Idaho National Laboratory

U.S. Department of Energy, Vehicle Technologies Program, Advanced Vehicle Testing Activity (AVTA)

Update on PHEV Testing and Demonstration Activities

Jim Francfort
John Smart
Nov 12, 2008

This presentation does not contain any proprietary or sensitive information

AVTA Background and Goals

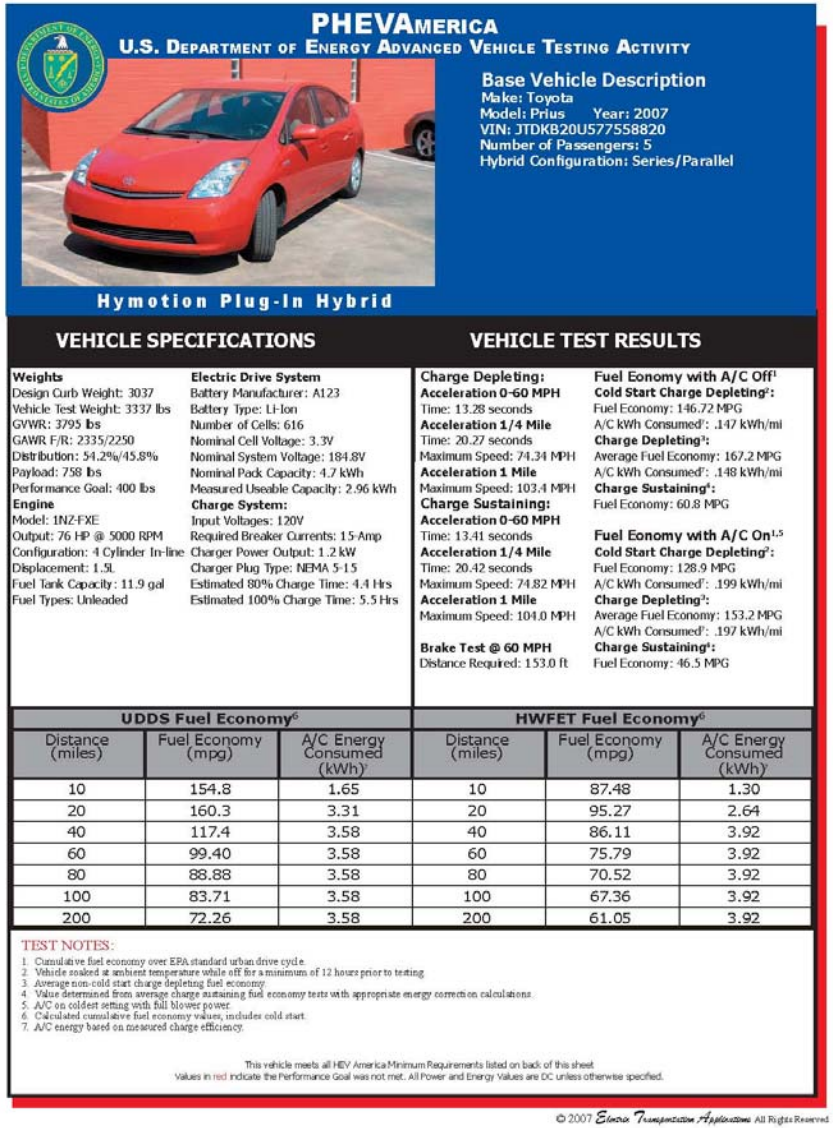
- **The Advanced Vehicle Testing Activity (AVTA) is part of DOE's Vehicle Technologies Program. The AVTA mission is to support DOE's strategic goal to reduce the nation's dependence on foreign oil**
- **The Idaho National Laboratory (INL) and Electric Transportation Engineering Corporation (ETEC) conduct the AVTA. Argonne National Laboratory performs dynamometer testing**

- **The AVTA goals:**
  - **Provide benchmark data to technology modelers, research and development programs, vehicle manufacturers (via VSATT), and target and goal setters**
  - **Assist fleet managers in making informed vehicle purchase, deployment and operating decisions**

AVTA Testing History

- Plug-in hybrid electric vehicles (PHEV)
  - 9 models, ~95 vehicles
- Hybrid electric vehicles (HEV)
  - 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

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: 758 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[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.
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.

