

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

PHEV and Other Electric Drive Testing Results and Resources

Jim Francfort

**Electric Drive Session
Alternative Fuels & Vehicles
Las Vegas, Nevada – May 2008**

This presentation does not contain any proprietary or sensitive information

AVTA Background

- **Idaho National Laboratory**
 - 890 square mile site with 3,600 staff, multi-program DOE laboratory
- The AVTA is conducted by the INL and Electric Transportation Applications (ETA), 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 in making informed vehicle purchase, deployment and operating decisions

Vehicle Testing Objectives

- **Benchmark and reduce operational uncertainties of emerging vehicle technologies**
 - **Perform independent vehicle testing in track, laboratory and on-road/fleet environments**
 - **Document battery life, charging patterns and demand profiles, vehicle operations, and fuel use**
 - **Document fueling infrastructure requirements and costs in real-world environments (both electricity and gasoline, when applicable)**
 - **Document life-cycle costs**



AVTA Testing History

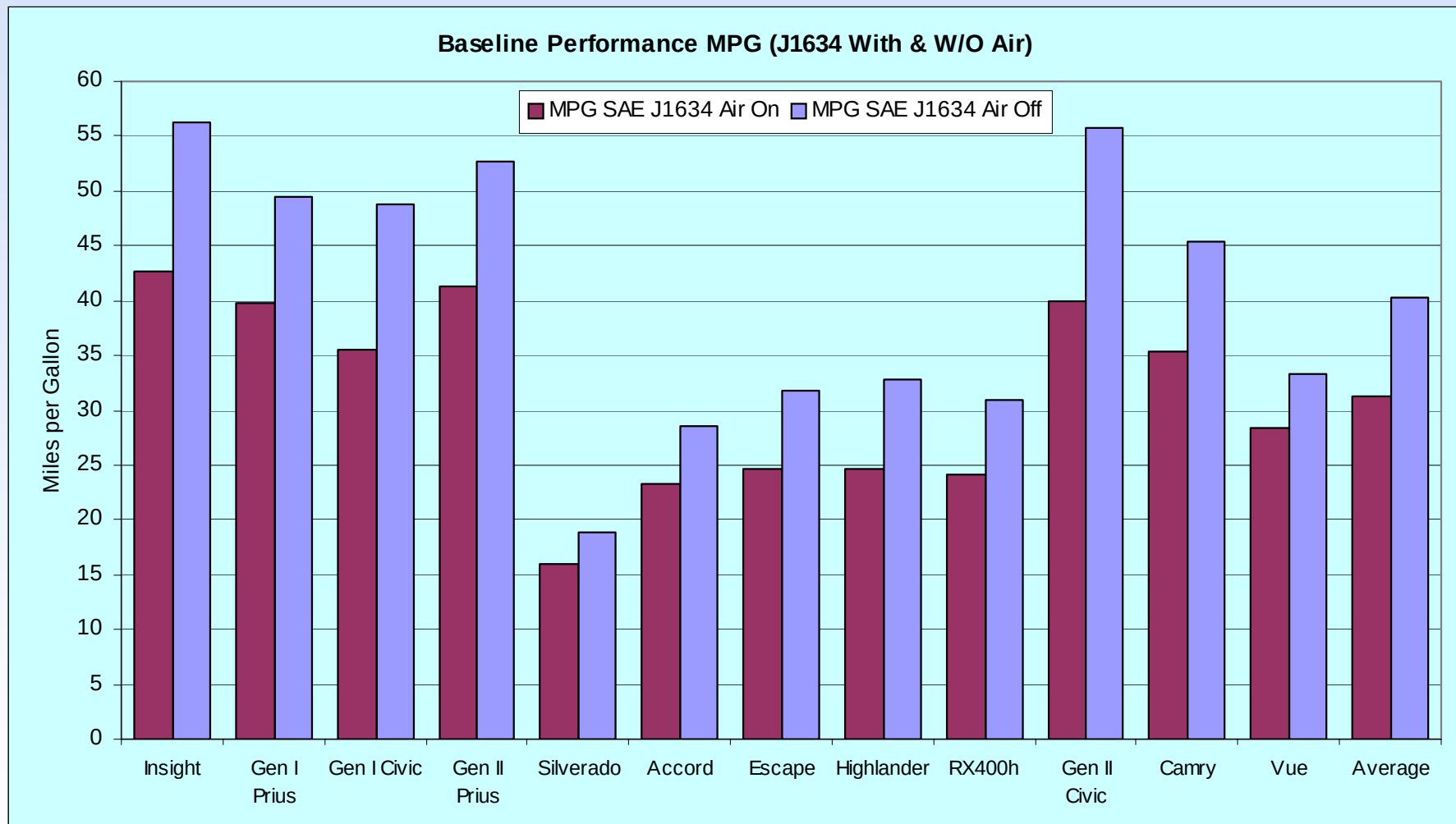
- **Plug-in hybrid electric vehicles**
 - 6 models, ~75 vehicles in fleets
- **Hybrid electric vehicles**
 - 14 models, 3.7 million test miles
- **Hydrogen ICE (internal combustion engine) vehicles**
 - 6 models, 400,000 test miles
- **Full-size electric vehicles**
 - 40 EV models, 5+ million test miles
- **Neighborhood electric vehicles**
 - 16 models, 200,000 test miles
- **Urban electric vehicles**
 - 3 models, 1 million test miles



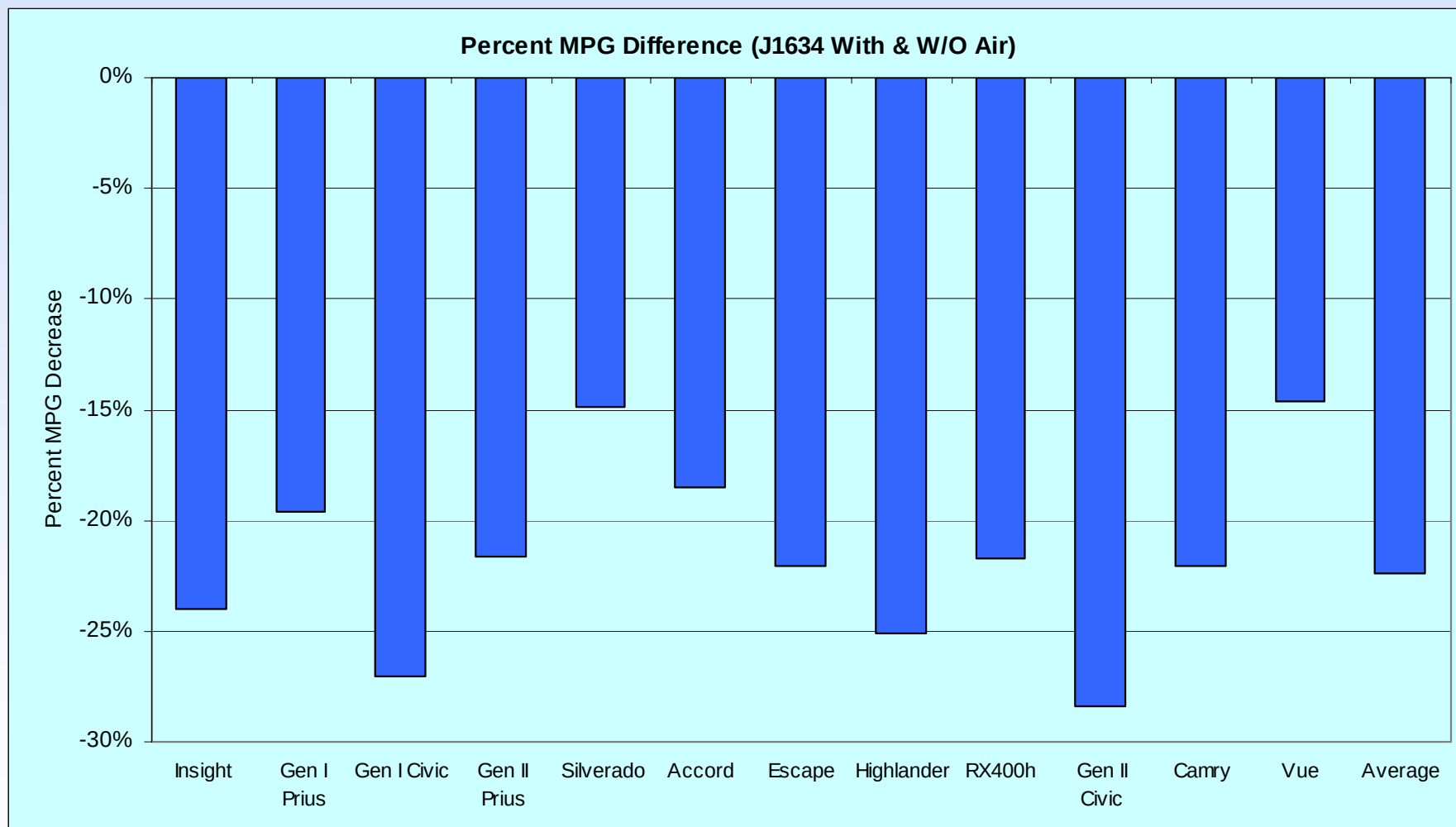
Hybrid Electric Vehicles (HEVs) in Testing

