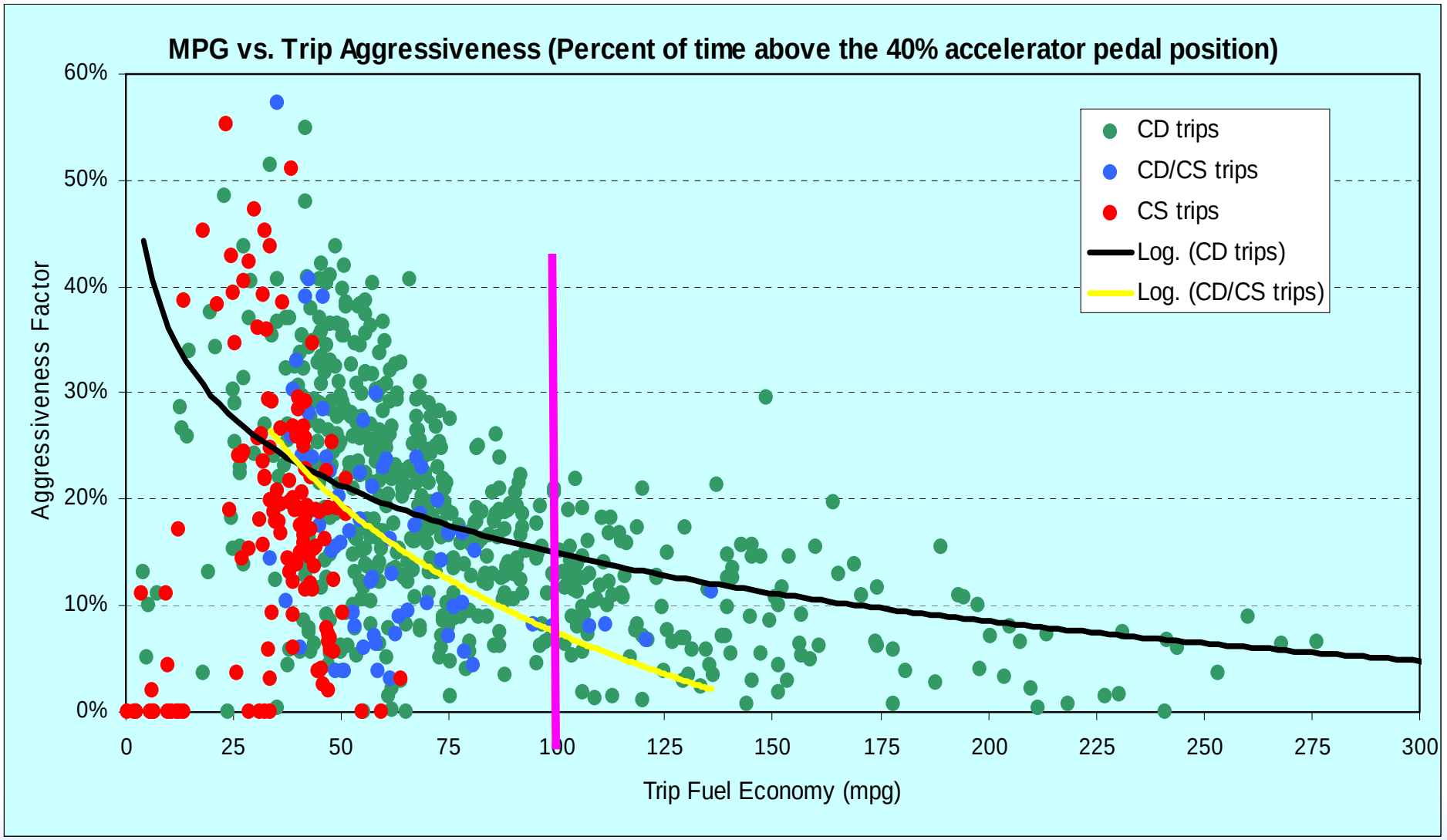
13 Hymotion Prius and Aggressive Driving



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PHEV Charging Infrastructure

- National Electric Code requires
  - Dedicated branch circuit
  - GFCI (ground fault circuit interrupt)
  - “EV” extension cord
  - Unique connector “plug”

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Neighborhood Electric Vehicles (NEV)