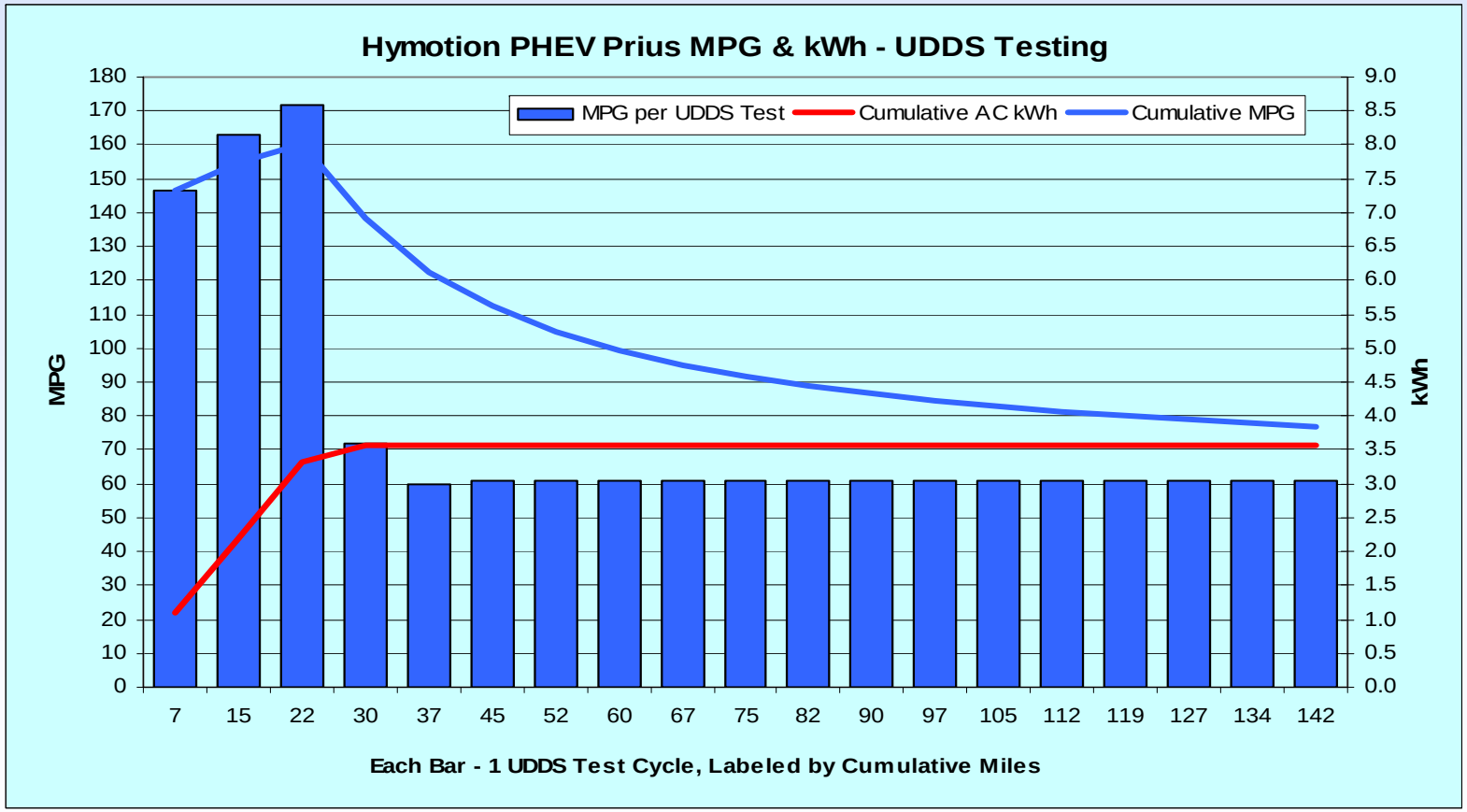
- Hymotion Prius
- Hymotion Escape
- EnergyCS Prius
- Electrovaya Escape
- Hybrids Plus Escape
- Hybrids Plus Prius
- Manzanita Prius (lead acid)
- Ford Escape
- Renault Kangoo (NiCad)
- (Vehicles equipped with lithium traction batteries unless noted)

PHEV Testing Objectives

- Perform independent testing of PHEVs, using:
  - Baseline performance testing – closed test tracks and dynamometers
  - Accelerated testing – dedicated drivers operating on defined onroad loops
  - Fleet testing – everyday unstructured use, with onboard data loggers
- Document battery life, charging patterns and demand profiles
- Document vehicle operations, fuel use (both gasoline and electricity) and infrastructure requirements (110 versus 220, offpeak and V2Grid charging)
- Document driver influences on fuel use
- Document PHEV life-cycle costs