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	

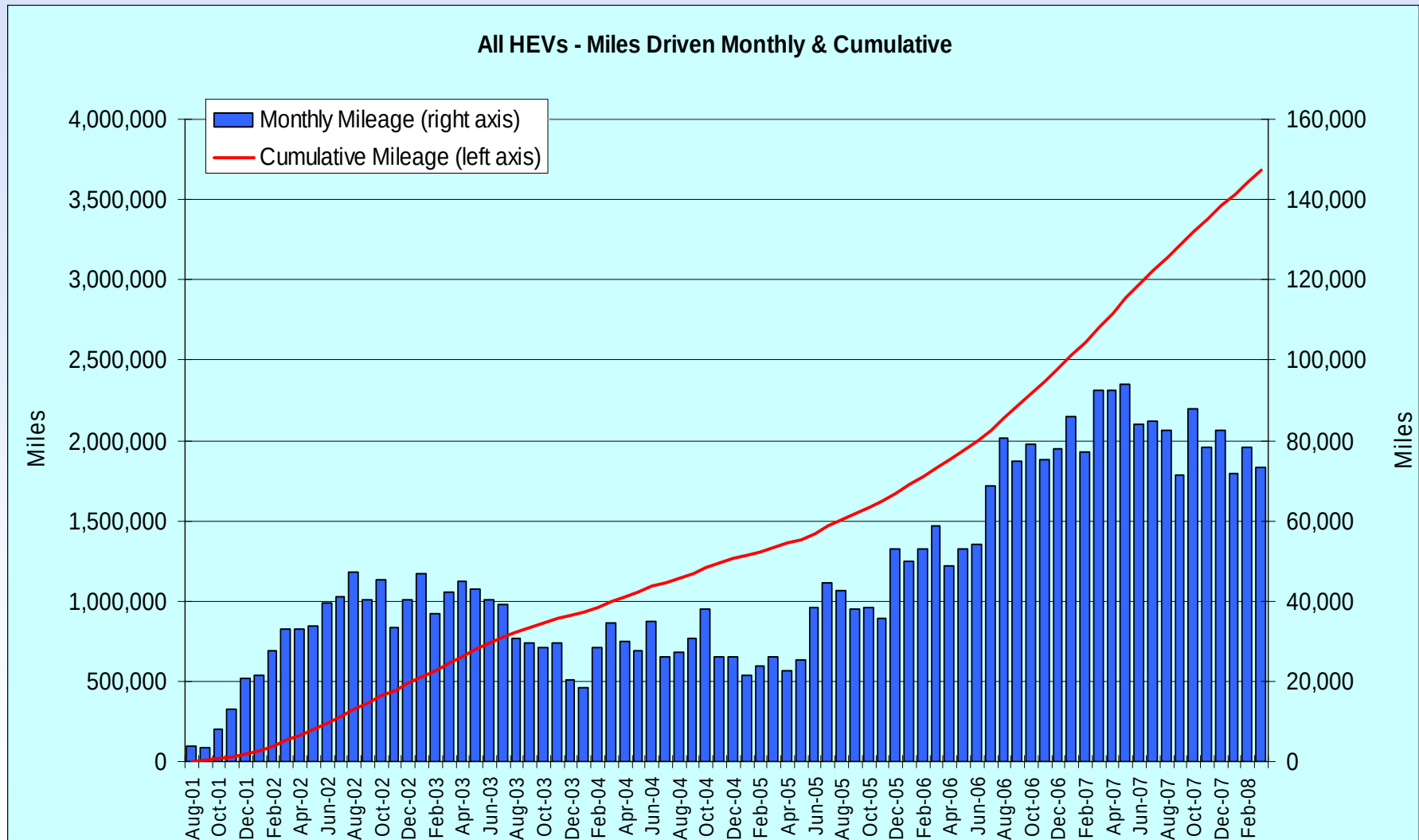
HEVs Baseline Performance Tested



Percent HEV MPG Decrease - A/C on

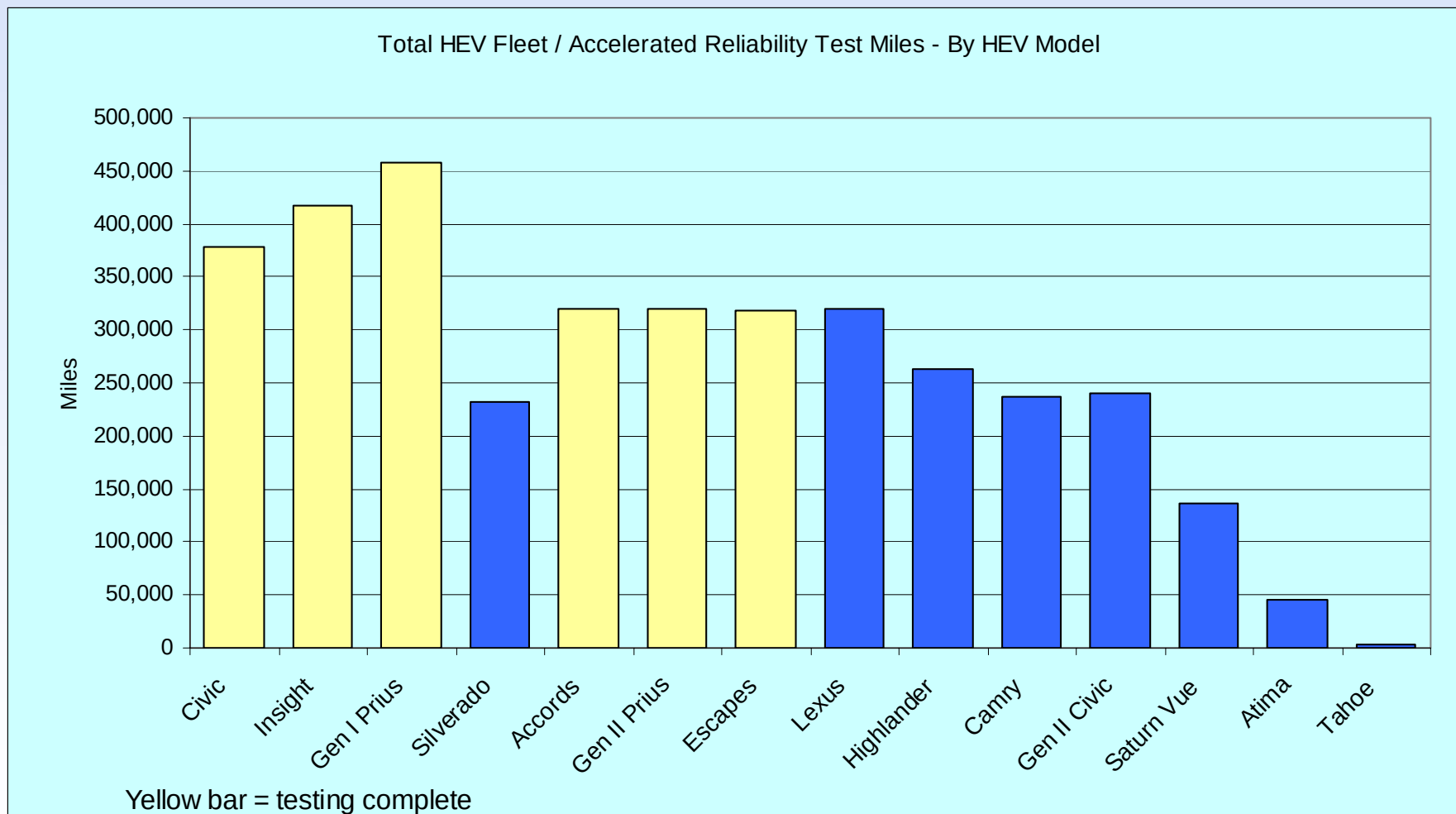


3.7 Million HEV Onroad Test Miles

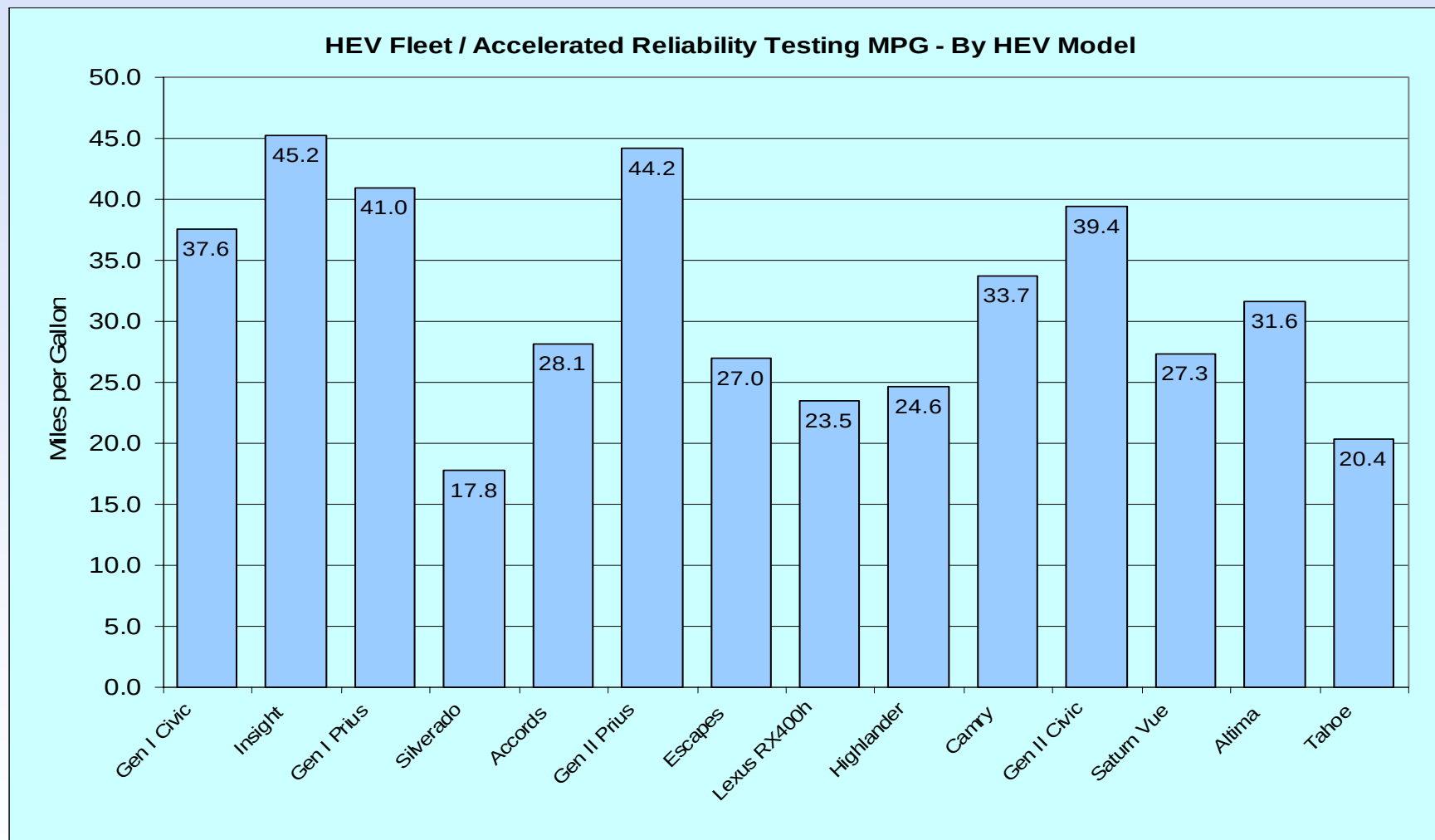


Onroad Test miles per HEV model

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



Onroad Miles per gallon by HEV model



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 P493 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

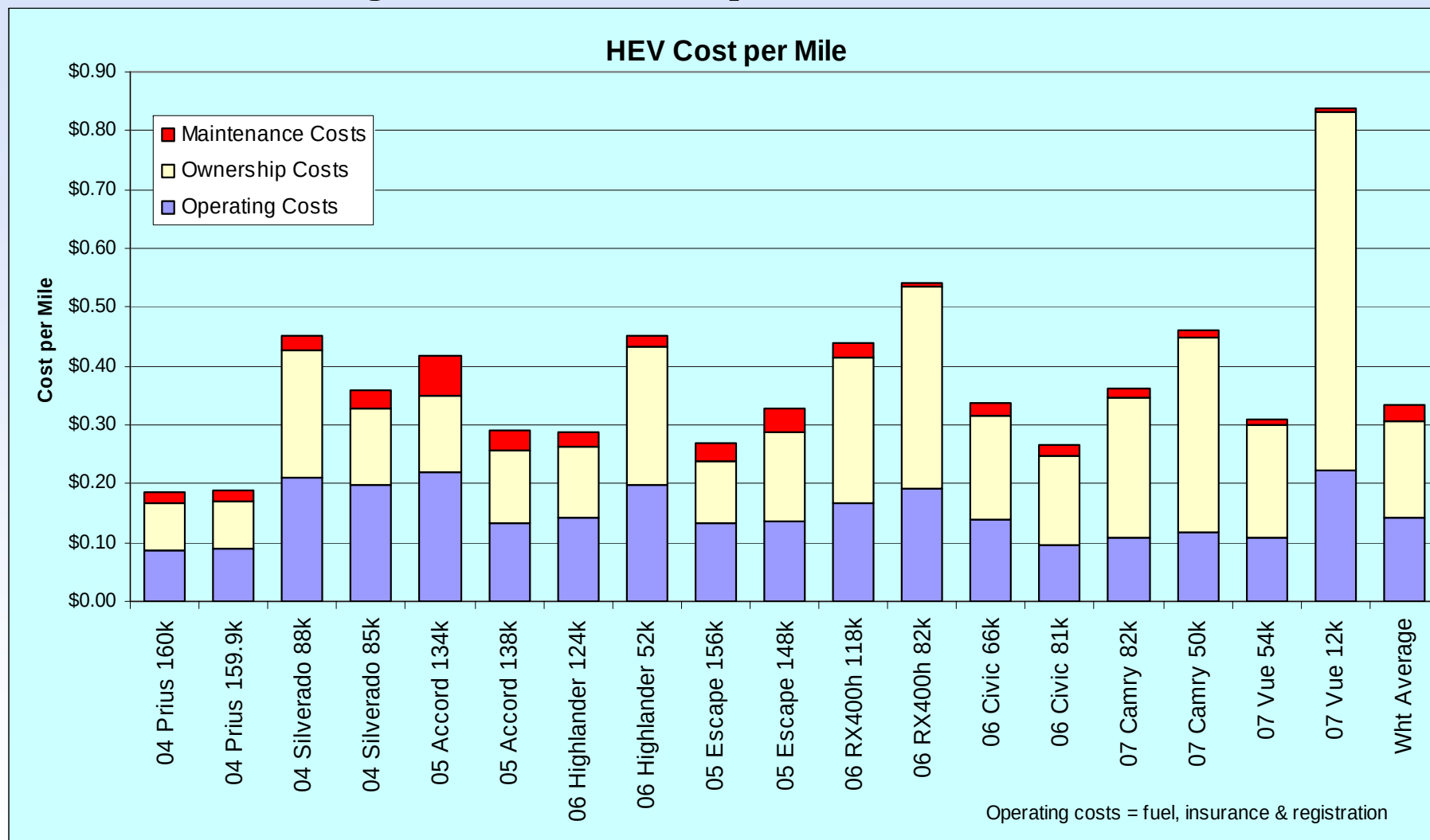


U.S. Department of Energy

Energy Efficiency and Renewable Energy

Bringing you a prosperous future where energy is clean, abundant, reliable, and affordable