- **A NEV is technically defined as a "Low Speed Vehicle" (LSV) by the National Highway Traffic Safety Administration's Federal Motor Vehicle Safety Standard No. 500.**
- **Per FMVSS No. 500, a LSV means a vehicle:**
  - **that is 4-wheeled**
  - **with a top attainable speed in 1 mile of more than 20 mph and not more than 25 mph on a paved level surface**
  - **with a Gross Vehicle Weight Rating of less than 2,500 pounds.**

NEVAmerica Testing

- CARB requires all Neighborhood Electric Vehicles (NEVs) be tested by the AVTA
- 5 NEVs completing testing in 2008:
  - 2 Miles Automotive: sedan & pickup
  - 1 Zen sedan
  - 2 GEMs: 6 passenger sedan & extended range pickup
- 14 NEVs previously tested:
  - 8 Gems (Global Electric Motors)
  - 2 Th!nk Neighbors
  - 2 Frazier Nashes
  - 2 ParCars

Neighborhood Electric Vehicles (NEV)

- These and other test results at http://avt.inl.gov

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

2007 Global Electric Motorcars e6

VEHICLE SPECIFICATIONS

Base Vehicle: 2007 Global Electric Motorcars e6 6-Passenger
VIN: 5ASAG67427F042894
Seatbelt Positions: Six
Standard Features:
Front Wheel Drive
Front Disc and Rear Drum Brakes
Regenerative Braking With Coast Down
Three-Point Safety Belts
Speedometer
Odometer
State-Of-Charge Meter
Back-up Alarm
On Board Battery Charger

BATTERY
Manufacturer: East Penn Deka
Type: 8G8VGC Gel Lead Acid
Number of Modules: 9
Weight of Modules: 30.8 kg
Weight of Pack(s): 277.6 kg
Pack(s) Location: Under Middle and Rear Seats
Nominal Module Voltage: 8V
Nominal System Voltage: 72V
Nominal Capacity (C/1): 85 Ah

TIRES
Tire Mfg: Nanking
Tire Model: Sceptor
Tire Size: P185/70R13 86T
Tire Pressure: 32 psi
Spare Installed: No

WEIGHTS
Design Curb Weight: 1560 lb
Delivered Curb Weight: 1878 lb
Distribution F/R: 46/54 %
GVWR: 2999 lb
GAWR F/R: 1380/1820 lb
Payload: 1122 lb[2]
Performance Goal: 400 lb

DIMENSIONS
Wheelbase: 133.0 inches
Track F/R: 45.5/45.5 inches
Length: 162.0 inches
Width: 55.0 inches
Height: 71.0 inches
Ground Clearance: 7.0 inches
Performance Goal: 5.0 inches

CHARGER
Level 1:
Location: On-board
Type: Conductive
Input Voltages: 115/230 VAC
Level 3:
Location: Off-board
Type: Conductive
Input Voltages: 208 VAC 3-Phase 240 VAC 1-Phase

PERFORMANCE STATISTICS

Acceleration (0-20 mph) @ 332 lbs Payload
At 100% SOC: 5.8 seconds
At 50% SOC: 8.1 seconds
Performance Goal: 6.0 seconds

Maximum Speed @ 170 lbs Payload
(FMVSS 49 CFR 571.500 S5.a)
At 100%: 24.9 mph
Performance goal < 25 mph

Maximum Speed @ 332 lbs Payload
At 100% SOC: Top Speed: 24.8 mph
At 50% SOC: Top Speed: 24.7 mph

Maximum Speed Range[1]
Range: 40.4 miles
Energy Used: 6.85 kWh
Average Power: 4.17 kW
Efficiency: 169.6 Wh-DC/mile
Specific Energy: 24.67 Wh/kg
Performance goal > 25 miles

Braking From 20 mph
Controlled Dry: 19.2 feet

Gradeability (Calculated)
Maximum Speed @ 3%: 20.5mph
Maximum Speed @ 6%: 18.2 mph
Maximum Grade: 34.0 %

Charging Efficiency:
Efficiency: 268.1 Wh-Ac/mi
Energy Cost: @ $0.10/kWh: $0.026/mi

