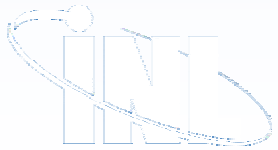
U.S. Department of Energy's Vehicle Technologies Program -

Advanced Vehicle Testing Activity's HEV, NEV, HICE, and PHEV Testing Results and Resources

Jim Francfort

Clean Cities National Leadership Retreat
Big Sky, Montana – September 2008

Idaho National Laboratory



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AVTA Background

- **The Advanced Vehicle Testing Activity (AVTA) is conducted for DOE (Lee Slezak) by the Idaho National Laboratory (INL) and Electric Transportation Engineering Corporation (ETEC), with Argonne National Laboratory providing testing support**

- **AVTA Goal**
  - **Provide vehicle and fueling infrastructure benchmark data to technology modelers, research and development programs, and target and goal setters**
  - **Assist fleet managers (often the early adaptors of alternative fuel vehicles) in making informed vehicle purchase, deployment and operating decisions**

AVTA Testing History

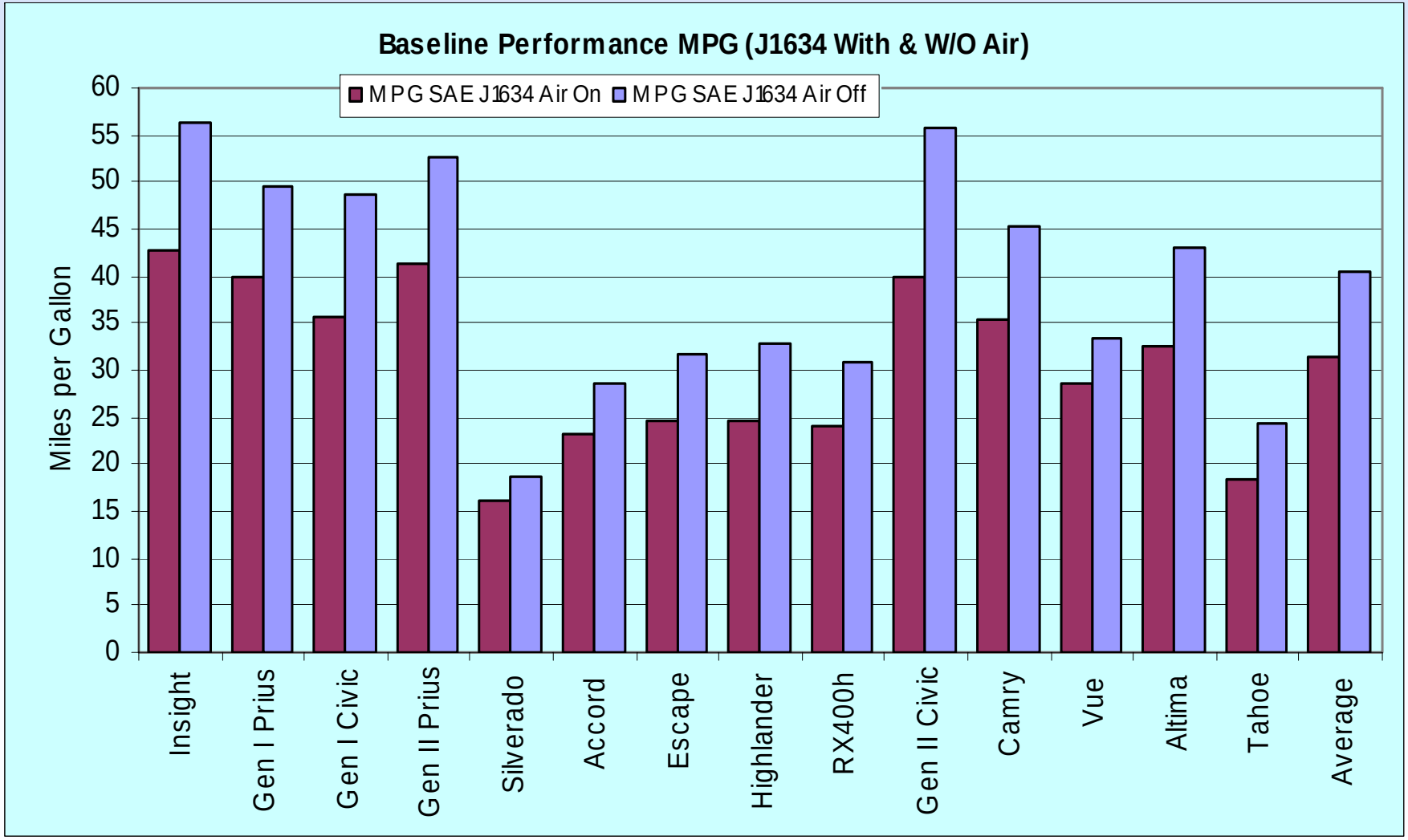
- Plug-in hybrid electric vehicles
  - 9 models, ~75 vehicles
- Hybrid electric vehicles
  - 14 models, 4 million test miles
- Hydrogen ICE (internal combustion engine) vehicles
  - 7 models, 400,000 test miles

- 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

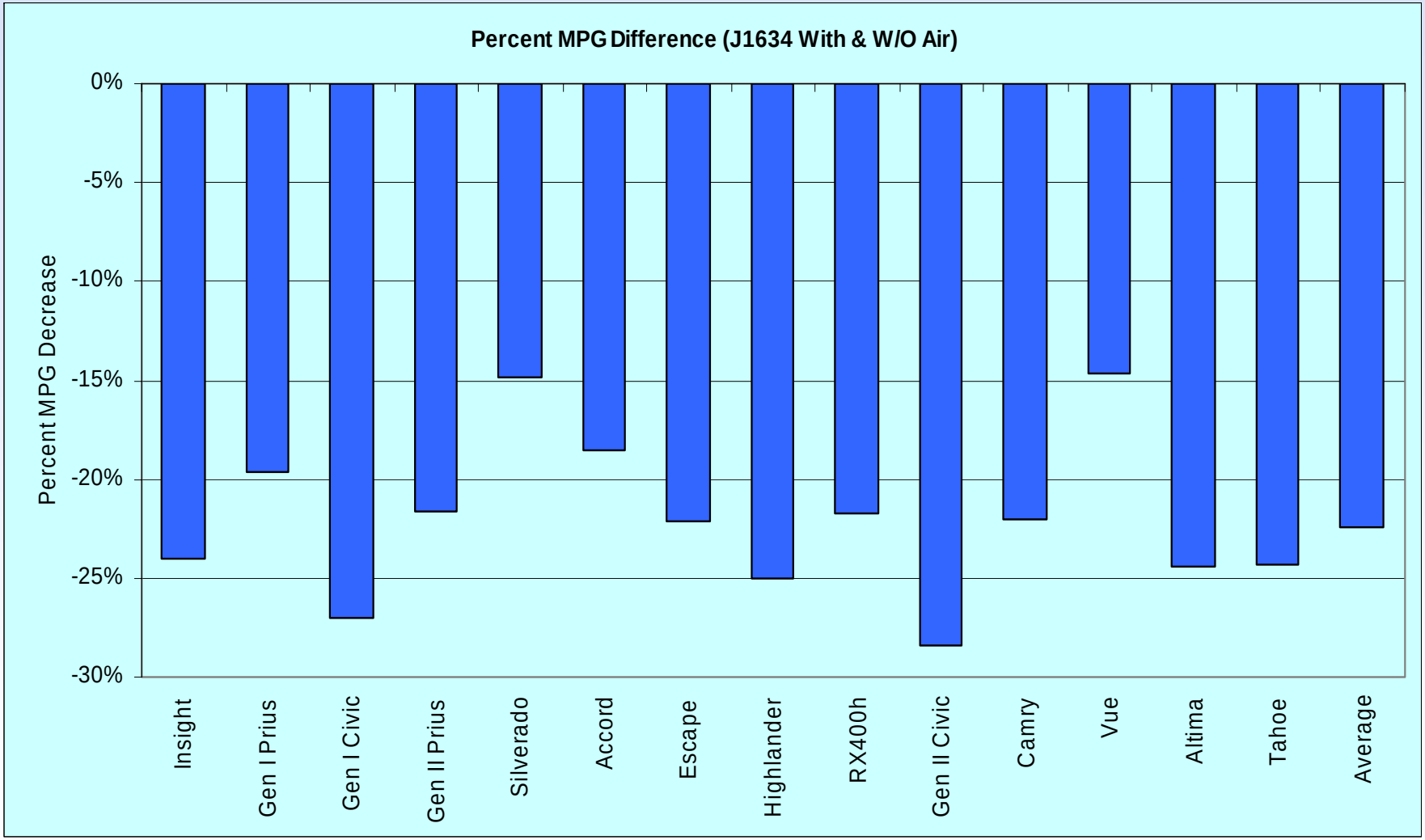
Hybrid Electric Vehicles (HEVs) in Testing