Hymotion Prius – UDDS Fuel Use

- **5 kWh A123Systems (Li) V1 and Prius packs (AC kWh)**



Hymotion Prius – HWFETS Fuel Use

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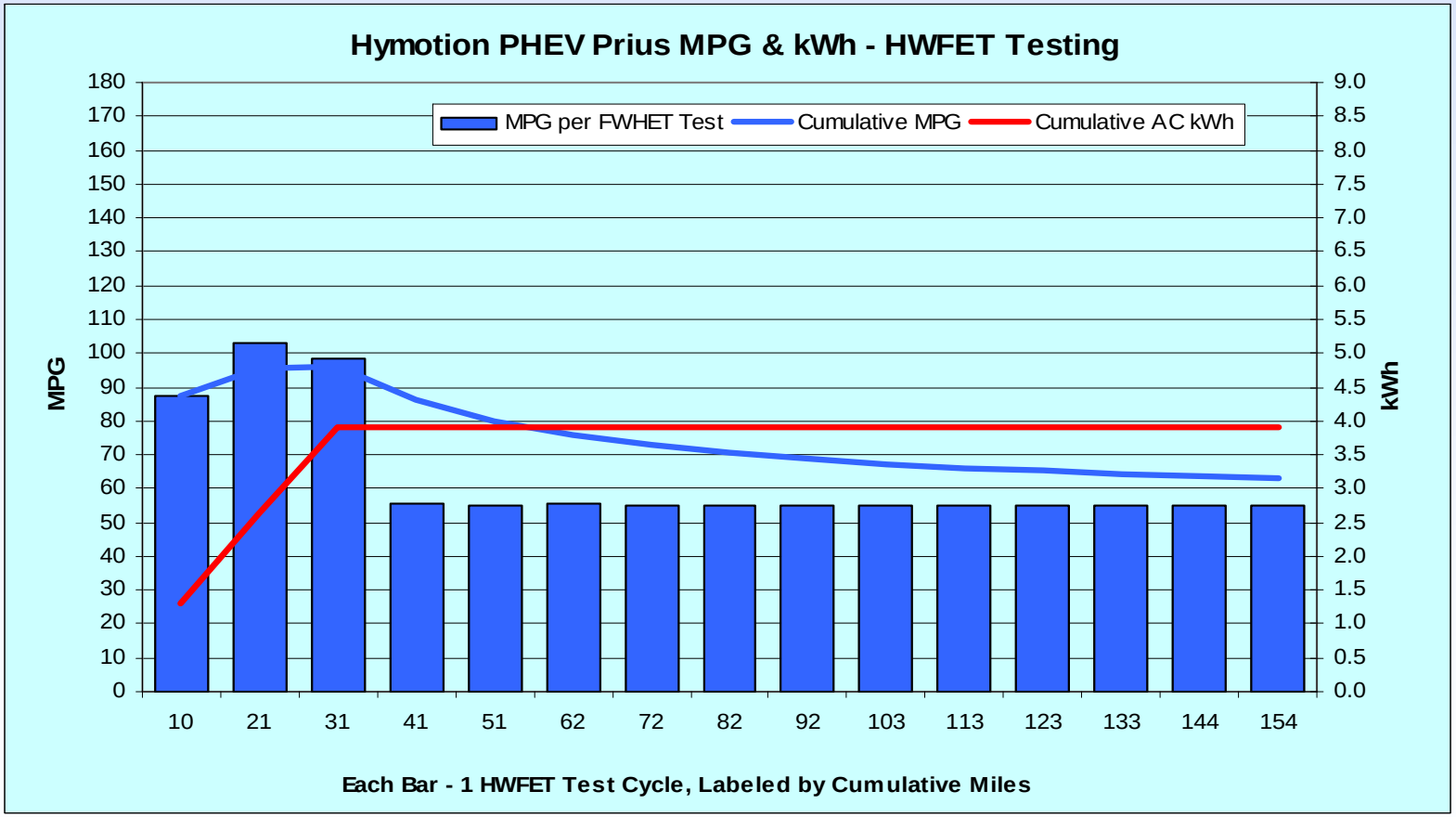
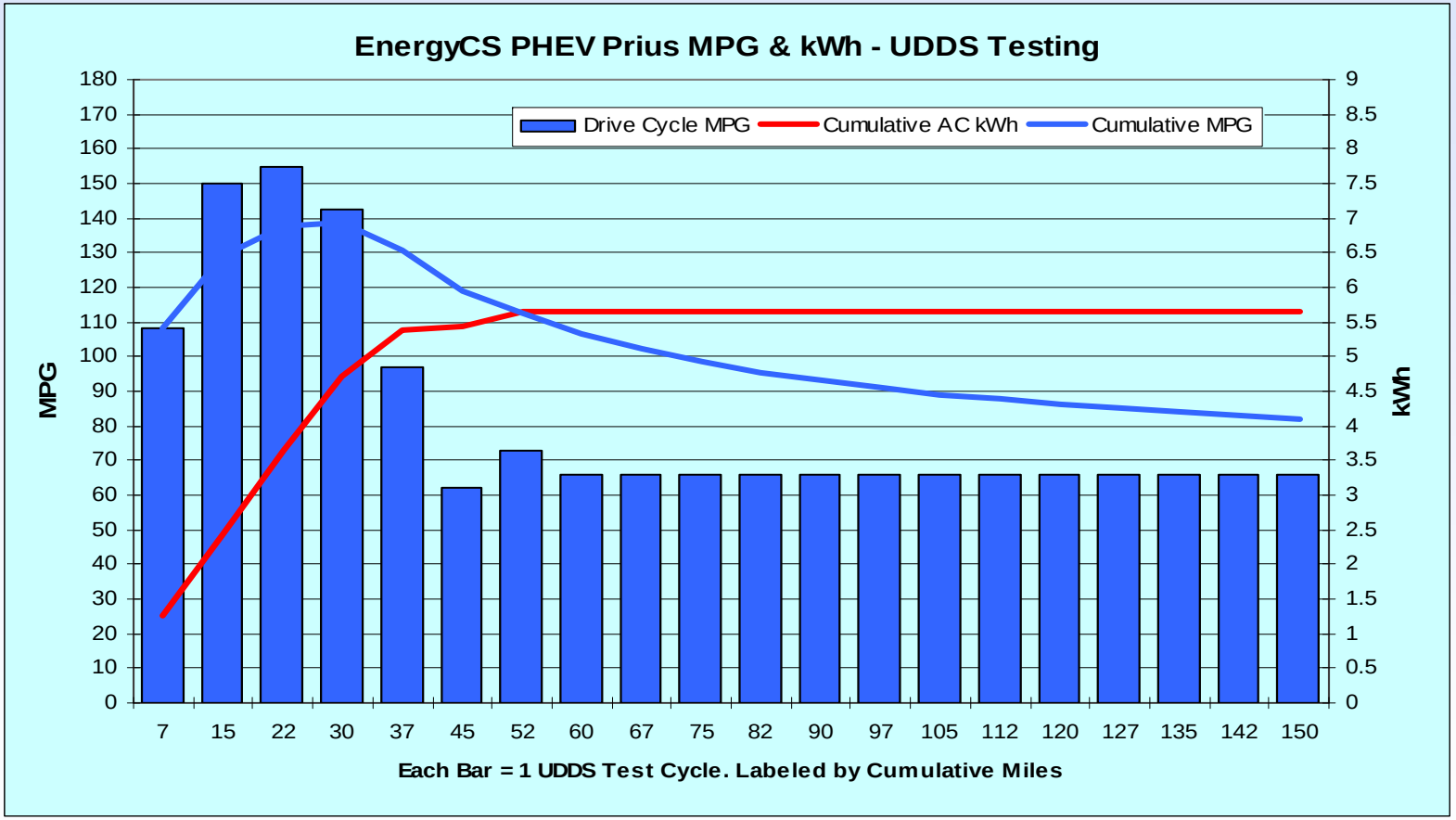