HEV Life-Cycle Costs per Mile



NEVAmerica Testing

NEVAmerica U.S. DEPARTMENT OF ENERGY ADVANCED VEHICLE TESTING ACTIVITY		PERFORMANCE STATISTICS
		Acceleration (0-20 mph) @ 13.2 lbs Payload At 50% SOC: 5.6 seconds Performance Goal: 6.0 seconds Maximum Speed @ 170 lbs Payload (JMV500-49 CTR: 571,000 55A) At 50% SOC: 24.9 mph Performance goal: 25 mph Maximum Speed @ 132 lbs Payload At 50% SOC: Top Speed: 24.7 mph At 50% SOC: Top Speed: 24.7 mph Maximum Speed Range* Range: 30.4 miles Energy Used: 7.28 kWh Average Power: 3.59 kW Efficiency: 104.4 Wh/DC mile Specific Energy: 26.22 Wh/kg Parking: From 20 mph Controlled Dry: 24 feet Endurance (Calculated): Maximum Speed @ 170: 21.9 mph Maximum Speed @ 4%: 18.4 mph Maximum Grade: 55.5% Charging Efficiency: Efficiency: 292.4 Wh/Amp-hr Energy Cost: @ \$0.10/kWh: \$0.029/kWh Level 1 Charger: Max. Ground Current: <0.01 mA Max. Battery Leakage: <0.01 MBU Max. DC Charge Current: 13.8 A Max. AC Charge Current: 13.8 A Peak AC Demand: 1.28 kW Time to Recharge: To 80%: 7.4 Hours To 100%: 10.4 Hours To Complete: 14.7 Hours Performance Goal: 100% SOC within 12 hours Level 3 Charger: Max. Ground Current: <0.01 mA Max. Battery Leakage: <0.01 MBU Max. DC Charge Current: 10.9 A Max. AC Charge Current: 13.8 A Peak Demand: 10.36 kW Time to Recharge: To Complete: 1.1 Hours, 72.8% of Ah Discharged
VEHICLE SPECIFICATIONS		
Base Vehicle: 2007 Global Electric Motorcars eL XD 2 Passenger VIN: XASAE274770142896 Seated Position: Two Standard Features: Front Wheel Drive Front Disc and Rear Drum Brakes Regenerative Braking With Coast Down and Over Speed Three Power Safety Belts Spill-resistant On-board Charge View Backup Alarm On-board Battery Charger BATTERY Manufacturer: East Penn Dakota Type: RSVGC: Gel Lead Acid Number of Modules: 8 Weight of Module: 31.8 kg Weight of Pack(s): 277.6 kg Pack(s) Location: Under seat and Under Floor Nominal Module Voltage: 12V Nominal System Voltage: 72V Nominal Capacity (C1): 85 Ah TIRES Tire Mfg. Noting Tire Model: Surpass Tire Size: P185/70R13 80T Tire Pressure: 32 psi Tires Installed: Six		
WEIGHTS Design Curb Weight: 1572 lb Delivered Curb Weight: 1734 lb Distribution F/R: 56/44 % GVWR: 3000 lb GVWR F/R: 1385/1615 lb Payload: 750 lb Performance Goal: 400 lb DIMENSIONS Wheelbase: 114.0 inches Track F/R: 43.5/45.5 inches Length: 144.9 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 Voltage: 115/120 VAC Level 3 Location: Off-board Type: Conductive Input Voltage: 208 VAC 1-Phase Set VAC 1-Phase		
TEST NOTES: 1. Weight is reported as nominal; actual test weight may be higher or lower. 2. Performance goal is based on 100% SOC. 3. Energy consumption is based on 100% SOC. 4. Maximum speed is based on 100% SOC. 5. Maximum range is based on 100% SOC. 6. Maximum range is based on 100% SOC. 7. Maximum range is based on 100% SOC. 8. Maximum range is based on 100% SOC. 9. Maximum range is based on 100% SOC. 10. Maximum range is based on 100% SOC. 11. Maximum range is based on 100% SOC. 12. Maximum range is based on 100% SOC. 13. Maximum range is based on 100% SOC. 14. Maximum range is based on 100% SOC. 15. Maximum range is based on 100% SOC. 16. Maximum range is based on 100% SOC. 17. Maximum range is based on 100% SOC. 18. Maximum range is based on 100% SOC. 19. Maximum range is based on 100% SOC. 20. Maximum range is based on 100% SOC. 21. Maximum range is based on 100% SOC. 22. Maximum range is based on 100% SOC. 23. Maximum range is based on 100% SOC. 24. Maximum range is based on 100% SOC. 25. Maximum range is based on 100% SOC. 26. Maximum range is based on 100% SOC. 27. Maximum range is based on 100% SOC. 28. Maximum range is based on 100% SOC. 29. Maximum range is based on 100% SOC. 30. Maximum range is based on 100% SOC. 31. Maximum range is based on 100% SOC. 32. Maximum range is based on 100% SOC. 33. Maximum range is based on 100% SOC. 34. Maximum range is based on 100% SOC. 35. Maximum range is based on 100% SOC. 36. Maximum range is based on 100% SOC. 37. Maximum range is based on 100% SOC. 38. Maximum range is based on 100% SOC. 39. Maximum range is based on 100% SOC. 40. Maximum range is based on 100% SOC. 41. Maximum range is based on 100% SOC. 42. Maximum range is based on 100% SOC. 43. Maximum range is based on 100% SOC. 44. Maximum range is based on 100% SOC. 45. Maximum range is based on 100% SOC. 46. Maximum range is based on 100% SOC. 47. Maximum range is based on 100% SOC. 48. Maximum range is based on 100% SOC. 49. Maximum range is based on 100% SOC. 50. Maximum range is based on 100% SOC. 51. Maximum range is based on 100% SOC. 52. Maximum range is based on 100% SOC. 53. Maximum range is based on 100% SOC. 54. Maximum range is based on 100% SOC. 55. Maximum range is based on 100% SOC. 56. Maximum range is based on 100% SOC. 57. Maximum range is based on 100% SOC. 58. Maximum range is based on 100% SOC. 59. Maximum range is based on 100% SOC. 60. Maximum range is based on 100% SOC. 61. Maximum range is based on 100% SOC. 62. Maximum range is based on 100% SOC. 63. Maximum range is based on 100% SOC. 64. Maximum range is based on 100% SOC. 65. Maximum range is based on 100% SOC. 66. Maximum range is based on 100% SOC. 67. Maximum range is based on 100% SOC. 68. Maximum range is based on 100% SOC. 69. Maximum range is based on 100% SOC. 70. Maximum range is based on 100% SOC. 71. Maximum range is based on 100% SOC. 72. Maximum range is based on 100% SOC. 73. Maximum range is based on 100% SOC. 74. Maximum range is based on 100% SOC. 75. Maximum range is based on 100% SOC. 76. Maximum range is based on 100% SOC. 77. Maximum range is based on 100% SOC. 78. Maximum range is based on 100% SOC. 79. Maximum range is based on 100% SOC. 80. Maximum range is based on 100% SOC. 81. Maximum range is based on 100% SOC. 82. Maximum range is based on 100% SOC. 83. Maximum range is based on 100% SOC. 84. Maximum range is based on 100% SOC. 85. Maximum range is based on 100% SOC. 86. Maximum range is based on 100% SOC. 87. Maximum range is based on 100% SOC. 88. Maximum range is based on 100% SOC. 89. Maximum range is based on 100% SOC. 90. Maximum range is based on 100% SOC. 91. Maximum range is based on 100% SOC. 92. Maximum range is based on 100% SOC. 93. Maximum range is based on 100% SOC. 94. Maximum range is based on 100% SOC. 95. Maximum range is based on 100% SOC. 96. Maximum range is based on 100% SOC. 97. Maximum range is based on 100% SOC. 98. Maximum range is based on 100% SOC. 99. Maximum range is based on 100% SOC. 100. Maximum range is based on 100% SOC.		

- CARB requires all Neighborhood Electric Vehicles (NEVs) be tested by the AVTA
- 5 NEVs completing testing:
 - 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