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	

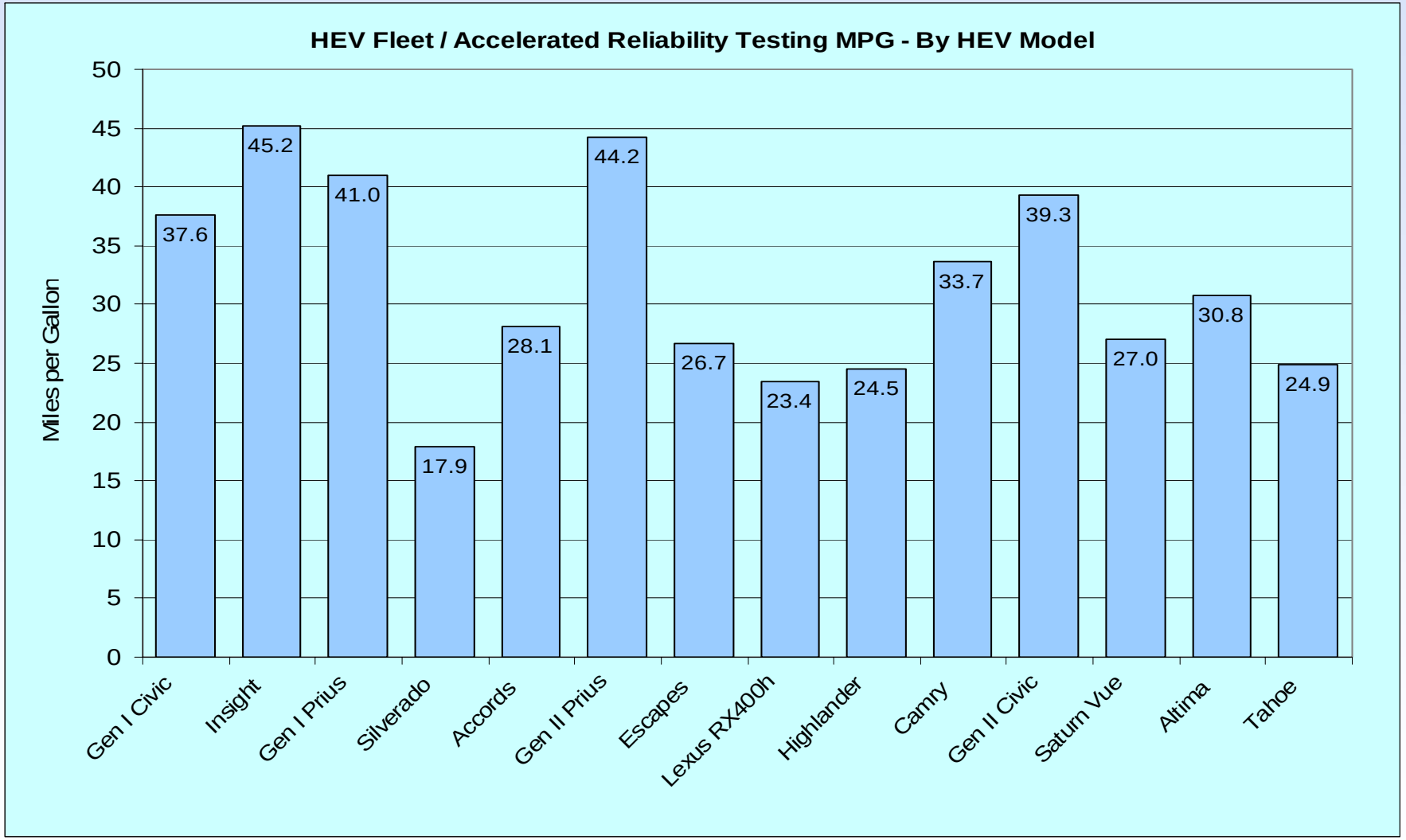
HEVs Baseline Performance Tested



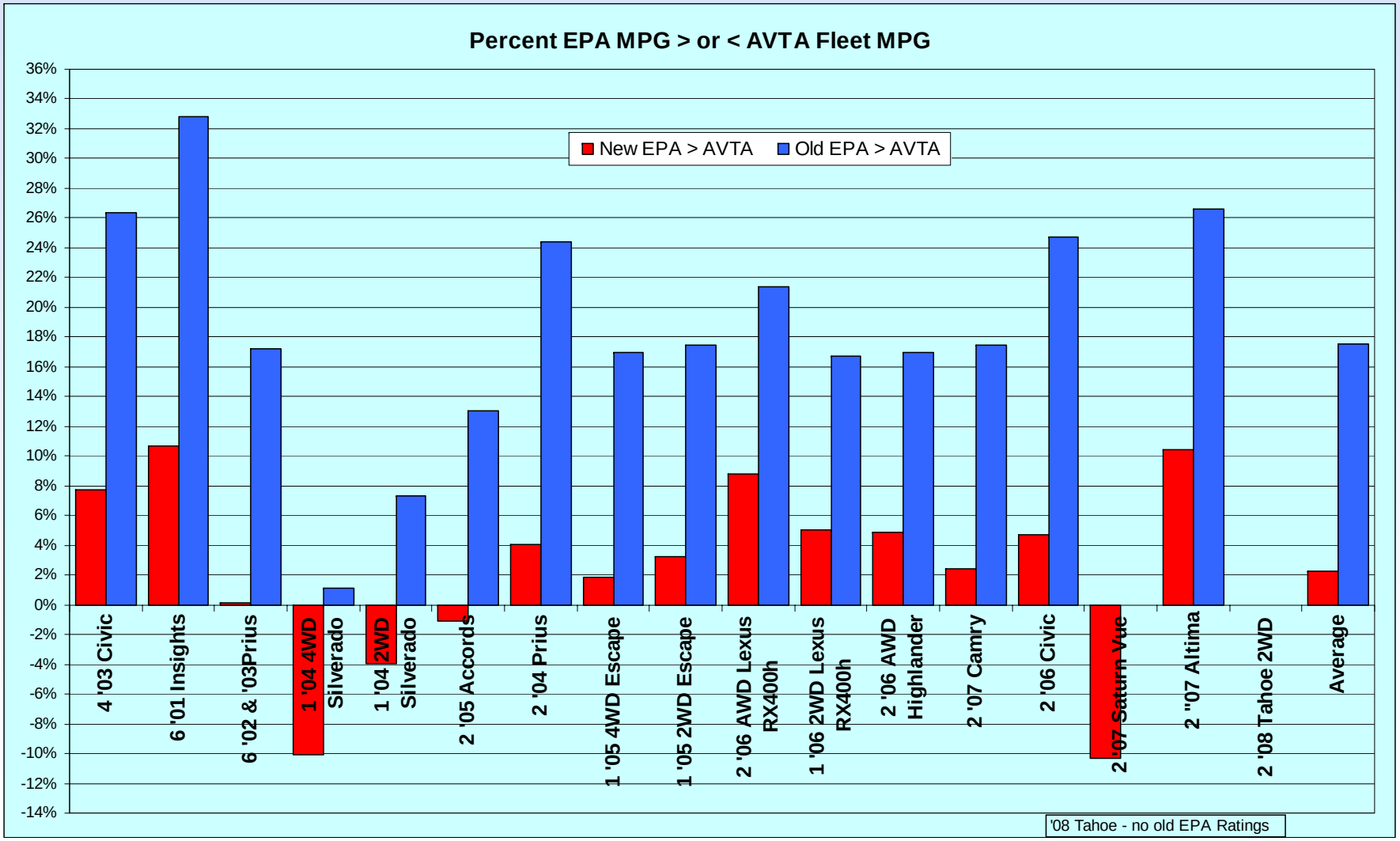
Percent HEV MPG Decrease - A/C on



4 Million HEV Test Miles – MPG by model



AVTA HEV Fleet MPG and EPA MPG



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

U.S. Department of Energy
Energy Efficiency and Renewable Energy
Bringing you a prosperous future where energy is clean, abundant, reliable, and affordable