Level 1 Charger
Max Ground Current: <0.01 mA
Max Battery Leakage : <0.01 MIU
Max DC Charge Current: 12.2 A
Max AC Charge Current: 9.05 A
Peak AC Demand: 1.15 kW
Time to Recharge:
To 80%: 7.4 Hours
To 100%: 9.6 Hours
To Complete: 14.7 Hours
Performance Goal: 100% SOC within 12 hours

Level 3 Charger[3]
Max Ground Current: <0.01 mA
Max Battery Leakage : <0.01 MIU
Max DC Charge Current: 103.2 A
Max AC Charge Current: 36.4 A
Peak Demand: 11.83 kW
Time to Recharge:
To Complete[1,4]: 1.3 Hours, 80% of Ahr Discharged

TEST NOTES:
1. Vehicle started with 100% SOC and was operated at maximum attainable speed until 20 mph could no longer be maintained.
2. As delivered payload was 1122 Lbs.
3. Level 3 charging was completed using 208 VAC 3-Phase input voltage.
4. Hours were calculated at time that charger indicated completion.

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

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

ZENN Motor Company
2008 ZENN 2-passenger

VEHICLE SPECIFICATIONS

Base Vehicle: 2008 Zenn Cars Zenn 2-Passenger
VIN: ZFHAS15A68S001001
Seatbelt Positions: Two
Standard Features:
Front Wheel Drive
Front Disc and Rear Disc Brakes
Regenerative Braking With Coast Down and Over Speed
Three-Point Safety Belts
Speedometer
Odometer
State-Of-Charge Meter
Back-up Alarm
On Board Battery Charger

BATTERY
Manufacturer: Discover
Type: EV31A-A Sealed Lead Acid
Number of Modules: 6
Weight of Modules: 32 kg
Weight of Pack(s): 192 kg
Pack(s) Location: Under Rear Floor and Front Hood
Nominal Module Voltage: 12V
Nominal System Voltage: 72V
Nominal Capacity (C/1): 63 Ah

TIRES
Tire Mfg: Kleber
Tire Model: Viaxer
Tire Size: P145/70R13 71T
Tire Pressure: 30 psi
Spare Installed: No

WEIGHTS
Design Curb Weight: 1200 lb
Delivered Curb Weight: 1404 lb
Distribution F/R: 53/47 %
GVWR: 1807 lb
GAWR F/R: 815/992 lb
Payload: 403 lb[2]
Performance Goal: 400 lb

DIMENSIONS
Wheelbase: 81.8 inches
Track F/R: 55.5/55.5 inches
Length: 120.8 inches
Width: 58.0 inches
Height: 55.9 inches
Ground Clearance: 7.25 inches
Performance Goal: 5.0 inches

CHARGER
Level 1:
Location: On-board
Type: Conductive
Input Voltages: 115/230 VAC

PERFORMANCE STATISTICS

Acceleration (0-20 mph) @ 332 lbs Payload
At 100% SOC: 5.3 seconds
At 50% SOC: 5.2 seconds
Performance Goal: 6.0 seconds

Maximum Speed @ 170 lbs Payload
(FMVSS 49 CFR 571.500 S5.a)
At 100%: 25.0 mph
Performance goal ≥ 25 mph

Maximum Speed @ 332 lbs Payload
At 100% SOC: Top Speed: 25.0 mph
At 50% SOC: Top Speed: 25.0 mph

Maximum Speed Range[1]
Range: 64.6 miles
Energy Used: 6.38 kWh
Average Power: 2.38 kW
Efficiency: 98.76 Wh-DC/mile
Specific Energy: 33.2 Wh/kg

Braking From 20 mph
Controlled Dry: 20.0 feet

Gradeability (Calculated)
Maximum Speed @ 3%: 24.7 mph
Maximum Speed @ 6%: 23.4 mph
Maximum Grade: 23 %

Charging Efficiency:
Efficiency: 139.3 Wh-Ac/mi
Energy Cost: @ $0.10/kWh: $0.013/mi

Level 1 Charger
Max Ground Current: <0.01 mA
Max Battery Leakage : <0.01 MIU
Max DC Charge Current: 17.9 A
Max AC Charge Current: 12.6 A
Peak AC Demand: 1.51 kW
Time to Recharge:
To 80%: 6.7 Hours
To 100%: 9.4 Hours
To Complete: 14.2 Hours
Performance Goal: 100% SOC within 12 hours

TEST NOTES:
1. Vehicle was operated at maximum attainable speed until 20 mph could no longer be maintained.
2. As delivered payload was 403 Lbs.
3. Hours were calculated at time that charger indicated completion.