eGSEAmerica Testing



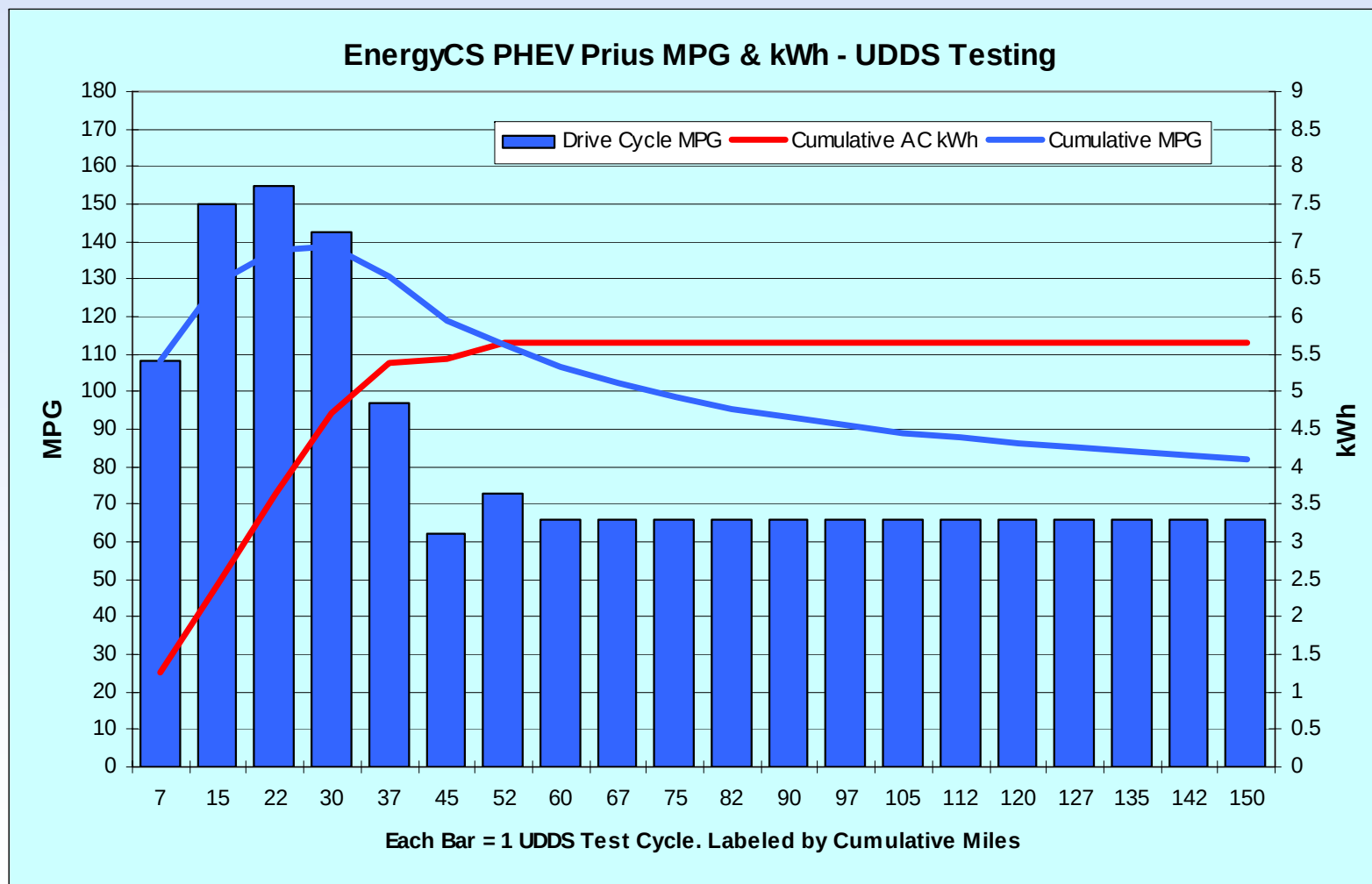
- **Developed economic payback software model for electric Ground Support Equipment (eGSE)**
 - **For baggage tractors, belt loaders, and pushback tractors propelled by electric motors or petroleum engines (diesel and gasoline)**
 - **Includes fueling infrastructure**
 - **Based on operations of two airlines at four airports**
 - **Partners: EPRI, SCE, SMUD, Georgia Power, Southwest and Delta Airlines**

PHEV Testing (Plug-in Hybrid Electric Vehicle)