NEVAmerica Testing – 21 models tested


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

2007 Global Electric Motorcars eL XD

VEHICLE SPECIFICATIONS

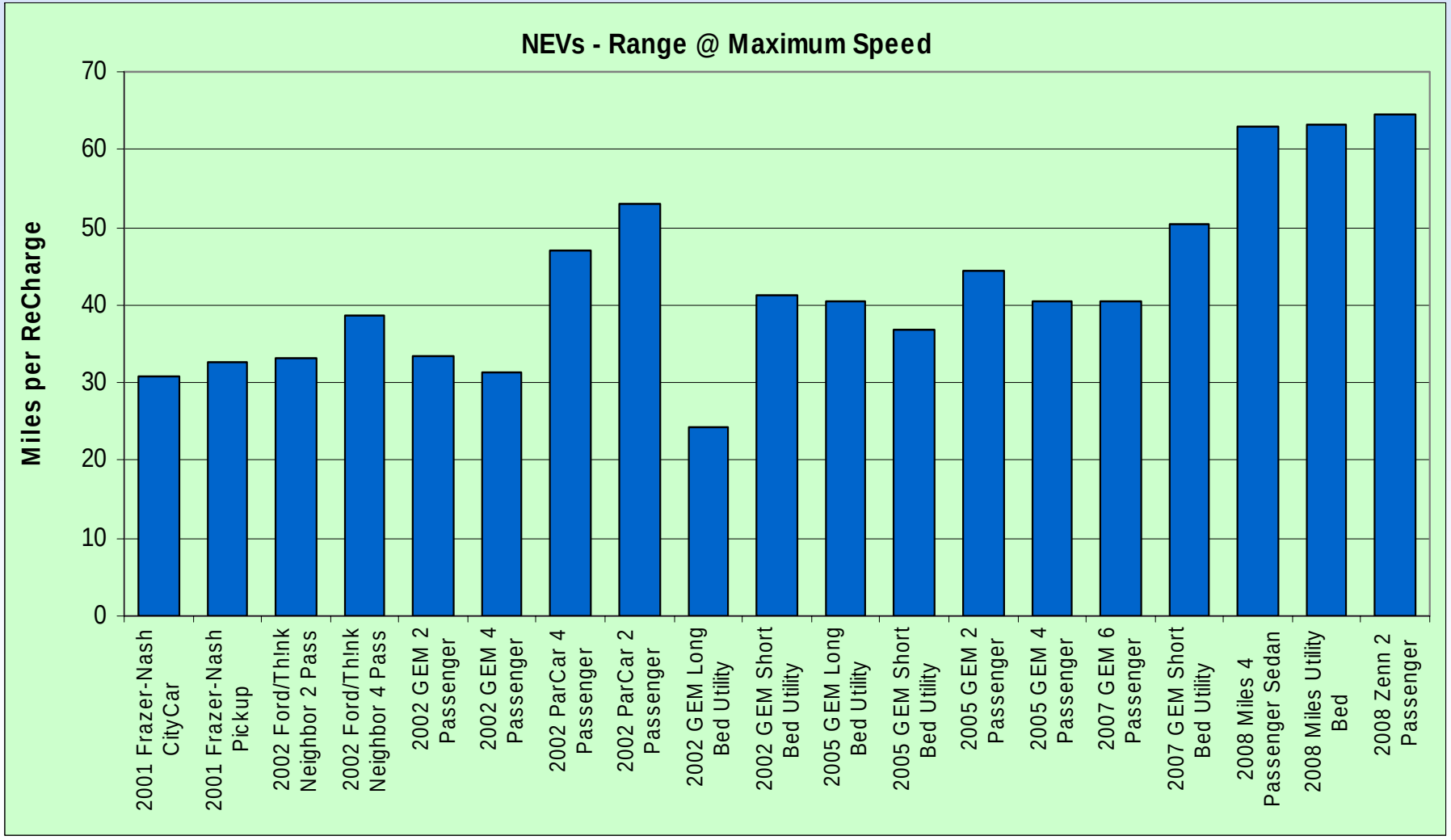
PERFORMANCE STATISTICS

- CARB now requires all Neighborhood Electric Vehicles (NEVs) be tested by the AVTA
- 5 NEVs completed testing in 2008
  - 2 Miles Automotive: sedan & pickup
  - 1 Zen sedan
  - 2 GEMs
- 15 NEVs previously tested:
  - 8 Gems, 2 Th!nk Neighbors, 2 Frazier Nashes, 2 ParCars, 1 Katech

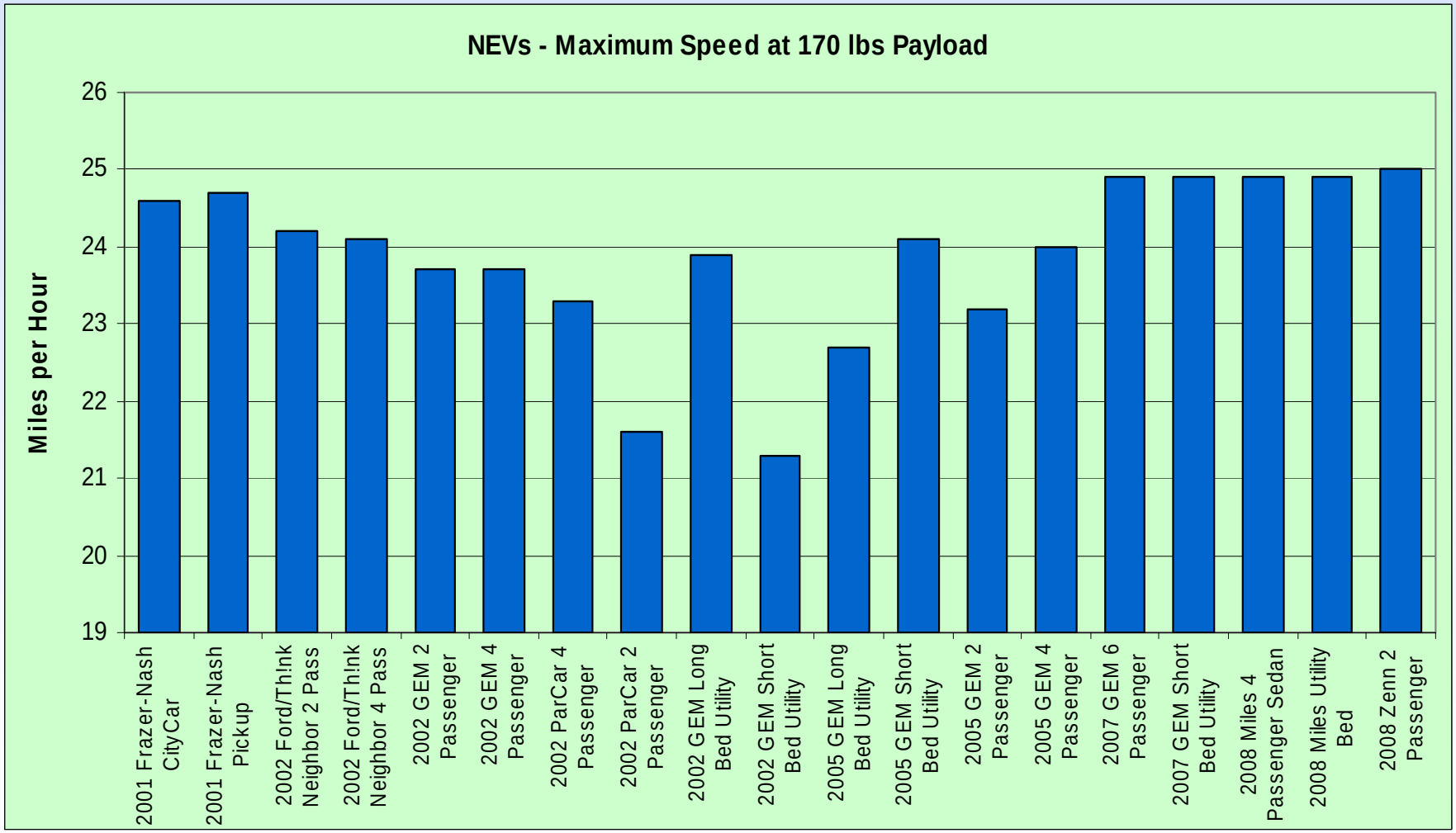
NEVAmerica Testing Includes

- NEV test variables
  - Acceleration 0 to 20 mph
  - Maximum speed
  - Range per charge at maximum speed
  - Braking from 20 mph
  - Gradeability
  - Charging Efficiency (Wh-AC/mile and cents/mile)
  - Level 1 and 3 (if equipped) charger
    - Maximum AC and DC current and demand
    - Time to recharge to 80%, 100% and complete
- Vehicle specifications
  - Batteries, tires, charger, dimensions, and weights