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

Neighborhood Electric Vehicles (NEV)

Basic results for some vehicles tested

Make/Model	Max Range (mi)	Max Speed (mph)	Recharge time (hrs)
2008 Zenn 2 passenger	65	25	9 - 14
2007 GEM 6 passenger	40	25	9 - 14
2007 GEM Long bed	50	25	10 - 14
2005 GEM 4 passenger	41	24	7
2005 GEM 2 passenger	44	23	7
2005 GEM Long bed	41	23	7
2005 GEM Short bed	37	24	6
2002 Th!nk Neighbor 2 Passenger	39	24	8
2002 Th!nk Neighbor 4 Passenger	33	23	8
2001 Frazer-Nash Car	31	25	1
2001 Frazer-Nash Truck	33	25	1

Hydrogen
and
Compressed Natural Gas (CNG)
Internal Combustion Engine
Vehicle Testing

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

HC=Total Hydrocarbons

NOx=Oxides of Nitrogen

CH_4=Methane

CO=Carbon Monoxide

CO_2=Carbon Dioxide

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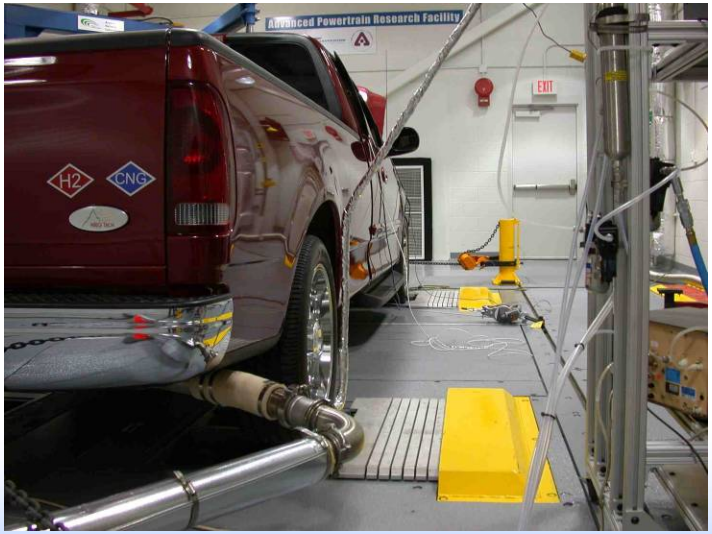
50% HCNG F150 Emissions Testing

- **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
CO_2 = carbon dioxide
NOx = oxides of nitrogen



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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)

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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.

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Hydrogen and CNG Infrastructure

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 by electrolysis**
- **Hydrogen & CNG fueling**