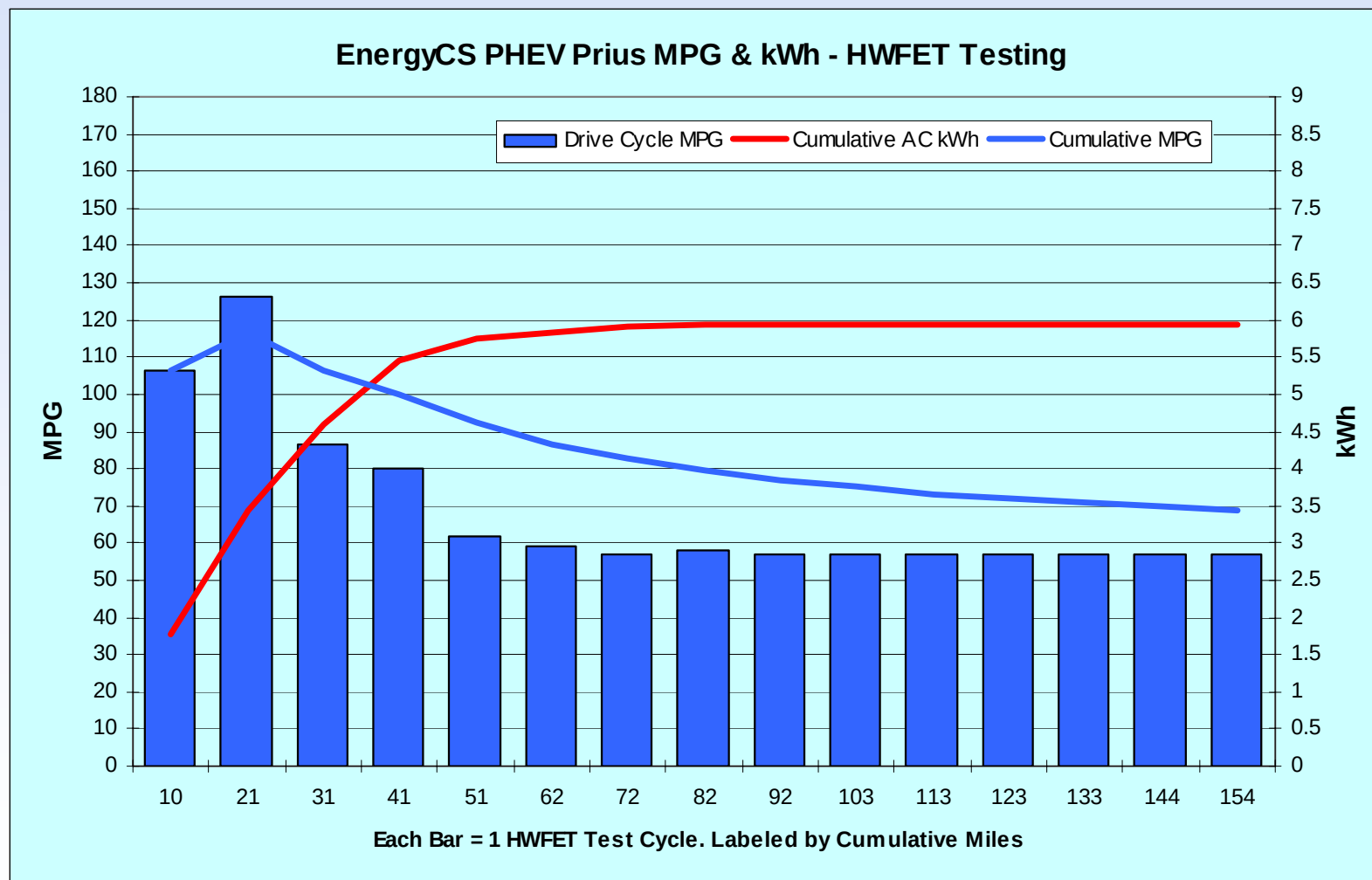
EnergyCS Prius – UDDS Fuel Use

- 9 kWh Valence lithium pack – AC kWh



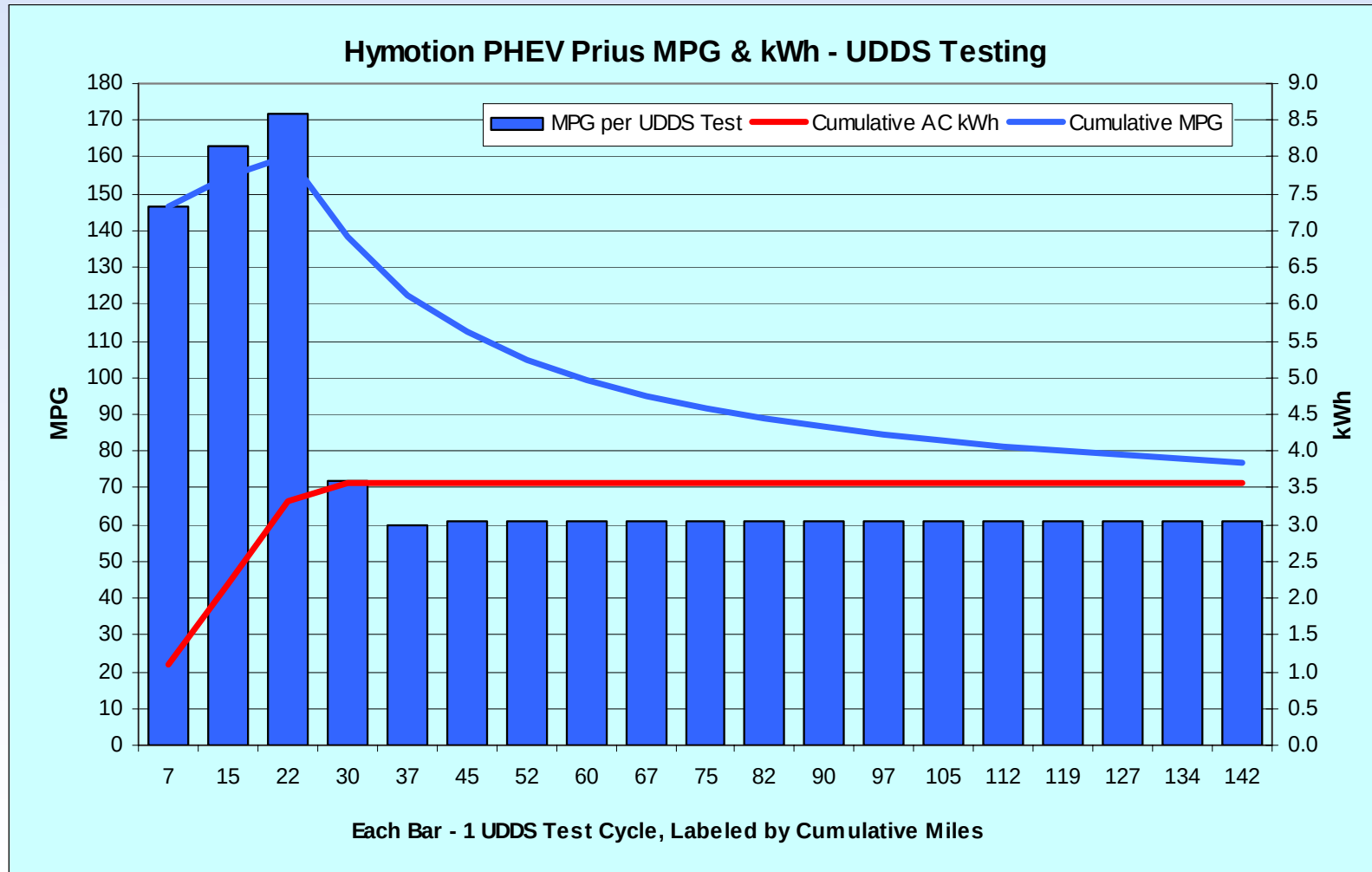
EnergyCS Prius – HWFET Fuel Use

- 9 kWh Valence lithium pack – AC kWh



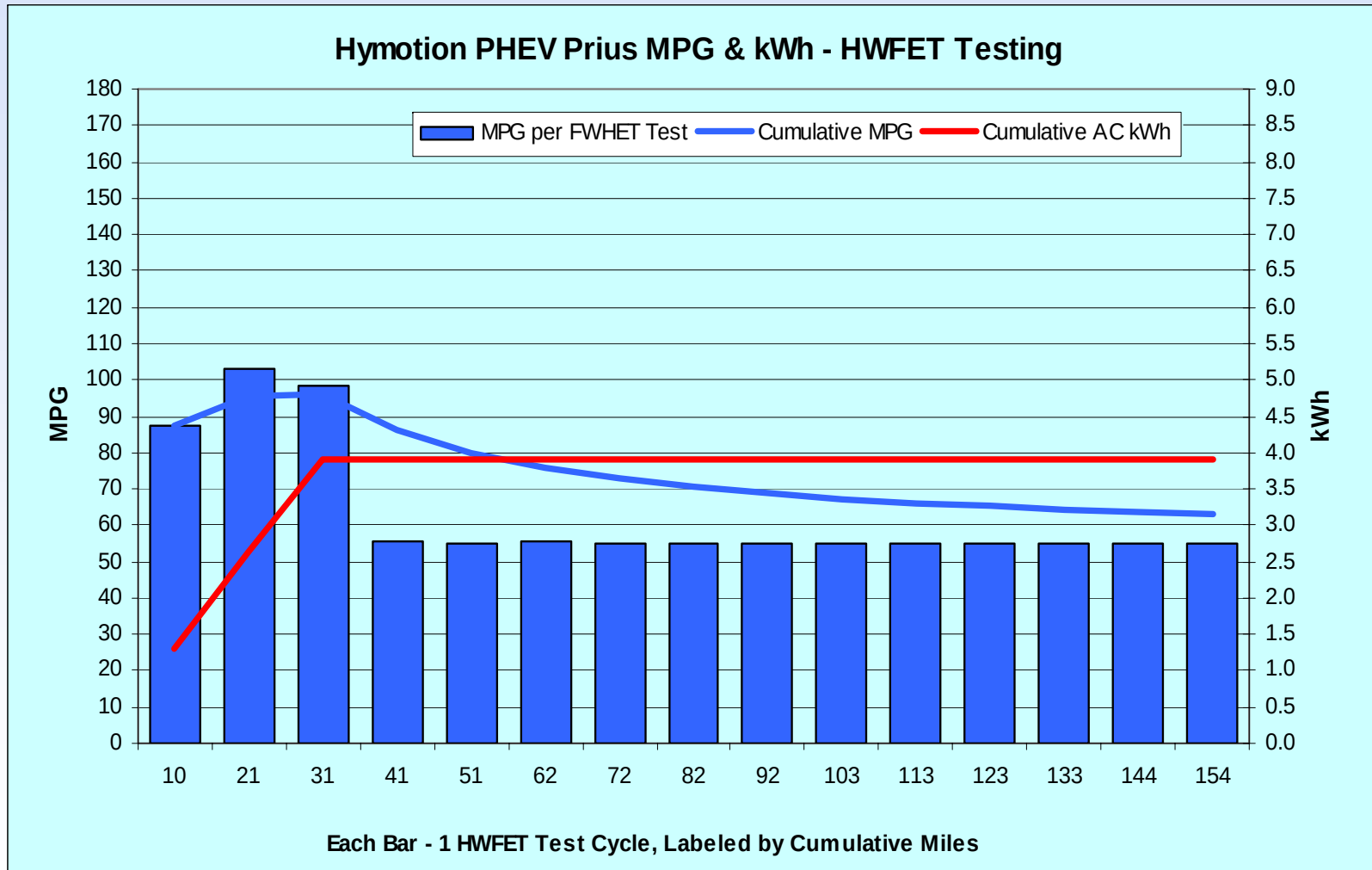
Hymotion Prius – UDDS Fuel Use

- 5 kWh A123 lithium & Prius packs – AC kWh



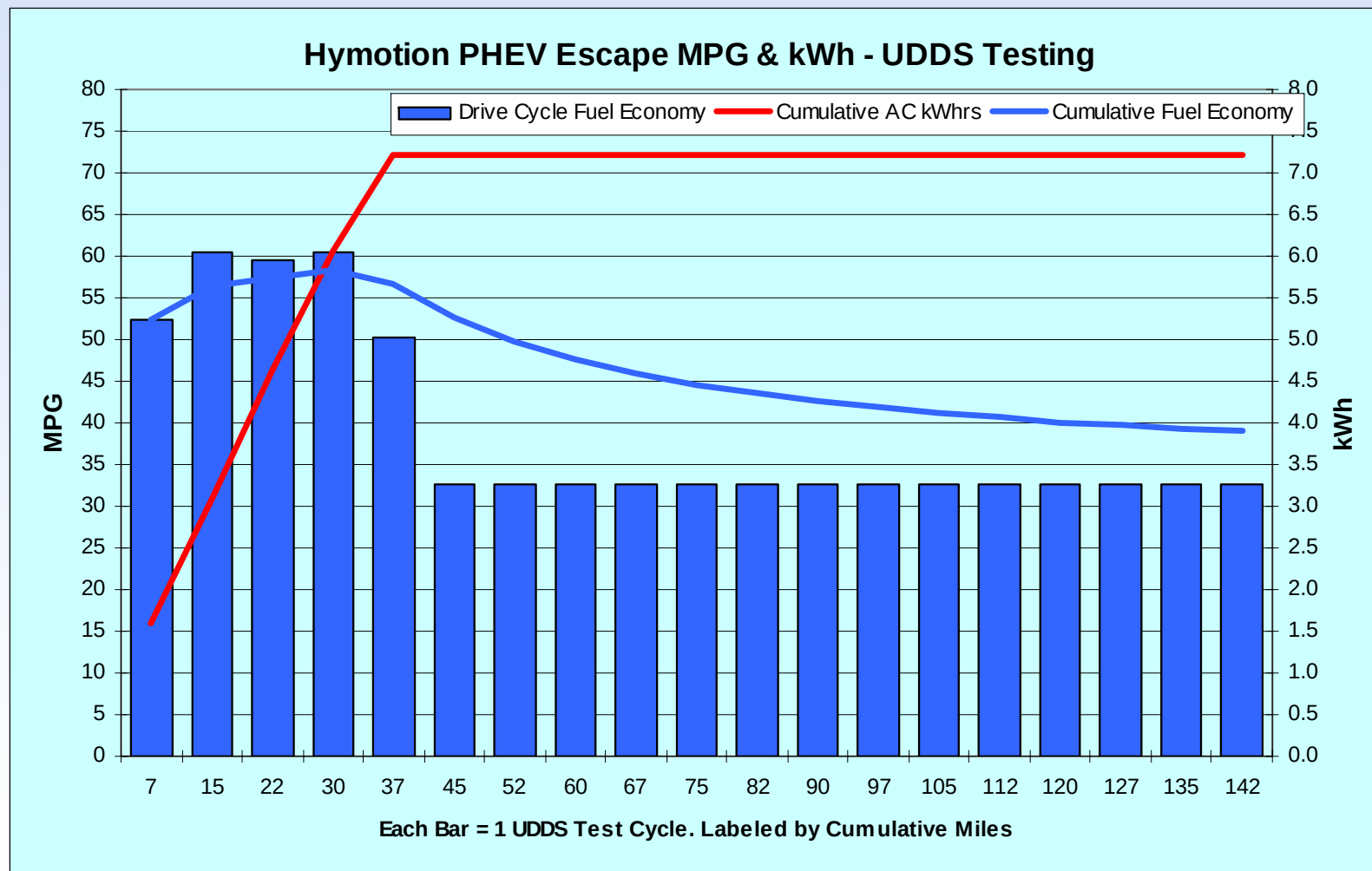
Hymotion Prius – HWFET Fuel Use

- 5 kWh A123 lithium & Prius packs – AC kWh



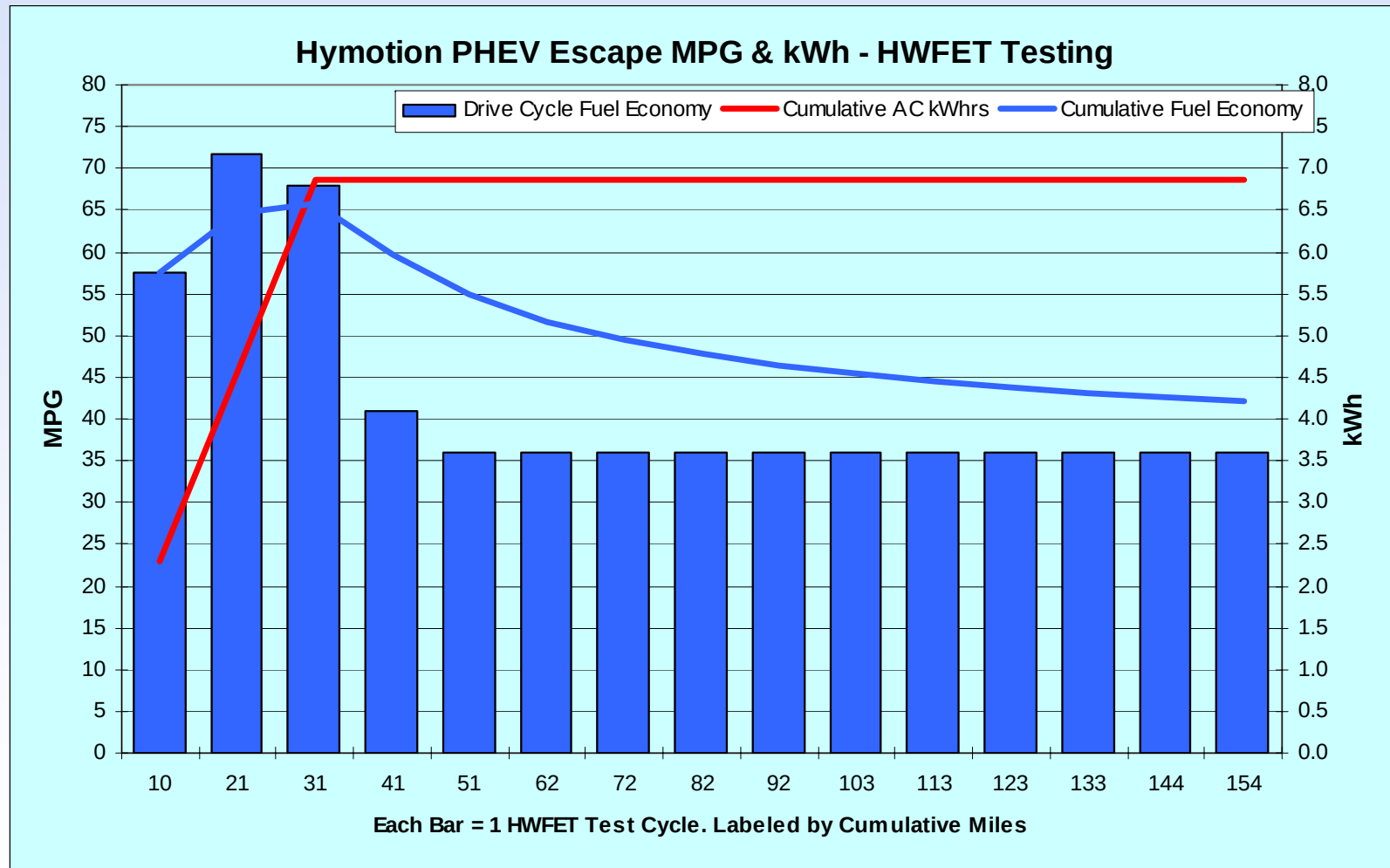
Hymotion Escape – UDDS Fuel Use

- 8.5 kWh A123 lithium & Escape packs – AC kWh



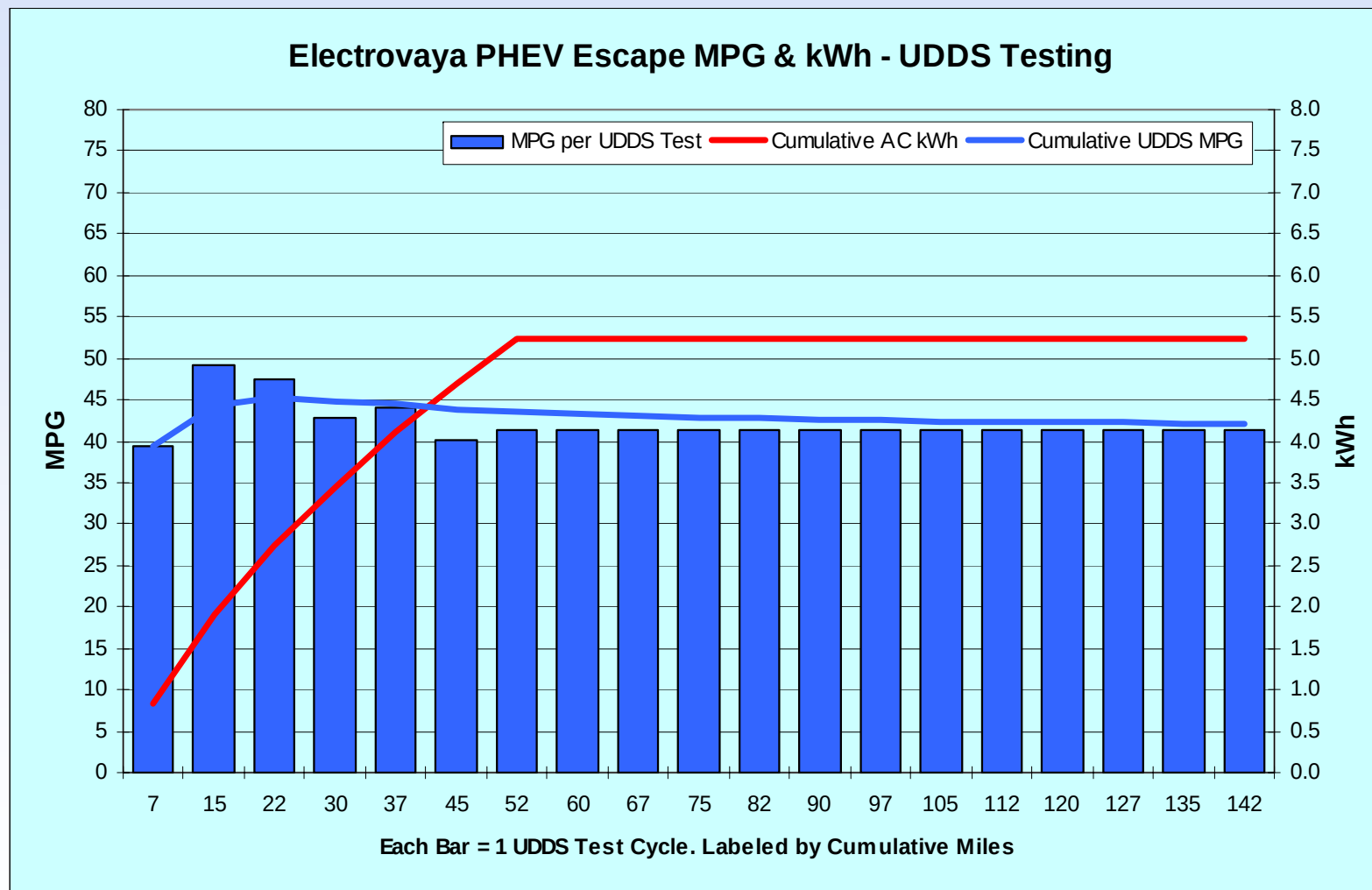
Hymotion Escape – HWFET Fuel Use

- 8.5 kWh A123 lithium & Escape packs – AC kWh



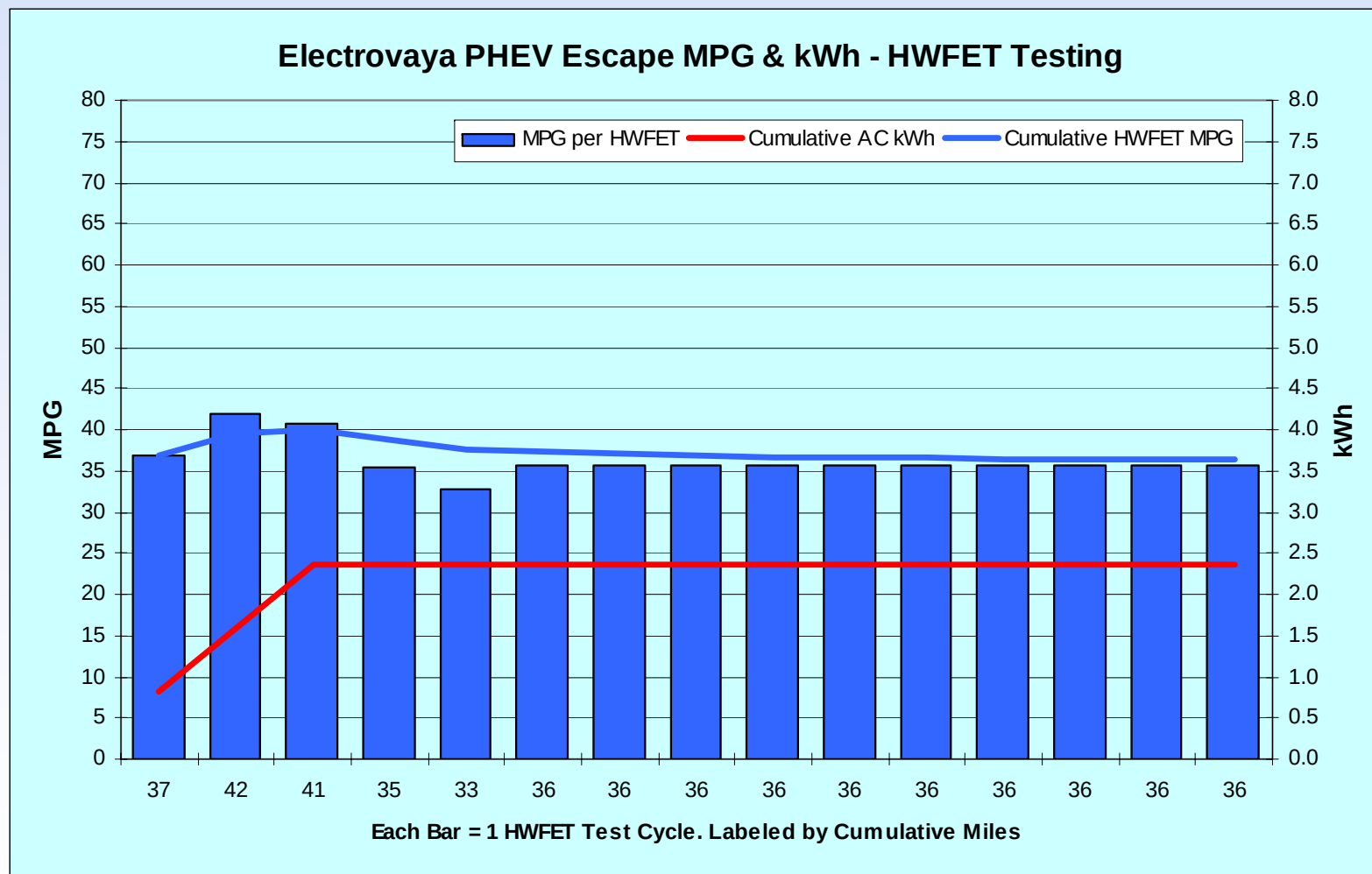
Electrovaya Escape – UDDS Fuel Use

- 12 kWh Electrovaya lithium & Prius packs – A/C kWh



Electrovaya Escape – HWFET Fuel Use

- 12 kWh Electrovaya lithium & Prius packs – A/C kWh



Accelerated Onroad Testing

- Uses dedicated drivers
- Predetermined and repeatable drive cycles
- Combinations of urban and highway loops
- 5,440 total onroad test miles per PHEV model