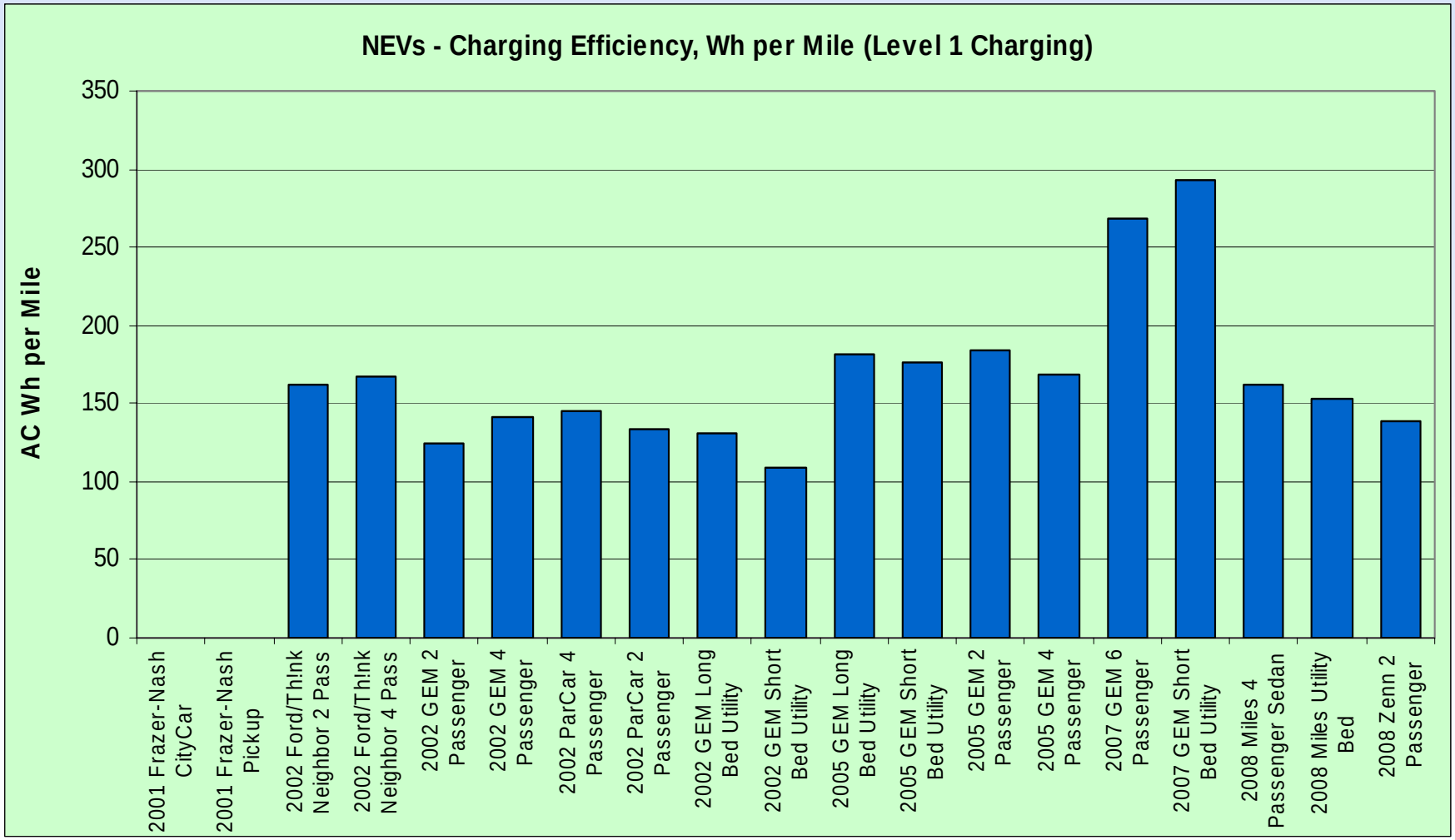
NEV Testing Results – Range per Charge



NEV Testing Results – Maximum Speed



NEV Testing Results – Wh per Mile



Hydrogen Internal Combustion Engine (HICE) Vehicle Testing

- Assess HICE vehicle safety, reliability and operating characteristics
- Identify any engine or vehicle system degradations
- Eight 100% HICE pickups (Roush CNG conversions), equipped with data loggers, fueled at the Integrated Waste Hydrogen Utilization Project in Vancouver, BC
- 7 HICE and HCNG models tested to date
- Operating APS Alternative Fuel Pilot Plant since 2002

HICEVAmerica Roush Testing Fact Sheet

HICEV AMERICA

US DOE ADVANCED VEHICLE TESTING ACTIVITY

2005 Hydrogen ICE[1] Truck

VEHICLE SPECIFICATIONS

CONVERSION VEHICLE
Base Vehicle: 2005 Chevy Silverado
VIN: 1GCGC13U95F889816
Seatbelt Positions: Six
Features:
6.0L V8
Fuel Injected
4 Speed Automatic Transmission
Power Locks and Windows
Front and Rear Disk Brakes
Rear Wheel Drive
Power Steering
Air Conditioning
AM/FM Stereo w/ CD Player
Dual Airbags

FUEL TANKS
Manufacturer: Dynetek
Model: W150/350G8
DOT Type 3[a]
Description: Carbon Fiber Wrap/ Aluminum Lined
Number of Tanks: 3
Tank Liquid Volume: 150 liters
Total Liquid Volume: 450 liters
Nominal Pressure: 5000 psi
Maximum Pressure: 6350 psi
Fuel Capacity[b]: 10.5 GGE[c]
Fueling Inlet: WEH C1C136

WEIGHTS
Base Design Curb Weight: 6300 lbs
Delivered Curb Weight: 5825lbs
Distribution F/R: 53/47%
GVWR: 8600 lbs
GAWR F/R: 4410/6000 lbs
Payload: 2775 lbs
Requirement: ≥ 400 lbs

DIMENSIONS
Wheelbase: 153.0 inches
Track F/R: 68.6/66.0 inches
Length: 237.2 inches
Width: 79.7 inches
Height: 77.0 inches
Rear Overhang: 48.6 inches
Ground Clearance: 7.4 inches
Requirement: ≥ 5.0 inches

TIRES
Tire Mfg: Bridgestone
Tire Model: V-Steel 265
Tire Size: 245/75 R16
Tire Pressure F/R: 50/80psi
Spare Included: Yes

TEST NOTES:

PERFORMANCE STATISTICS

Acceleration

ACCELERATION 0-60 mph
Acceleration Time: 21.98 seconds
Performance Goal: 13.5 seconds

MAXIMUM SPEED
Speed At One Mile: 79.2[a] mph
Performance Goal: ≥ 70 mph
Speed At Quarter Mile: 60.2 mph

CONSTANT SPEED FUEL ECONOMY
Distance Traveled: 61.78 miles
Average Speed: 44.94 mph
Fuel Consumed: 2.288[a] GGE[c]
Fuel Economy: 27.0 miles/GGE[c]

SAE J1634 DRIVING CYCLE FUEL ECONOMY (A/C OFF)
Distance Traveled: 35.2 miles
Fuel Consumed: 1.91[a] GGE[c]
Fuel Economy: 17.7 miles/GGE[c]

SAE J1634 DRIVING CYCLE FUEL ECONOMY (A/C ON)
Distance Traveled: 35.2 miles
Fuel Consumed: 2.22[a] GGE[c]
Fuel Economy: 15.2 miles/GGE[c]

BRAKING FROM 60 mph
Controlled Dry: 246.8 feet

GRADEABILITY (CALCULATED)
Maximum Speed @ 3%: 62.6 mph
Maximum Speed @ 6%: 52.1 mph
Maximum Grade: 33.2%

- **22 seconds 0 to 60 mph acceleration**
- **27 miles/GGE at 45 mph constant speed**
- **SAE J1634 17.7 miles/GGE AC off and 15.2 miles/GGE AC on**
- **79 mph maximum speed at 1 mile**
- **Three carbon fiber wrap / aluminum lined fuel tanks**
  - **5000 psi nominal**
  - **10.5 gasoline gallon equivalents (GGE)**

etec Idaho National Laboratory U.S. DEPARTMENT OF ENERGY

9 PHEVs Models in Testing/Demonstrations

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: 4.4 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[5]
Cold Start Charge Depleting[3]:
Fuel Economy: 146.72 MPG
A/C kWh Consumed[7]: .147 kWh/mi
Charge Depleting[4]:
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[3]:
Fuel Economy: 128.9 MPG
A/C kWh Consumed[7]: .199 kWh/mi
Charge Depleting[4]:
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)
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]