EnergyCS Prius – UDDS Fuel Use

- **9 kWh Valence (Li) pack only (AC kWh)**



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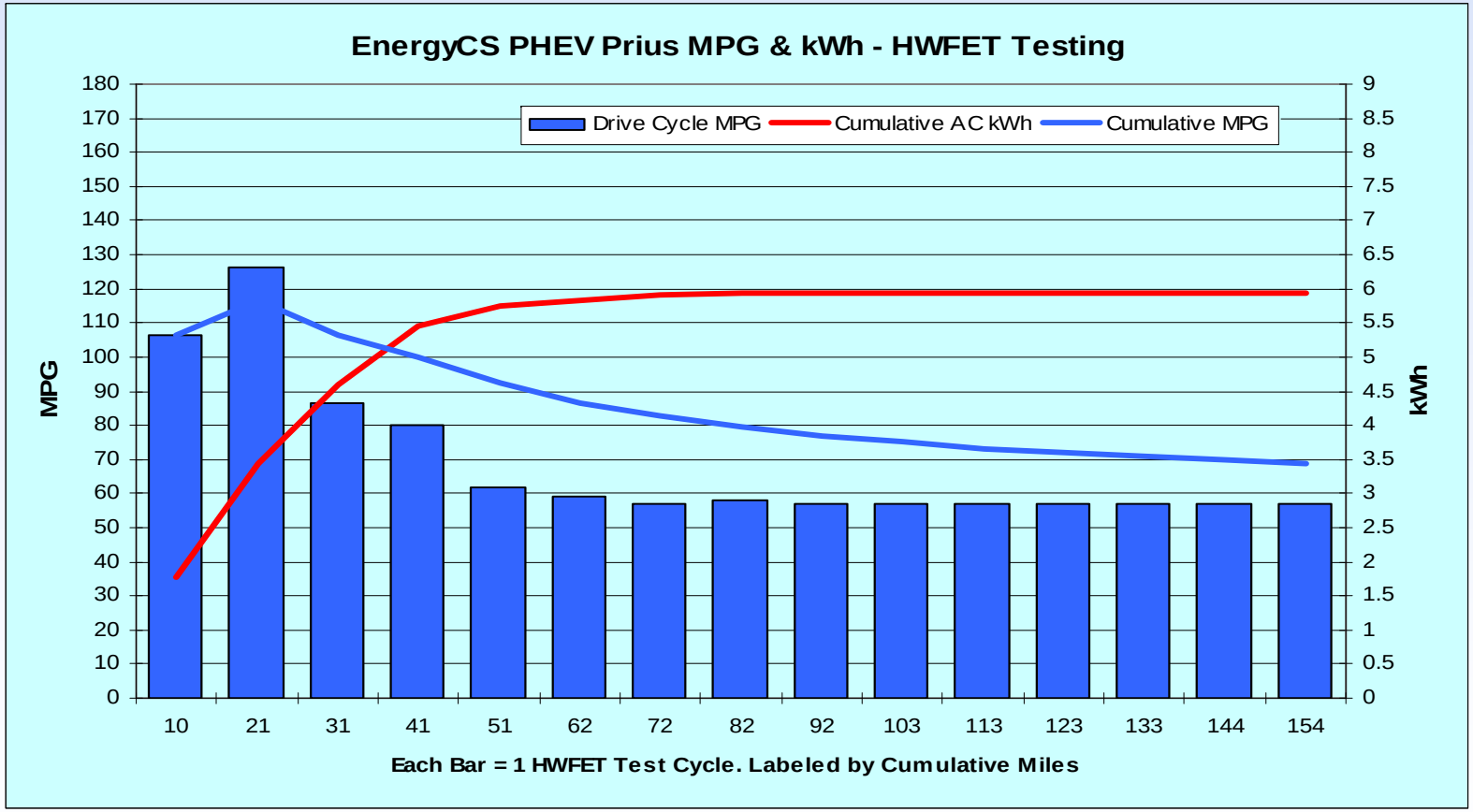
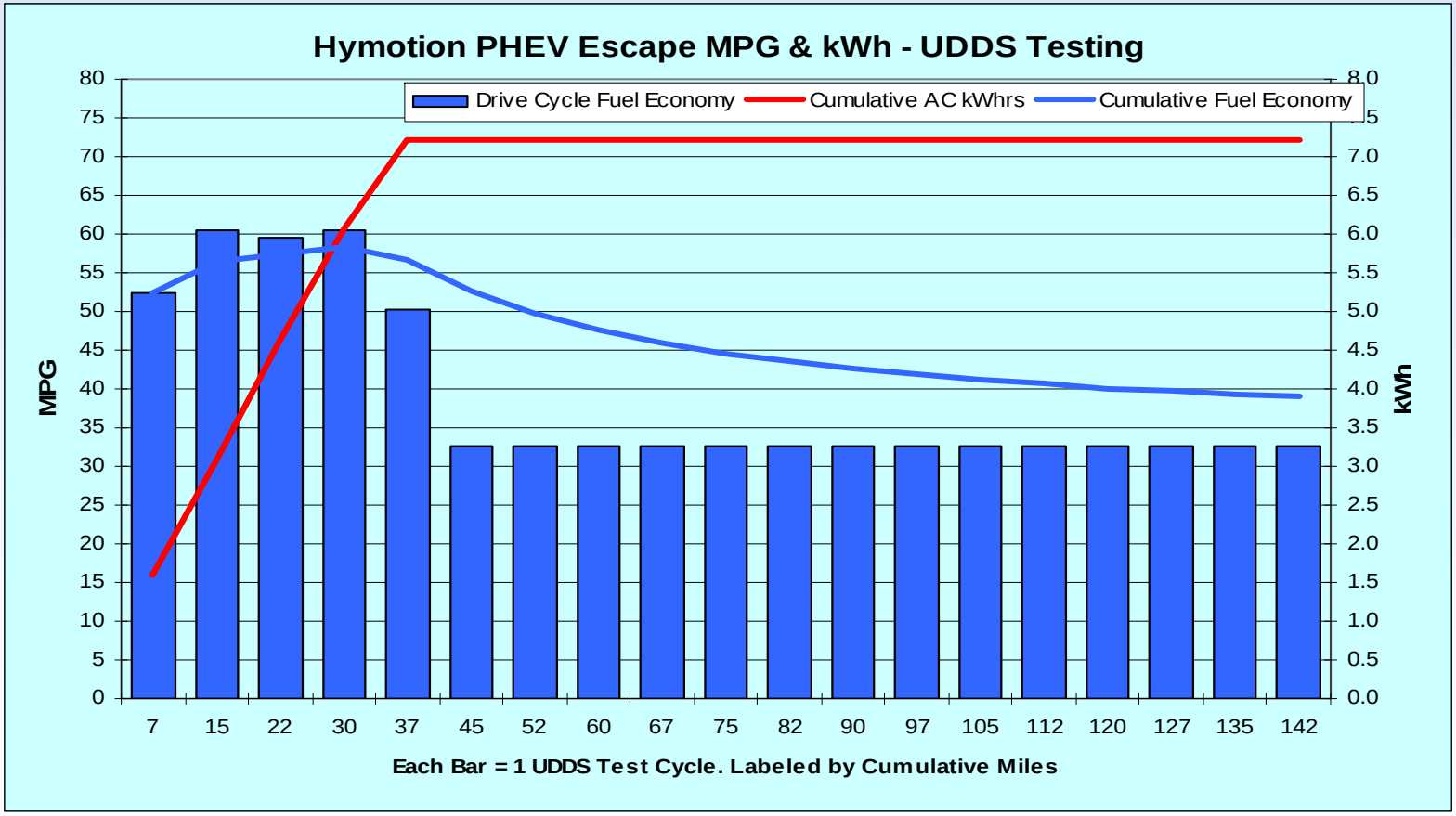