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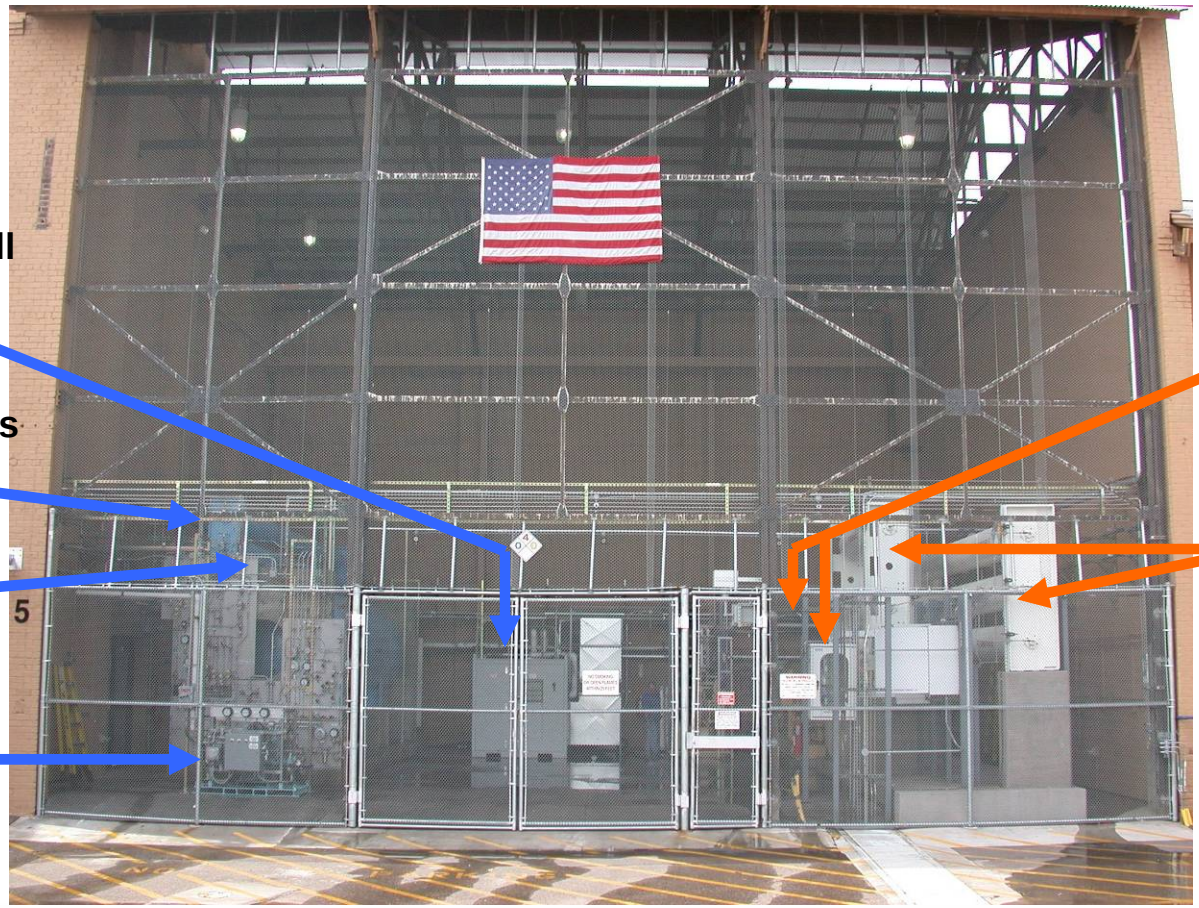
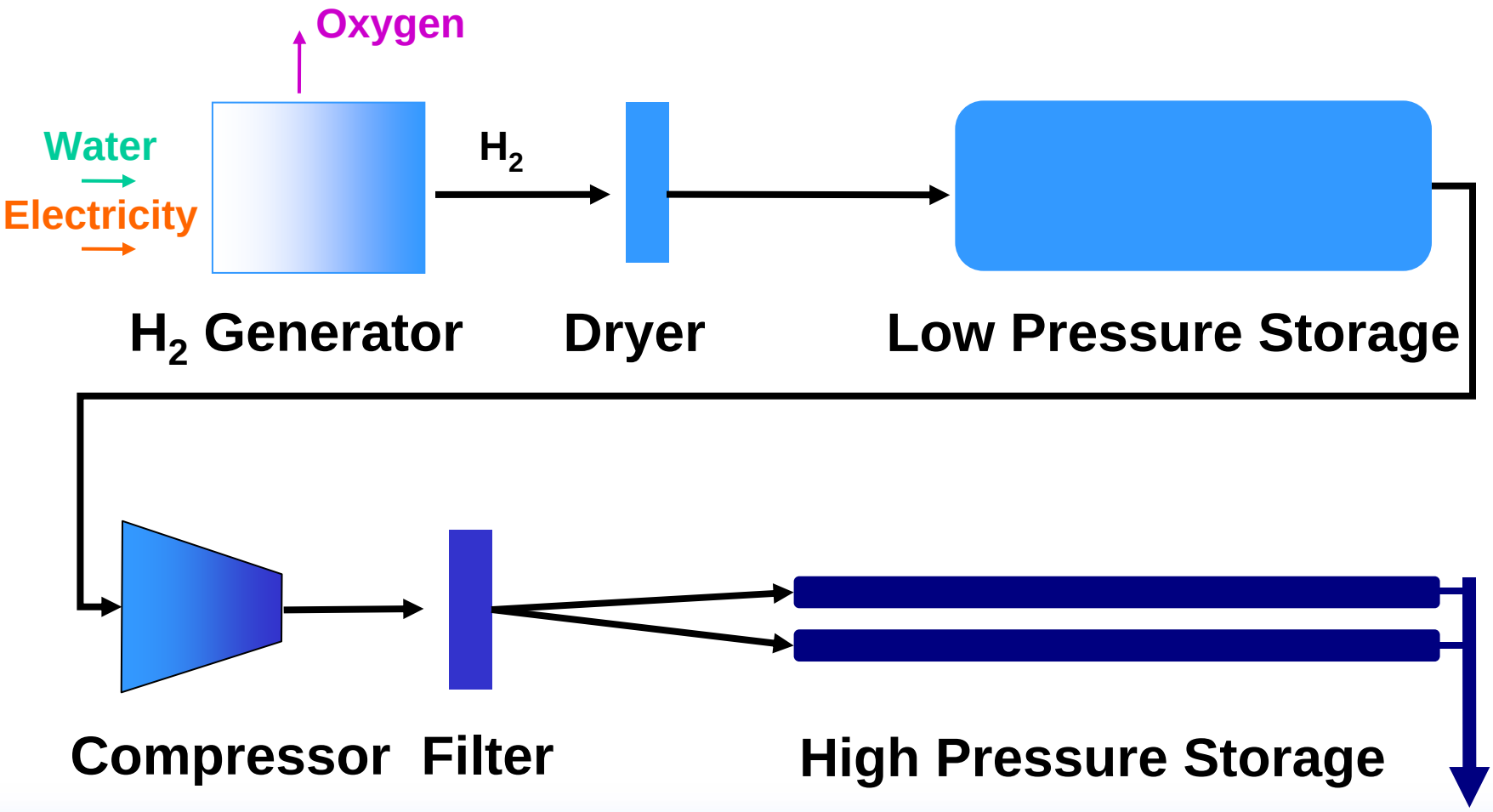
Pilot Plant - Layout