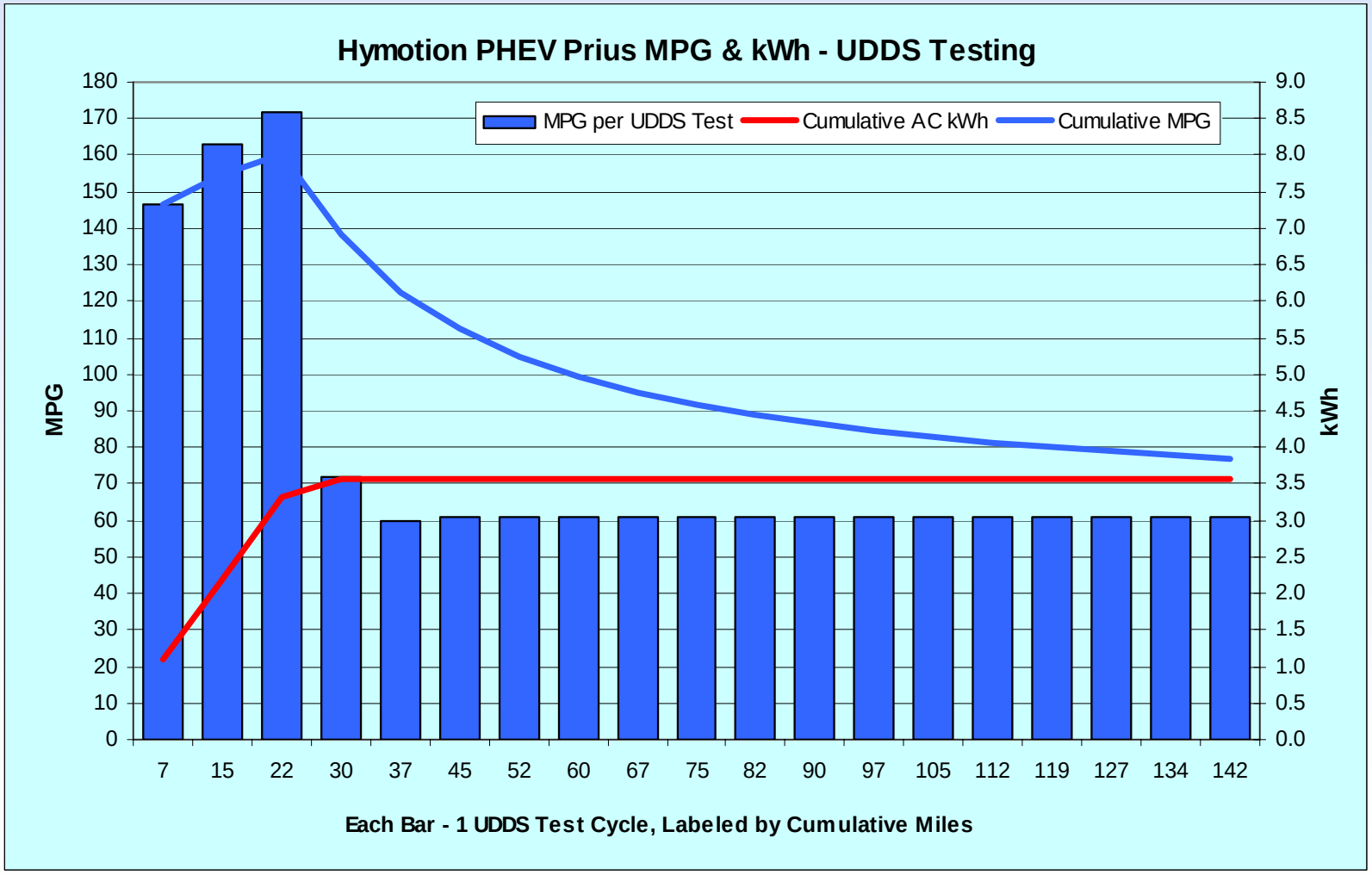
Distance (miles)	Fuel Economy (mpg)	A/C Energy Consumed (kWh)
10	87.48	1.30
20	95.27	2.64
40	86.11	3.92
60	75.79	3.92
80	70.52	3.92
100	67.36	3.92
200	61.05	3.92

TEST NOTES:

- **Most equipped with lithium traction batteries**
- **Hymotion Prius**
- **Hymotion Escape**
- **EnergyCS Prius**
- **Electrovaya Escape**
- **Hybrids Plus Escape**
- **Hybrids Plus Prius**
- **Manzanita Prius (lead acid)**
- **Ford Escape**
- **Renault Kangoo (NiCad)**

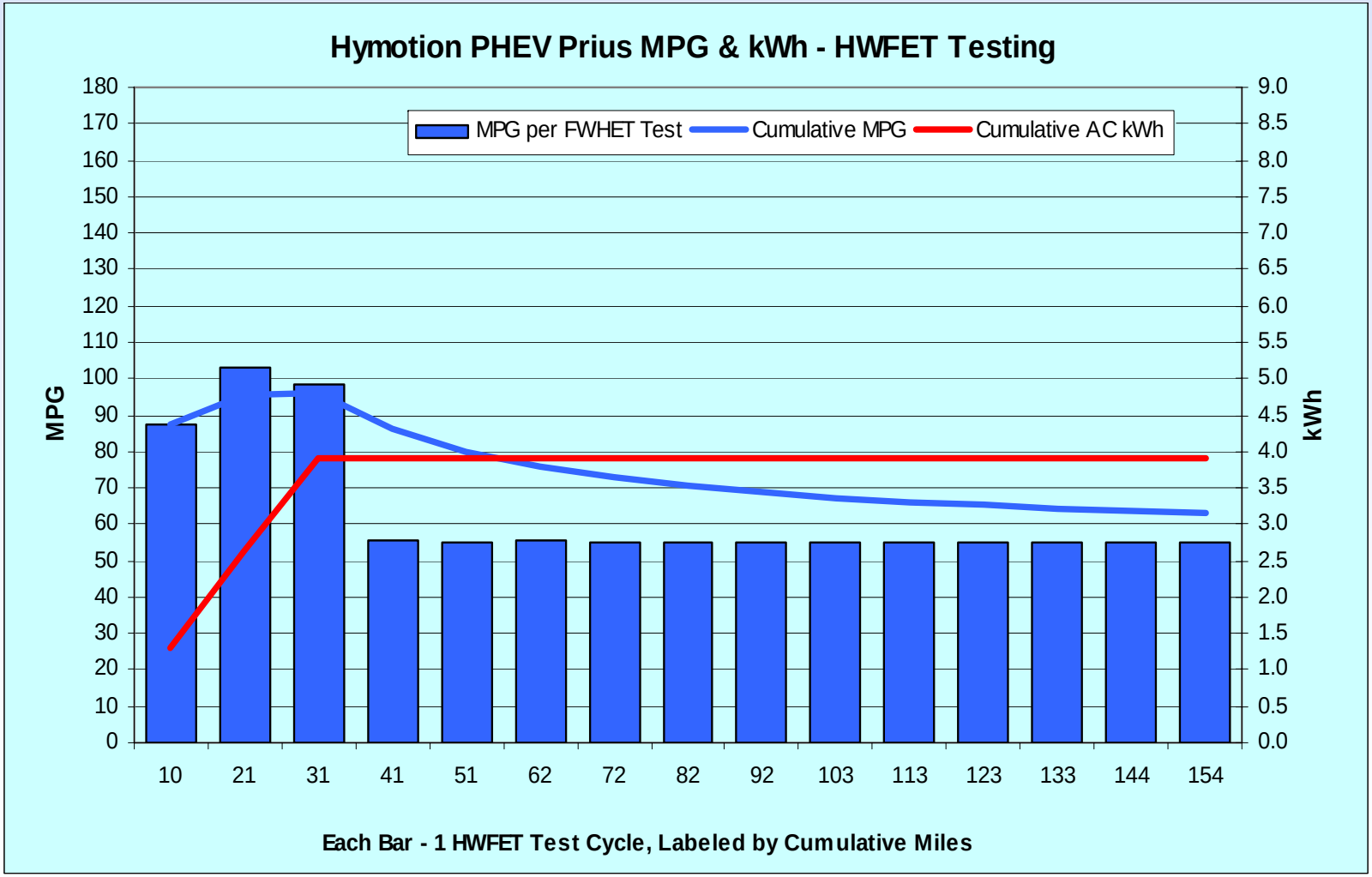
Hymotion Prius – UDDS Fuel Use

- **5 kWh A123 lithium & Prius packs – AC kWh**



Hymotion Prius – HWFET Fuel Use

- **5 kWh A123 lithium & Prius packs – AC kWh**



Hymotion Prius – 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		86.4

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

EnergyCS Prius – 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	115.58	4.78	128.1
20	1	1	8	30	600	86.21	7.95	77.9
40	4	0	12	5	200*	17.37	1.61	126.4
40	4	0	12	15	600**	26.48	11.31	54.1
40	2	2	12	5	200*	29.00	1.42	145.1
40	0	4	12	5	200*	30.00	2.43	85.5
60	2	4	12	10	600	65.00	5.90	103.7
80	2	6	12	8	640	39.04	10.09	65.8
100	2	8	12	6	600	22.67	8.81	70.8
200	2	18	12	3	600	12.98	10.46	57.8
Total	2340	2500	984	147	4840	Weighted Average		84.5

*** Rerun to 600 miles **Software updated and cells replaced. May be rerun. Each total distance slightly greater than 600 miles. HEV version = 44 mpg**

Hymotion Escape – Accelerated Testing

Cycle	Urban	Highway	Charge	Reps	Total	Electricity	Gasoline	
(mi)	(10 mi)	(10 mi)	(hr)	(N)	(mi)	AC kWh	Gals	MPG
10	1	0	4	60	600			
20	1	1	8	30	600	In	Testing	
40	4	0	12	15	600	57.51	14.91	41.1
40	2	2	12	15	600	76.29	15.99	38.7
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	26.09	17.72	33.5
Total	2340	3100	1344	162	5440	Weighted Average		