- 162 drive and charging cycles that include a minimum of 1,344 hours of charging
- Test PHEV batteries at completion of accelerated testing and at 25k, 50k and ? miles

PHEV Accelerated Testing

- Accelerated testing in Phoenix over 5,440 miles
- GPS units track distance, average & maximum speeds

Cycle (mi)	Urban (10 mi)	Highway (10 mi)	Charge (hr)	Reps (N)	Total (mi)	Reps (%)	Miles (%)
10	1	0	4	60	600	37%	11%
20	1	1	8	30	600	19%	11%
40	4	0	12	15	600	9%	11%
40	2	2	12	15	600	9%	11%
40	0	4	12	15	600	9%	11%
60	2	4	12	10	600	6%	11%
80	2	6	12	8	640	5%	12%
100	2	8	12	6	600	4%	11%
200	2	18	12	3	600	2%	11%
Total	2,340	3,100	1,344	162	5,440		
Average	43%	57%	8.3	18			

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 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

Hymotion Escape – 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			
40	0	4	12	15	600			
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			
200	2	18	12	3	600			
Total	2340	3100	1344	162	5440	Weighted Average		

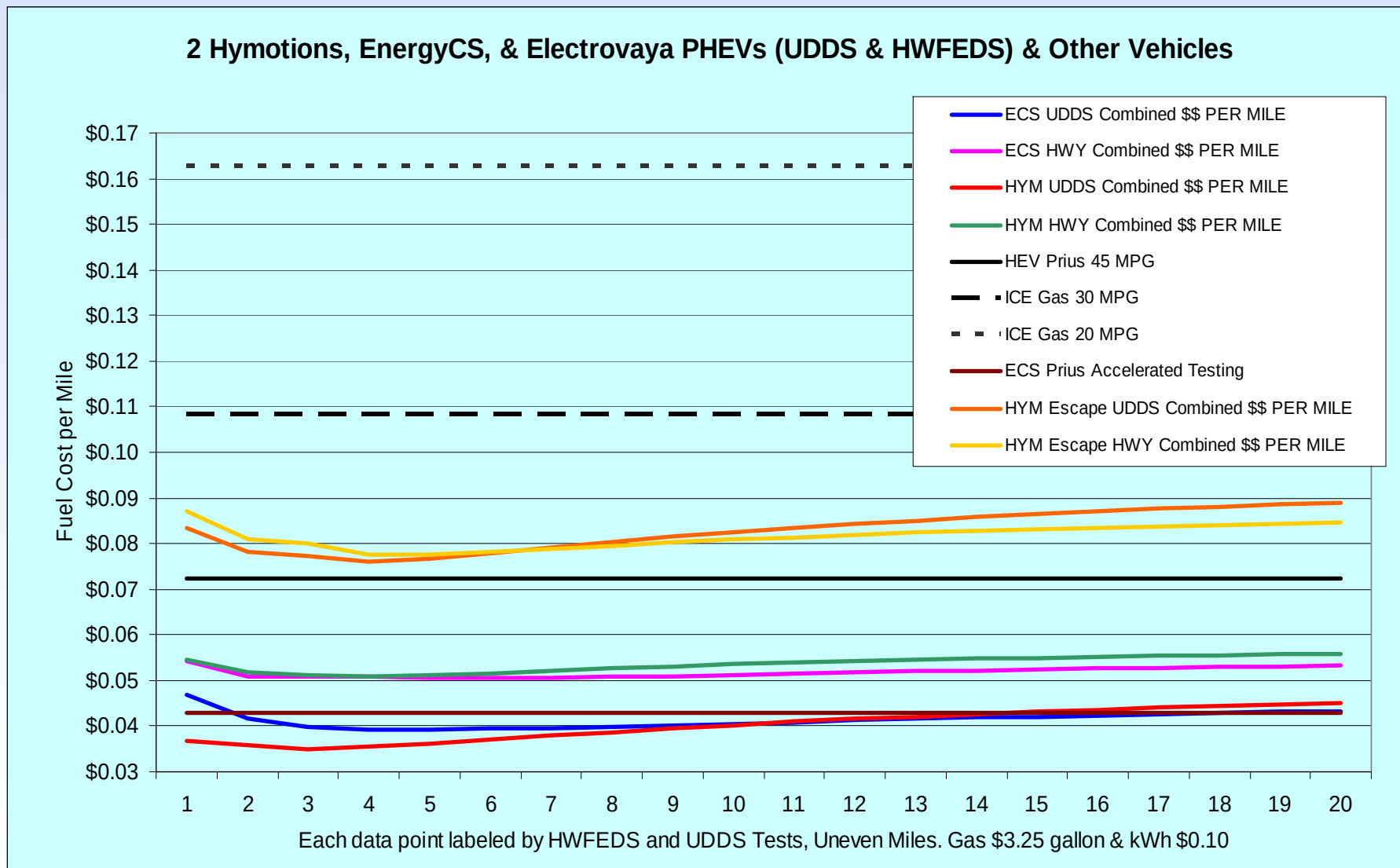
Each total distance slightly greater than 600 miles. HEV version = 27 mpg