Pilot Plant - Hydrogen Subsystems



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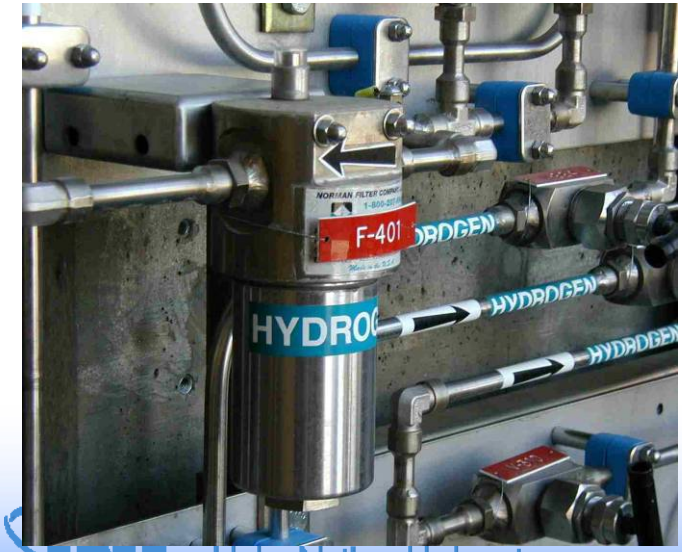
Pilot Plant – Hydrogen Subsystems cont'd