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

Electrovaya Escape – Accelerated Testing

Cycle	Urban	Highway	Charge	Reps	Total	Electricity	Gasoline	
(mi)	(10 mi)	(10 mi)	(hr)	(N)	(mi)	AC kWh	Gals	MPG
10	1	0	4	60	600			
20	1	1	8	30	600			
40	4	0	12	15	600	71.3	16.42	37.3
40	2	2	12	15	600	69.8	14.34	43.1
40	0	4	12	15	600	In	testing	
60	2	4	12	10	600	44.79	16.64	37.3
80	2	6	12	8	640	42.72	16.30	40.8
100	2	8	12	6	600	20.85	21.17	29.2
200	2	18	12	3	600			
Total	2340	3100	1344	162	5440	Weighted Average		

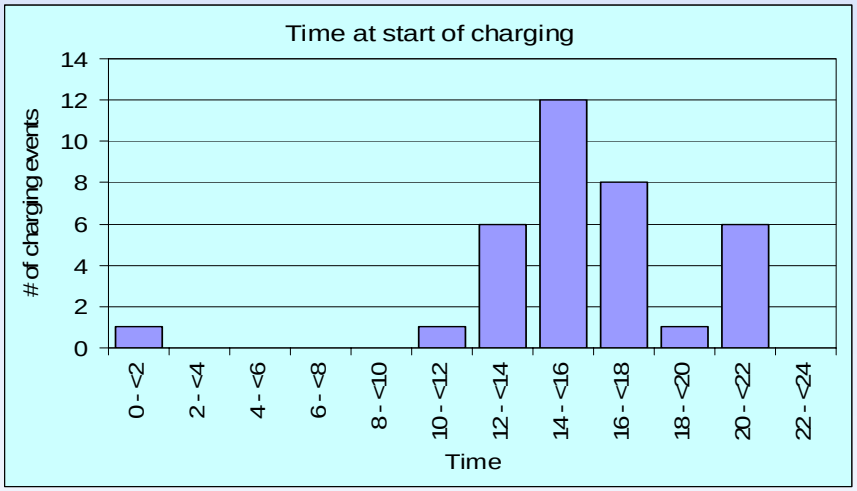
Each total distance slightly greater than 600 miles. HEV version = 27 mpg

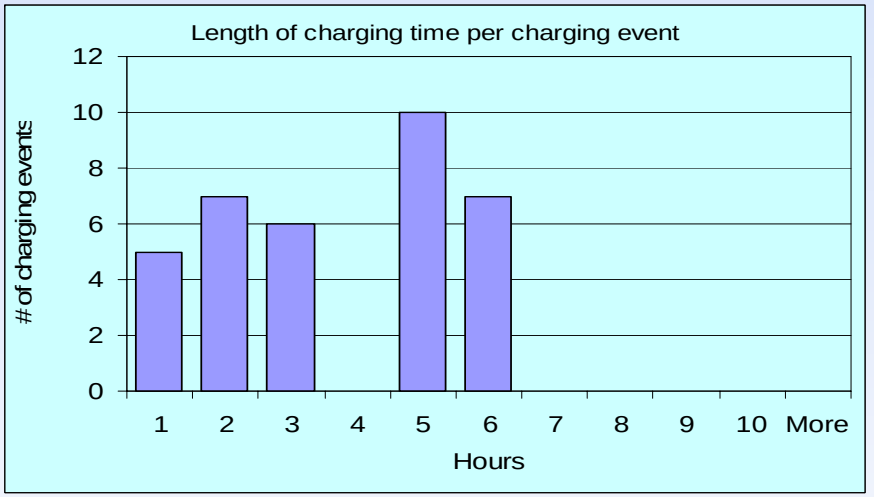
Hymotion Joint Data Collection

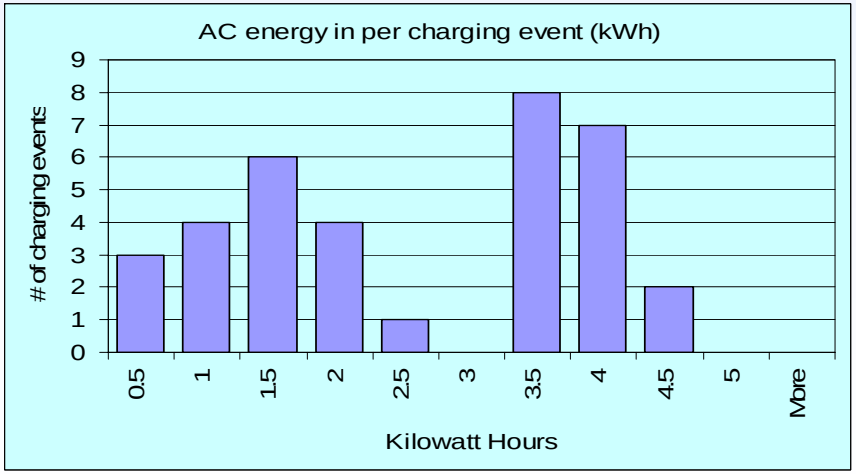
- Kvaser data loggers installed 50 PHEVs North America
- Onboard data includes vehicle performance, fuel use, and charging and driving profiles
- Participants include electric utilities, water agencies, universities, county and provincial governments:
  - Northeast: Vermont, New Hampshire, New York
  - East / South East: Toronto, Virginia, South Carolina, North Carolina, Kentucky, Florida
  - North / Central: Wisconsin, North Dakota, Indiana, Manitoba
  - Southwest: Arizona, Texas
  - West Coast: California, Oregon
- Started 2007