HybridsPlus Escape – 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		In progress	
20	1	1	8	30	600			
40	4	0	12	15	600			
40	2	2	12	15	600			
40	0	4	12	15	600			
60	2	4	12	10	600			
80	2	6	12	8	640			
100	2	8	12	6	600			
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

PHEV Fuel Costs per Mile



PHEV On-road Demonstration Partners and Fleet Data Collection Activities

Hymotion Joint Data Collection

- Kvaser data loggers installed 50 PHEVs in US & Canada
- Onboard data includes vehicle performance, fuel use, and charging and driving profiles
- Participates 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



EnergyCS Joint Data Collection

- EnergyCS provided onboard data for vehicles operating in North America fleets
- EnergyCS changing battery manufacturers
- 36 vehicles deployed (16 North America and 20 Europe)
- Modifying data collection to allow EnergyCS & INL server-to-server interface and wireless communication



NYSERDA

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

Model	Baseline Testing	Accelerated Testing	Delivery Status
EnergyCS Prius	Completed	Near completed	1 delivery
Hymotion Prius	Completed	Completed	1 delivery
Hymotion Escape	Completed	Ongoing	1 delivery
Electrovaya Escape	Completed - Problems	Waiting	4 deliveries required
HybridsPlus Escape	Waiting	Ongoing	3 deliveries required



Seattle-Area Demonstration

- 13 Hymotion Prius PHEV demonstration with:
 - The City of Seattle (4)
 - King County (4)
 - Port of Seattle (2)
 - Puget Sound Clean Air Agency (3)
- 1 Green Car Company lead acid Prius at King County
- Using V2Green cellular data loggers and GPS units
- Time-of-day charge demand study
- Started April 2008



Tacoma Power

- Two lead acid battery Prius PHEVs from the Green Car Company
- Two Hymotion Prius on order
- Testing includes charging and driving profiles as well as charging infrastructure analysis
- Using V2Green cellular data loggers and GPS units
- Started 1st quarter CY08



University of California Davis

- UCDavis will use 13 Hymotion Prius for public fleet demonstration
- Demonstration will include up to 70 drivers that are identified by AAA of California
- Each public driver will operate a vehicle for ~2 months
- Using V2Green cellular data loggers and GPS units
- AVTA provides data collection, handling, analysis and dissemination support
- AVTA, UCDavis and AAA partnering to capture first study of public use of PHEVs, including charging practices and locations
- Started April 2008

Washington State PHEV Demonstration

- Demonstrate 14 Hymotion Prius in coastal, desert, and island areas
- Testing partners include:
 - Port of Chelan (lead)
 - State of Washington
 - Five utilities and three colleges
 - Port agencies, cities and counties
 - Private company
- Will include daily solar (photovoltaic array) charging
- Electricity costs as low as 2.5 cents/kWh (hydropower)
- Using V2Green cellular data loggers and GPS units
- Started April of 2008



National Rural Electric Cooperative Association (NRECA)

- Total of ten Prius and Escape PHEVs from Hymotion, EnergyCS, and HybridsPlus will be / are operated by rural electric coops (6 delivered) in 10 states
- Collect and process onboard data from the fleets, and provide individual vehicle and fleet operations data to NRECA and fleets
- Started spring 2008



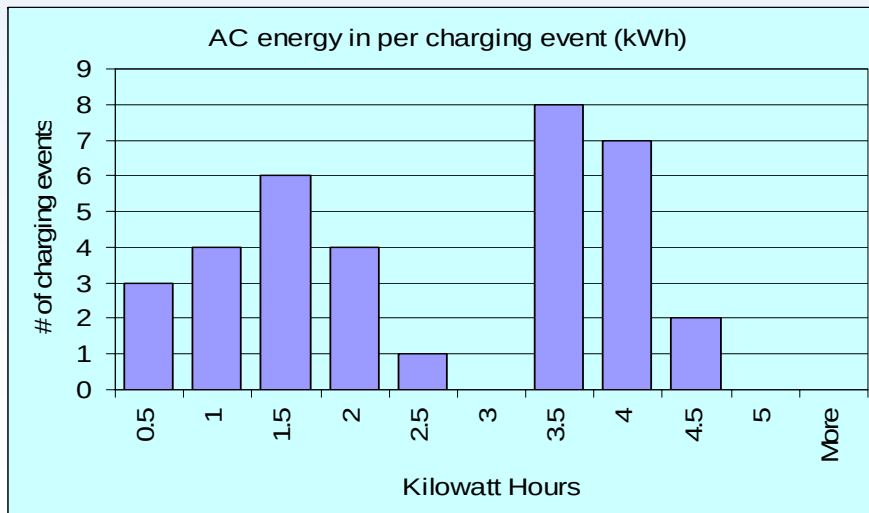
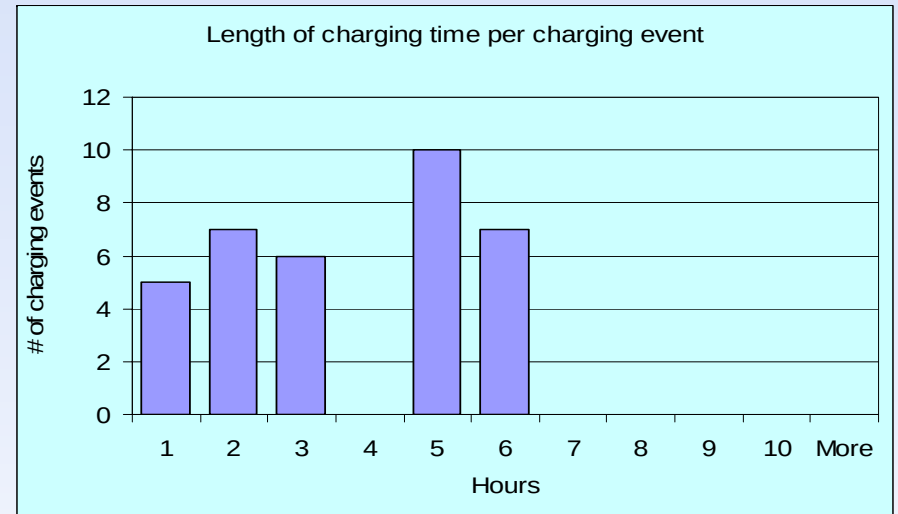
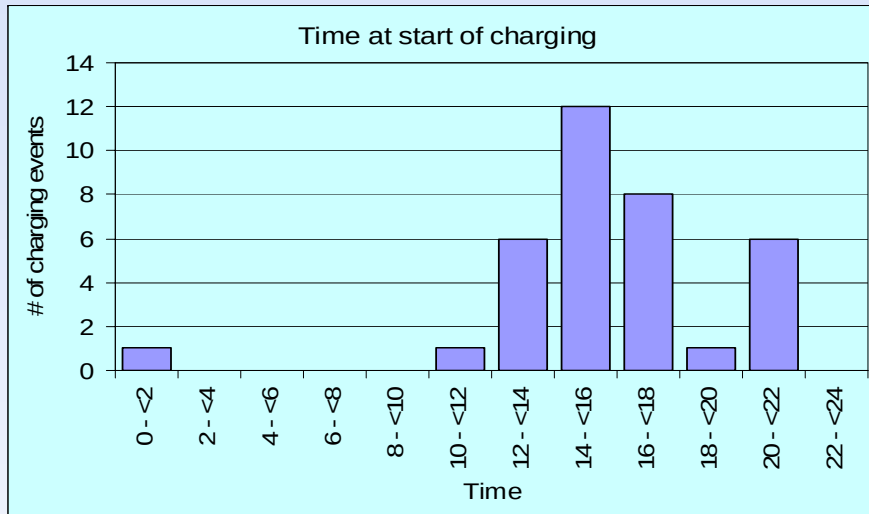
Hawaii PHEV Demonstration

- Demonstrate six Hymotion Prius on Maui and Oahu
- Testing partners:
 - State of Hawaii
 - University of Hawaii
 - Hawaiian Electric Company
 - Maui Electric Company
 - Maui County
 - U.S. Air Force
- Will use V2Green cellular data loggers and GPS units
- Start late summer 2008