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



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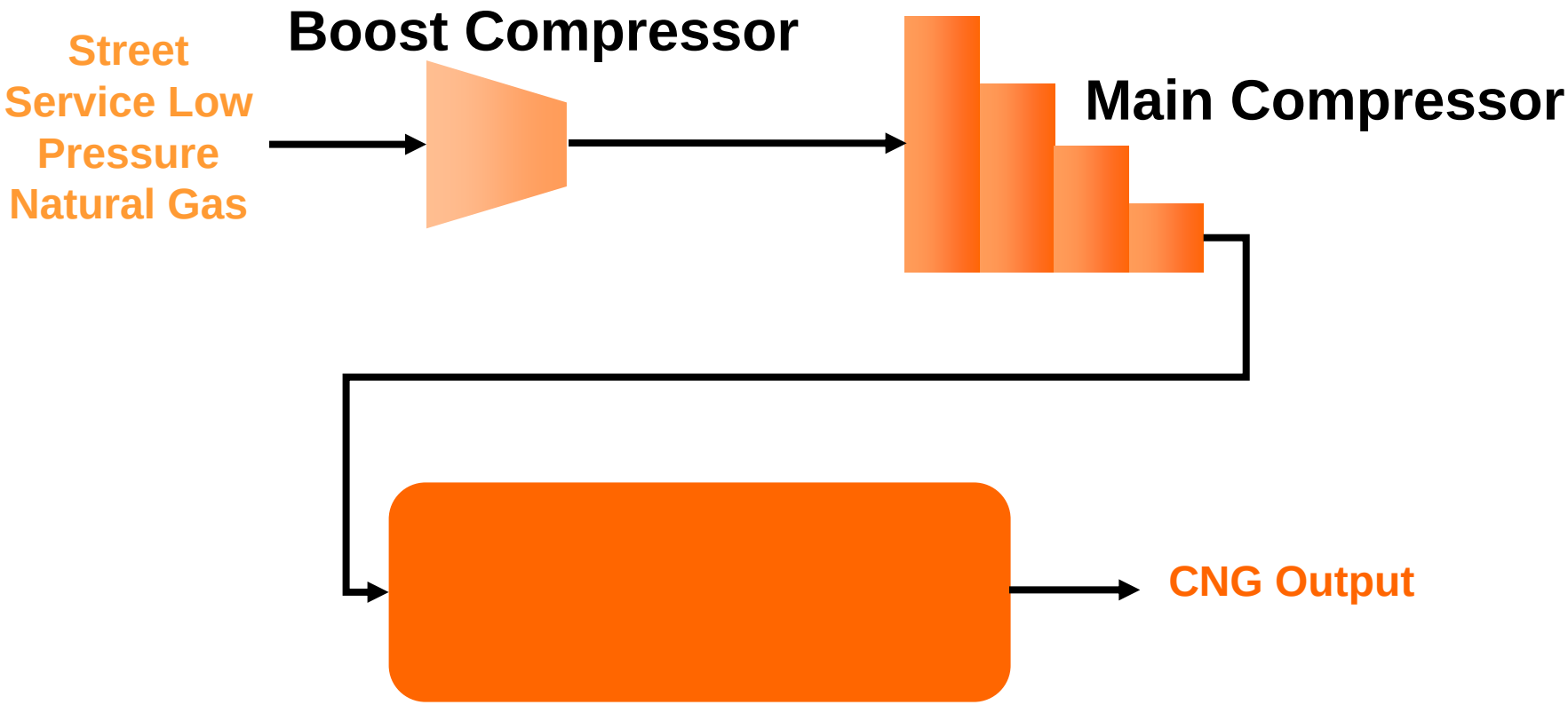
Pilot Plant - Hydrogen Subsystems cont'd

- 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 Subsystems



Pilot Plant - CNG Subsystems 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

- 100% H_2, 100% CNG, blends of HCNG
- Includes metering & electronic billing interface
- Fully permitted for motor fuel dispensing
- Public access

Trade-offs

- Vehicle
  - Cost
  - Performance (acceleration, range, fuel efficiency, etc)
  - Robustness (performance and reliability under all conditions
    - cold and hot temps is big challenge!
  - Safety
- Refueling / recharging Infrastructure
  - Cost
  - Availability
- Unintended consequences -- “Robbing Peter to pay Paul”
  - Overall economic impact
  - Trading one dependence for another

Broader picture

- Efficiency improvements possible without new technology!
- Market trend shifting
  - Smaller vehicles
  - Right size vehicle for purpose (we still need trucks)
- Automakers will improve conventional vehicles
  - Reduce weight
  - Improve engine, driveline efficiency
  - Improve aerodynamics (function over form?)

Broader picture

- **Best MPG is “n/a”**
  - **Public transit, bicycle, ride sharing**

Acknowledgement

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Tien Duong, Lee Slezak and Ro Sullivan

Additional Information

http://avt.inl.gov
or
http://www1.eere.energy.gov/vehiclesandfuels/avta/

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Discussion points

- What can small cities do?
  - Incentive ideas
    - Preferential parking
  - Example cities
  - Encourage market / public
  - Prepare for infrastructure
  - Encourage green buildings
  - Encourage green business

- Do you know where your power comes from?
- Do you know what you pay in gas? Electricity?
- Where can you plug in?