Single Hymotion Prius Charging Profiles

- **3 months, 2212 miles, 35 charges**

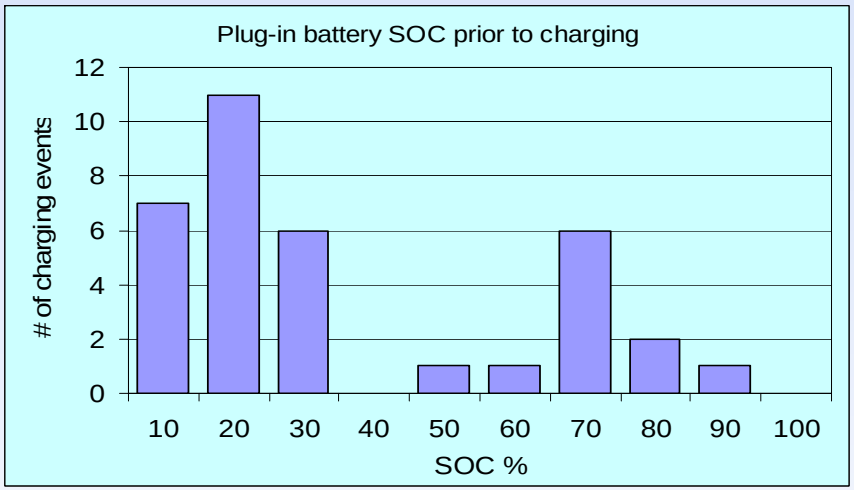


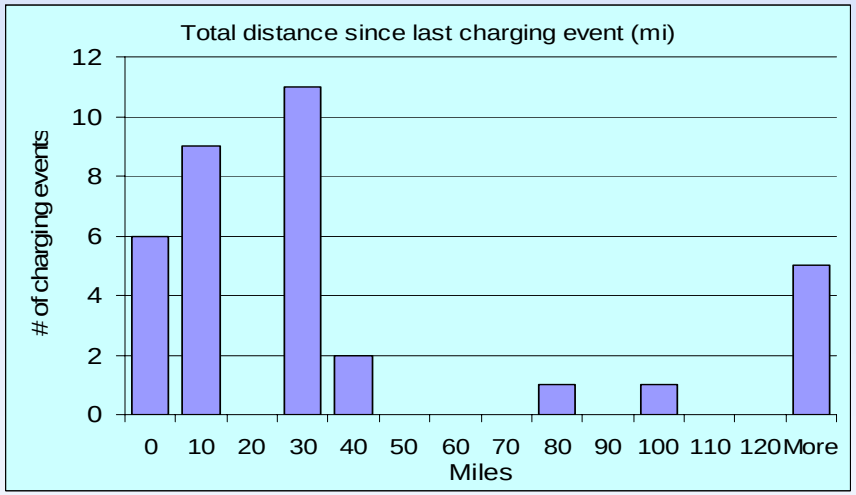


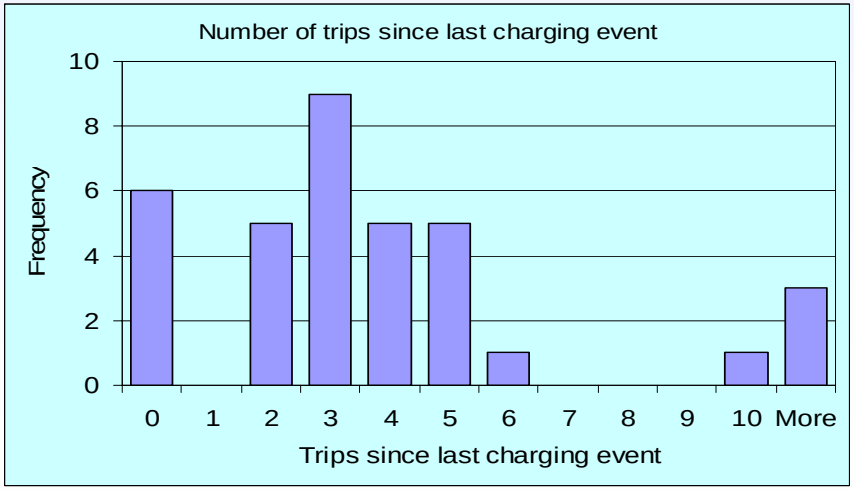


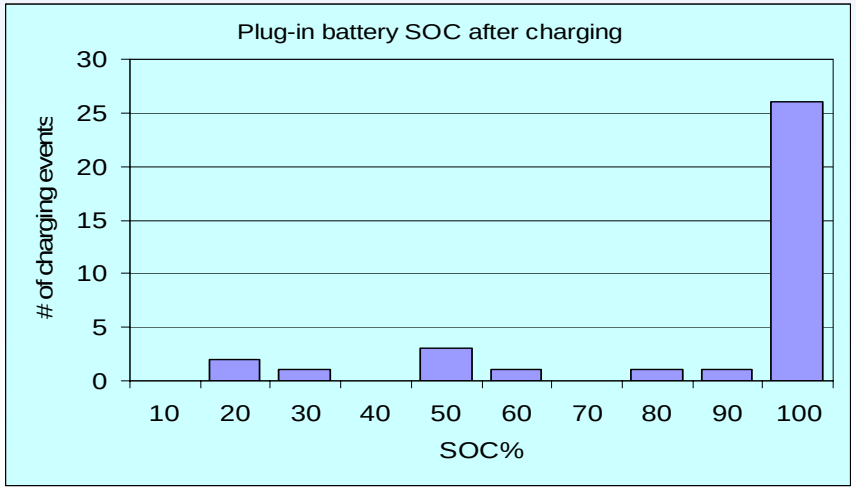
Single Hymotion Prius Charging Profiles

- **3 months, 2212 miles, 35 charges**







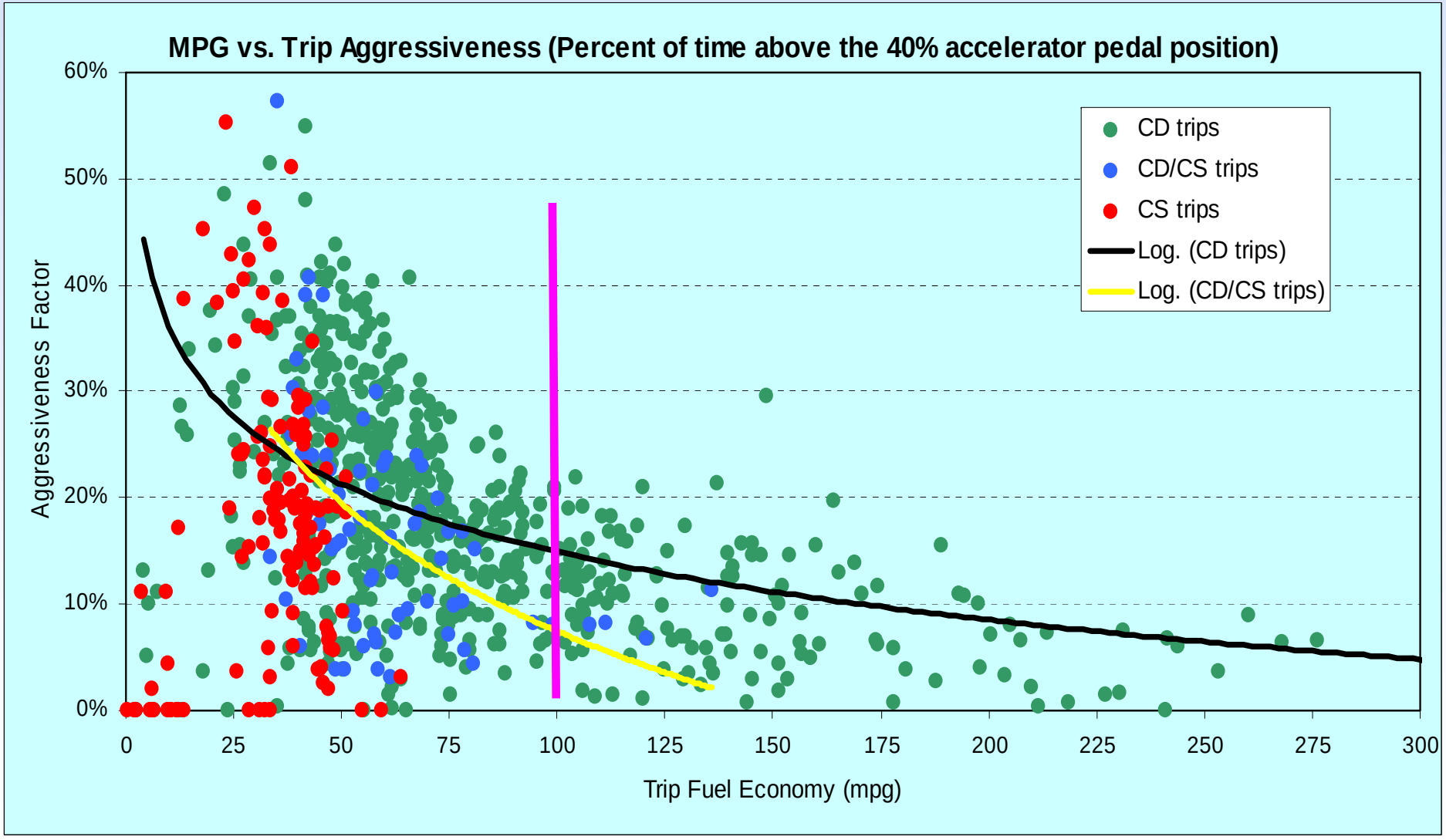


13 Hymotion Prius in May 2008 - MPG

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

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 and Aggressive Driving



NYSERDA Testing Partnership

- **AVTA is testing New York State Energy Research and Development Agency's PHEV conversions, stated 2007**
- **Fleet testing of ~20 PHEVs later CY08**

Model	Baseline Testing	Accelerated Testing
EnergyCS Prius	Completed	Near completion, restarted
Hymotion Prius	Completed	Completed
Hymotion Escape	Completed	Ongoing
Electovaya Escape	Completed (problems)	Restarted
HybridsPlus Escape	Not started	Suspended

EnergyCS Prius Data Collection

- **Provided AVTA onboard data for 12 vehicles operating in fleets in the U.S. and Canada**
- **Going forward, EnergyCS is using lithium batteries from various manufacturers**
- **~ 30 vehicles deployed (~15 North America and ~15 Europe)**

Seattle Area Demonstration

- 13 Hymotion Prius operations in partnership with:
  - City of Seattle (4)
  - King County (4)
  - Port of Seattle (2)
  - Puget Sound Clean Air Agency (3)
  - Started 4/2008, five vehicles converted to date, remainder September 2008

- City of Seattle lead time-of-day charging demonstration on above 13 Seattle area PHEVs. Includes INL battery impact analysis. Uses V2Green wireless charging control
- These and all future demonstration PHEVs are using V2Green onboard data loggers with cellular data transfer and GPS

Tacoma Power Demonstration

- Vehicle demonstration using
  - 2 Manzanita lead acid Prius, 1st quarter 2008
  - 2 Hymotion Prius adding late 2008
- Charging infrastructure study
  - After 4 PHEVs in operation, collect data on one section of administration building (800 amp, 480 volt, 3 phase load) and PHEV charging infrastructure
  - Document demand and energy profiles of PHEV charging as portion of facility profiles
  - WiFi local energy meter (LEM) data collection system