Hymotion Escape – UDDS Fuel Use

- **8.5 kWh A123Systems (Li) and Escape packs (AC kWh)**



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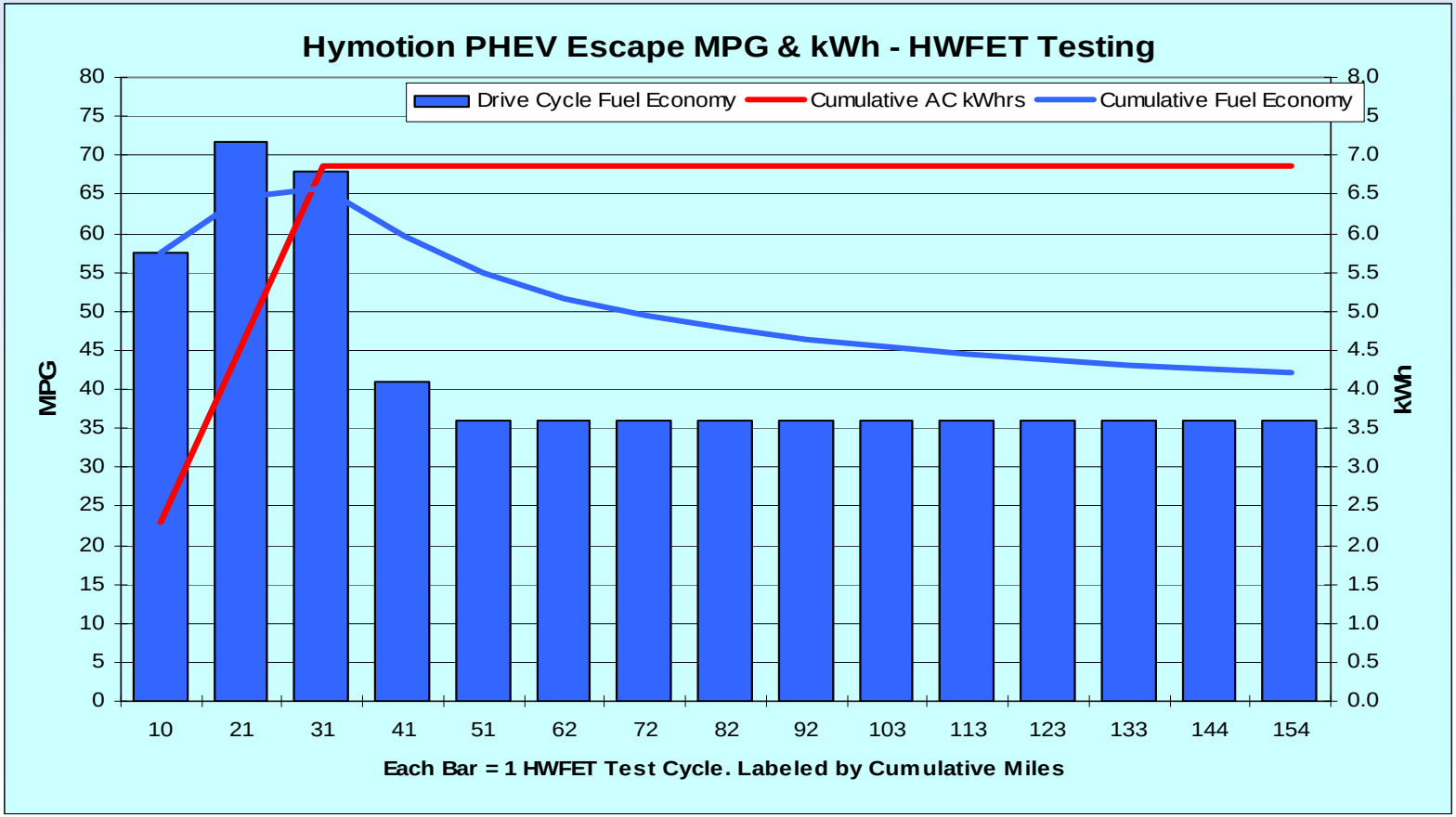
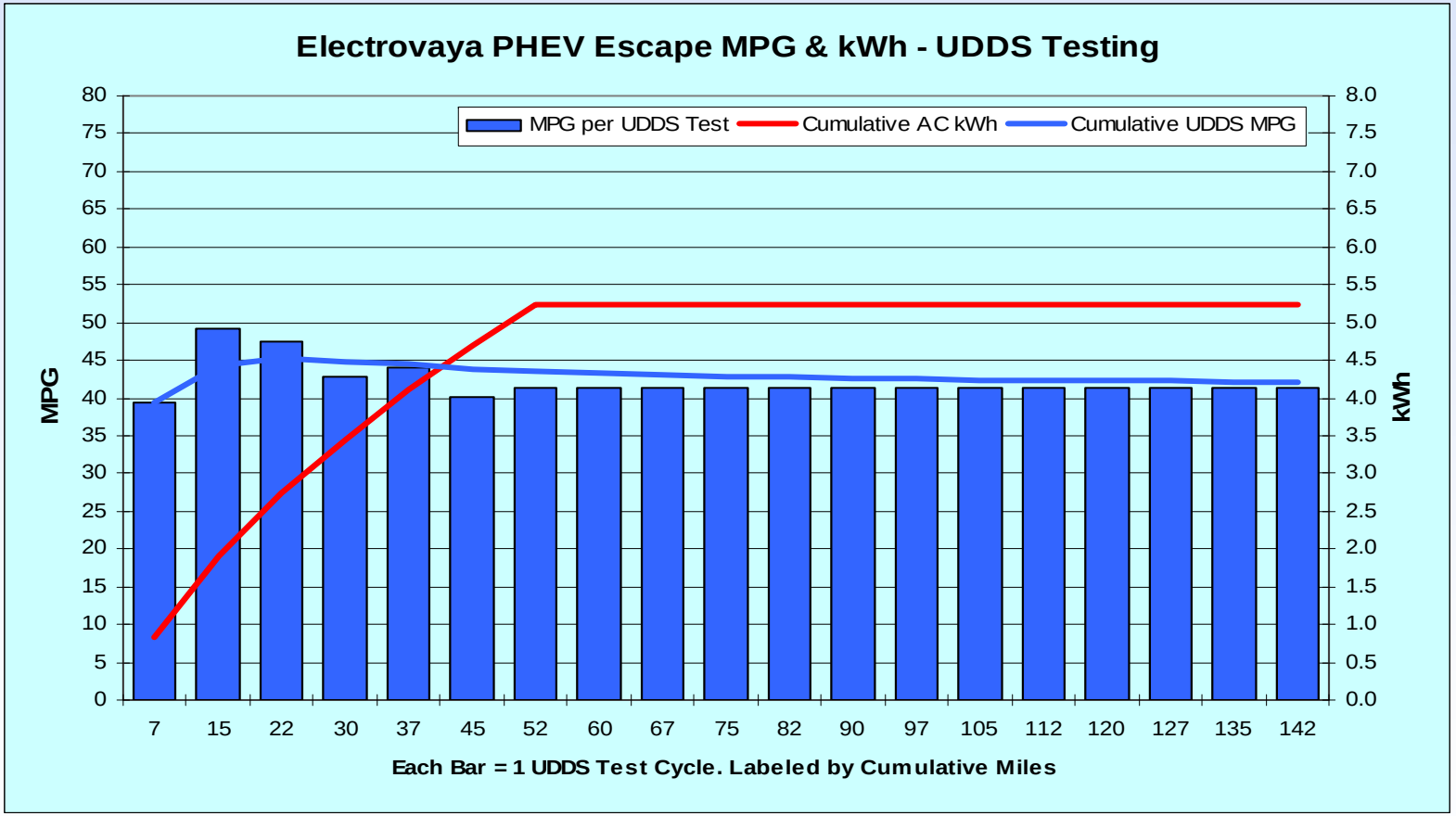