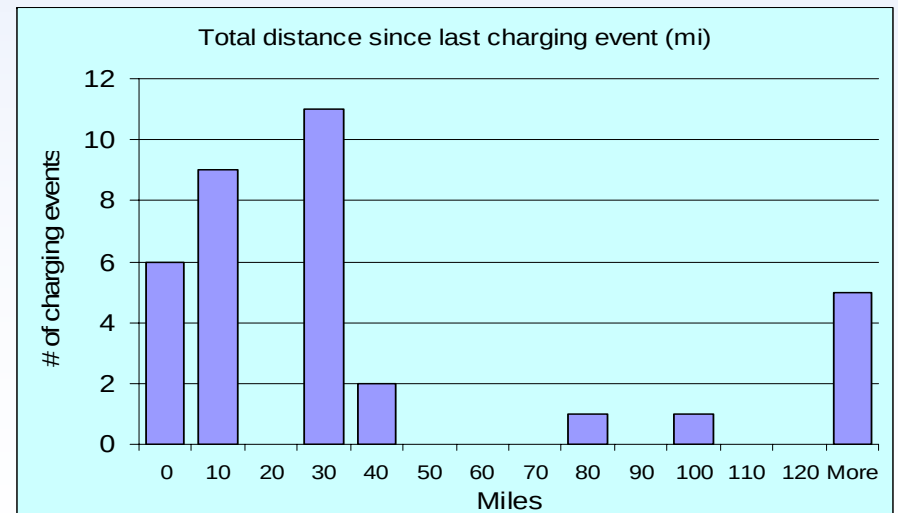
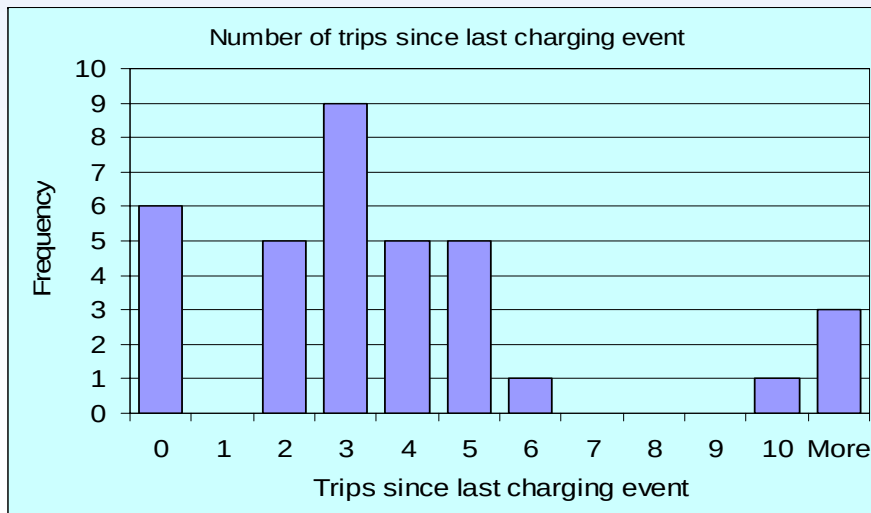
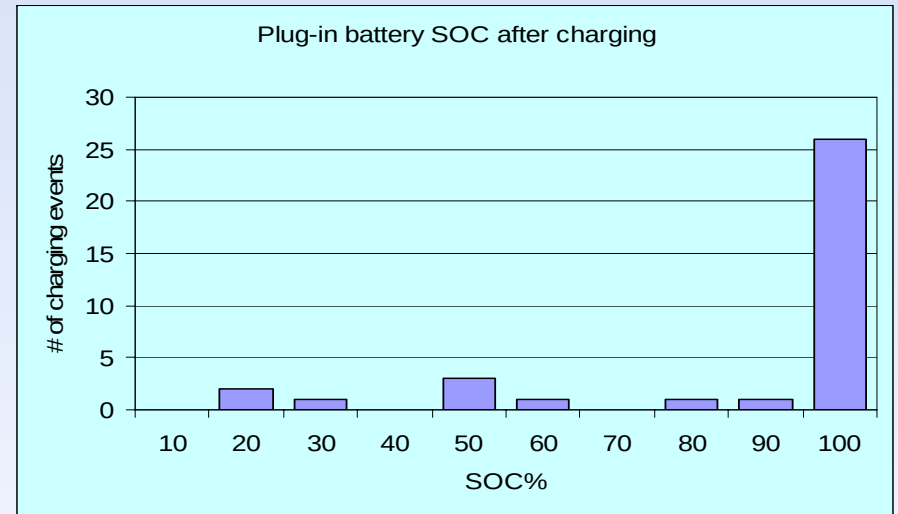
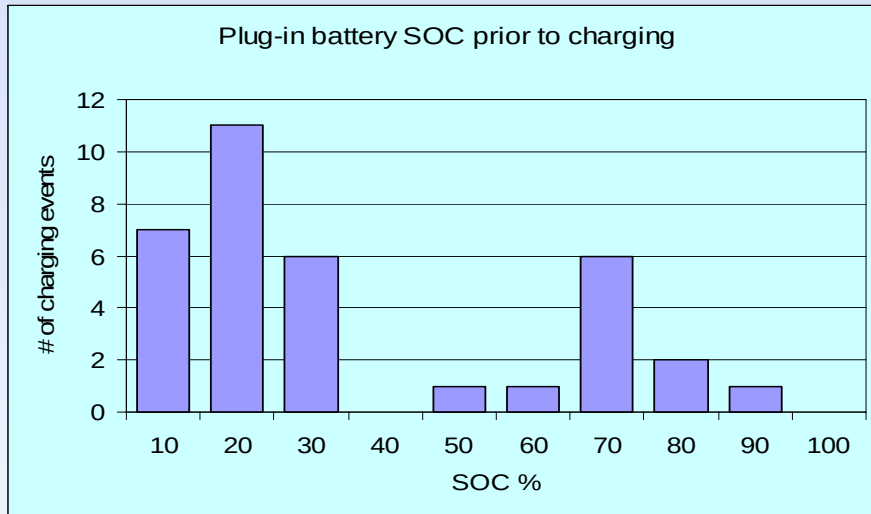
Hymotion Prius Charging Profiles

- 3 months, 2212 miles, 35 charges (single PHEV)



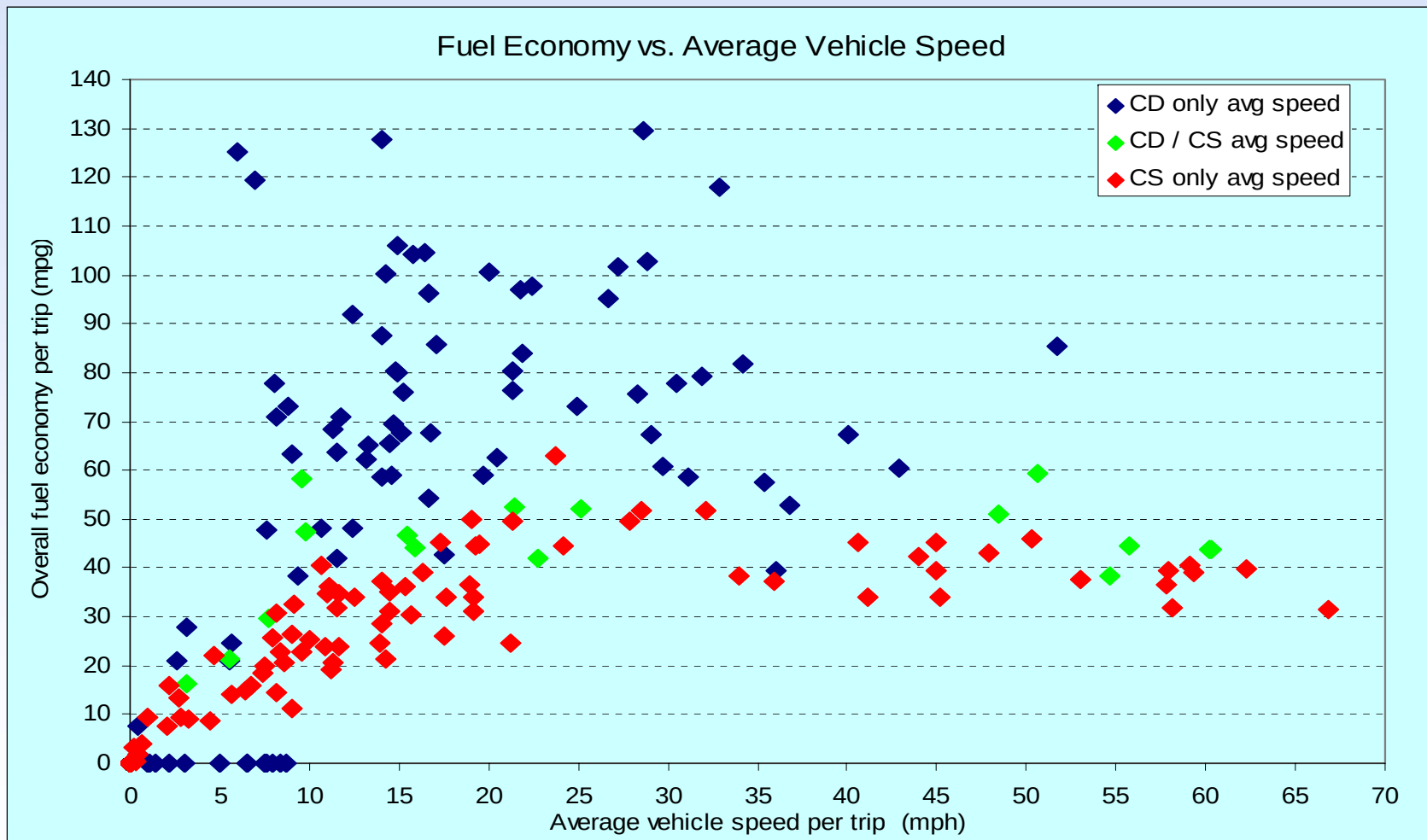
Hymotion Prius Charging Profiles

- 3 months, 2212 miles, 35 charges (single PHEV)



Hymotion Prius MPG Vs. Average Trip Speed

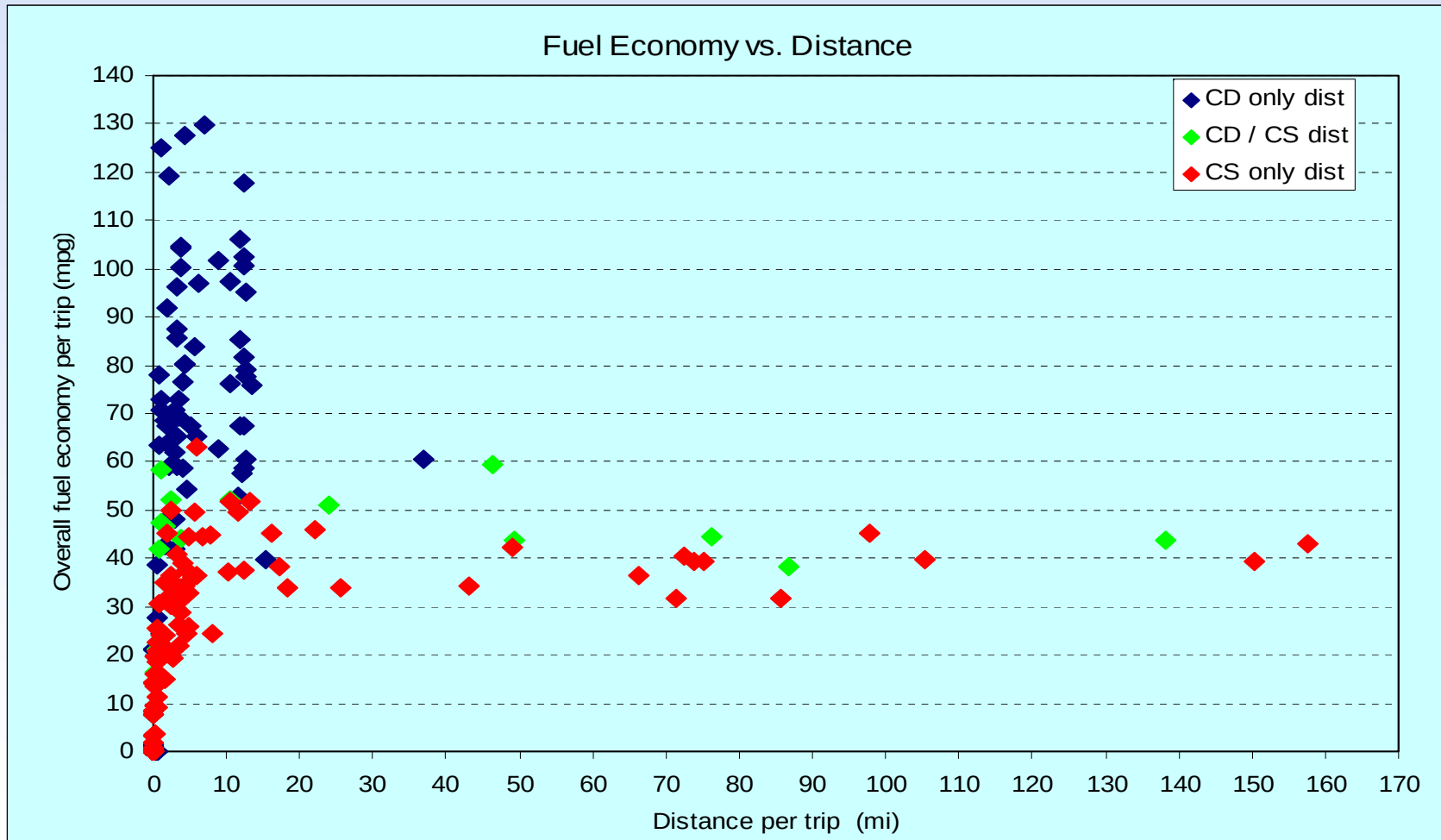
- 3 months, 2212 miles, 35 charges (single PHEV)



CD – charge depleting, S - sustaining

Hymotion Prius MPG Vs. Trip Distance

- 3 months, 2212 miles, 35 charges (single PHEV)



CD – charge depleting, S - sustaining

Charging Infrastructure



Charging Infrastructure



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Additional Information

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

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