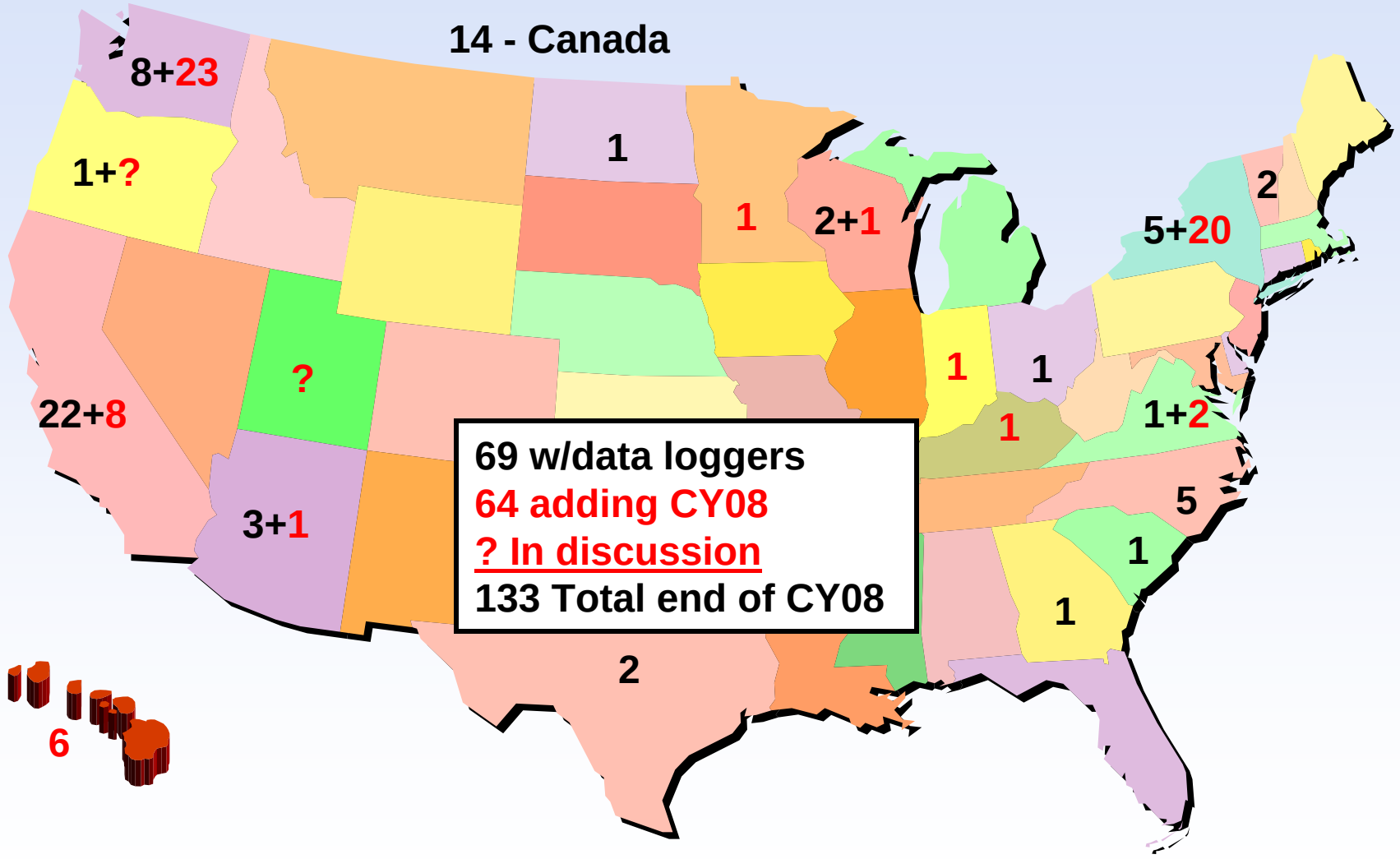
Fleet Demonstration Partners – cont'd

- **Washington State-wide, Port of Chelan leading, with 14 Hymotion Prius with:**
  - **Benton County PUD, Chelan County Public Works, City of Wenatchee, Douglas County PUD, Energy Northwest, Green IT Alliance, McKinstry, Port of Chelan, University of Washington, Walla Walla Community College and Wenatchee Valley College**
  - **Started 4/2008, 1 converted to date, more Sept. 2008**
- **University of California Davis, with 13 Hymotion Prius**
  - **Up to 70 AAA of California public drivers will each operate a vehicle for ~2 months**
  - **First study of public use of PHEVs, charging practices and locations, started April 2008**
  - **13 vehicles recently completed conversions**

Fleet Demonstration Partners – cont'd

- National Rural Electric Cooperative Association
  - Total of ten Prius and Escape PHEVs from Hymotion, EnergyCS, and Hybrids Plus operated by rural electric coop utilities, 6 converted to date, started 2007
  - Includes: Jackson Electric Membership Coop (GA), Salem Electric (OR), Four County Electric Membership Corp. (NC), Central Electric Power Coop (SC), Great River Electric (MN), and Buckeye Rural Electric Coop (OH)
- Hawaii, with 6 Hymotion Prius on Maui and Oahu
  - State of Hawaii, University of Hawaii, Hawaiian Electric Company, Maui Electric Company, Maui County, U.S. Air Force
  - Planned start 11/2008

Total PHEV Demonstrations



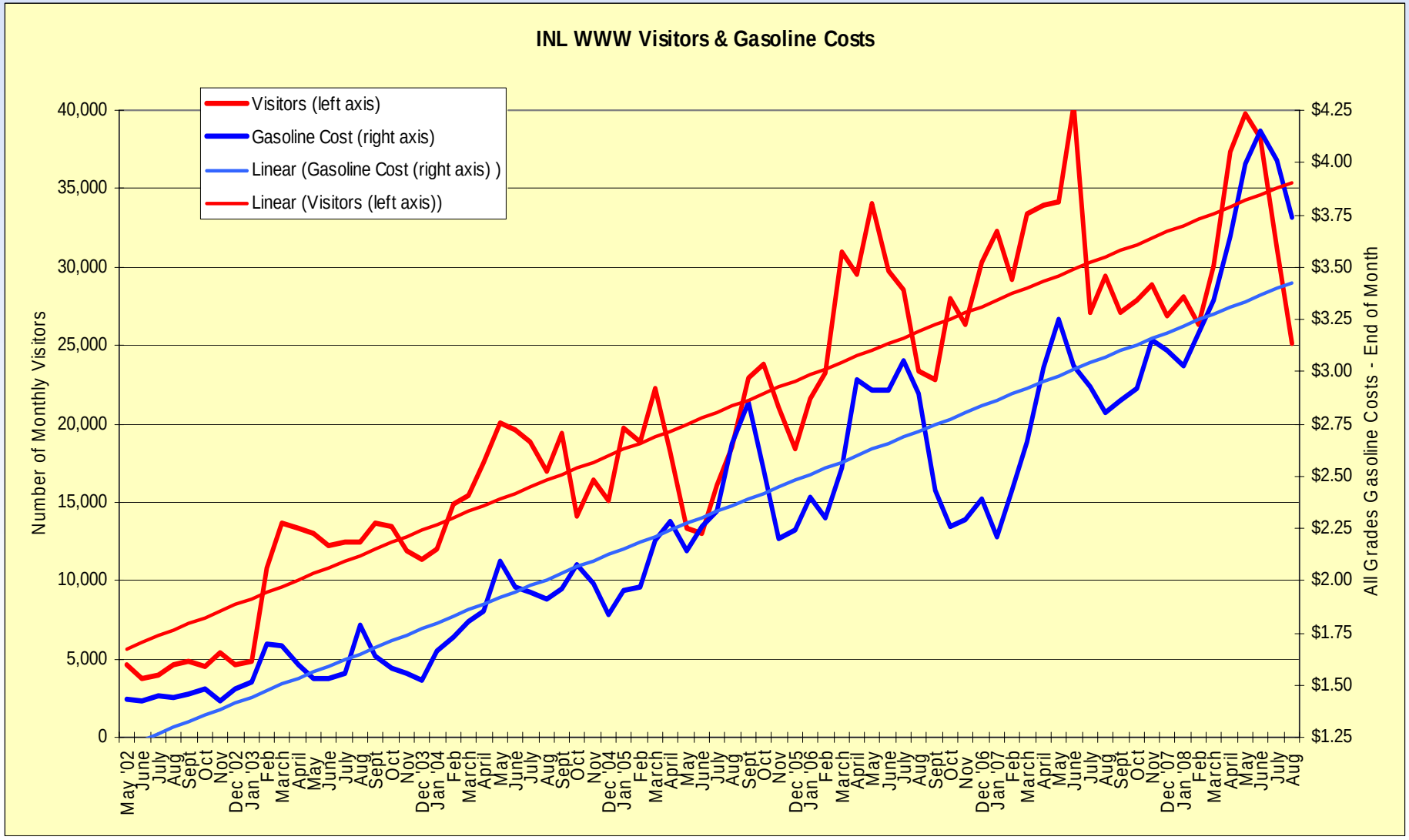
Other PHEV Testing

- **Hymotion/A123Systems V2 Prius battery hot weather vehicle/battery testing, summer 2008**
- **PHEV charging studies at three commercial facilities (Tacoma Power is one). Started 5/2008**
- **Bidirectional vehicle-to-grid (V2G) charging study with electric utilities participating. Fall 2008**
  - **6 kW and 20 kW levels, using two lithium battery PHEVs, V2Green cellular charging control, documenting infrastructure requirements and costs**
- **Conduct vehicle/battery testing on PHEVs when received via DOE's OEM PHEV solicitation**
- **Will consider other suitable PHEV conversions for vehicle/battery testing**

PHEV Charging Infrastructure

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

AVTA Webpage Use and Gasoline Costs



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Additional Information

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

INL/CON-08-14506