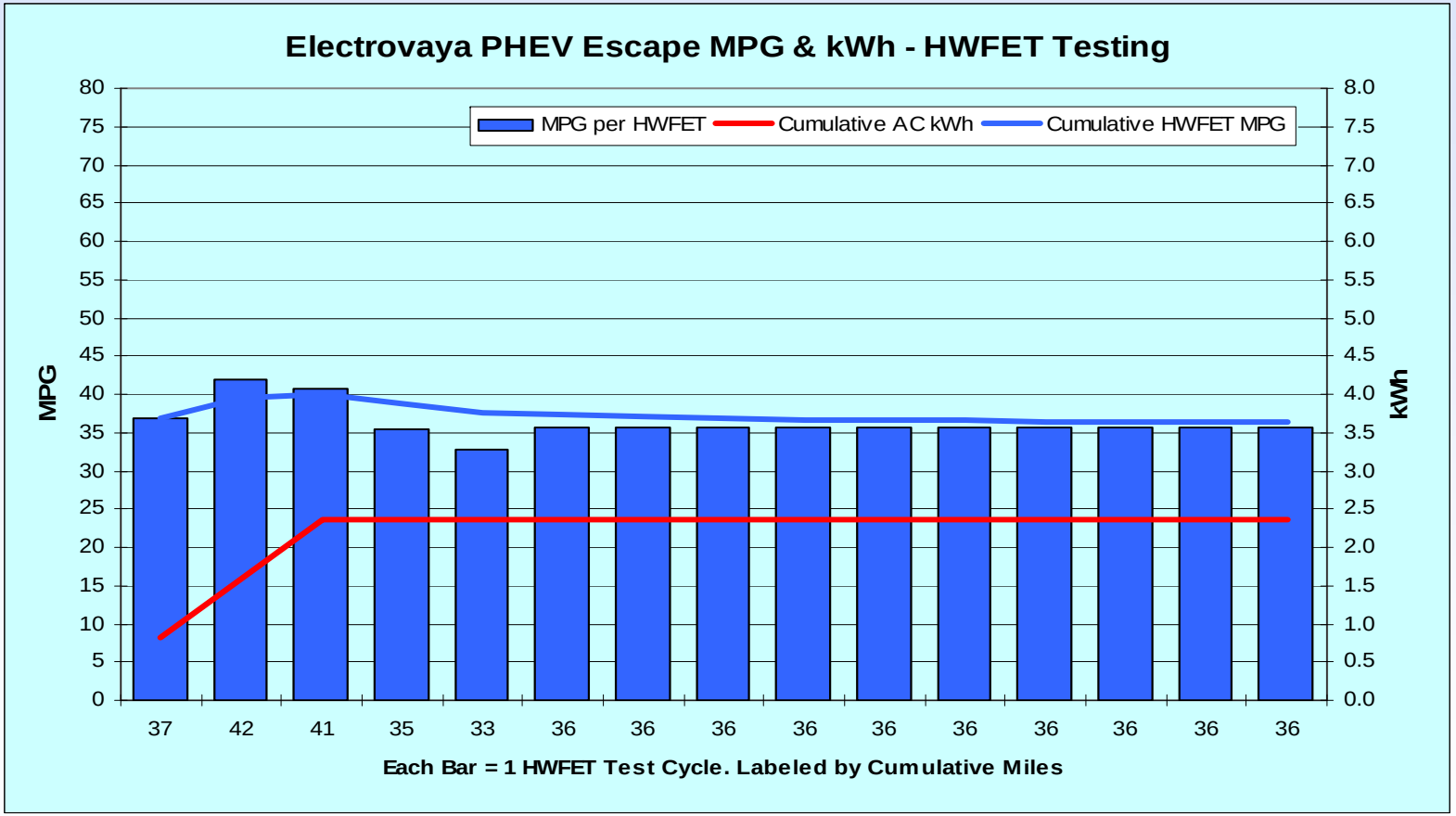
Electrovaya Escape – UDDS Fuel Use

- **12 kWh Electrovaya (Li) and Escape packs (AC kWh)**



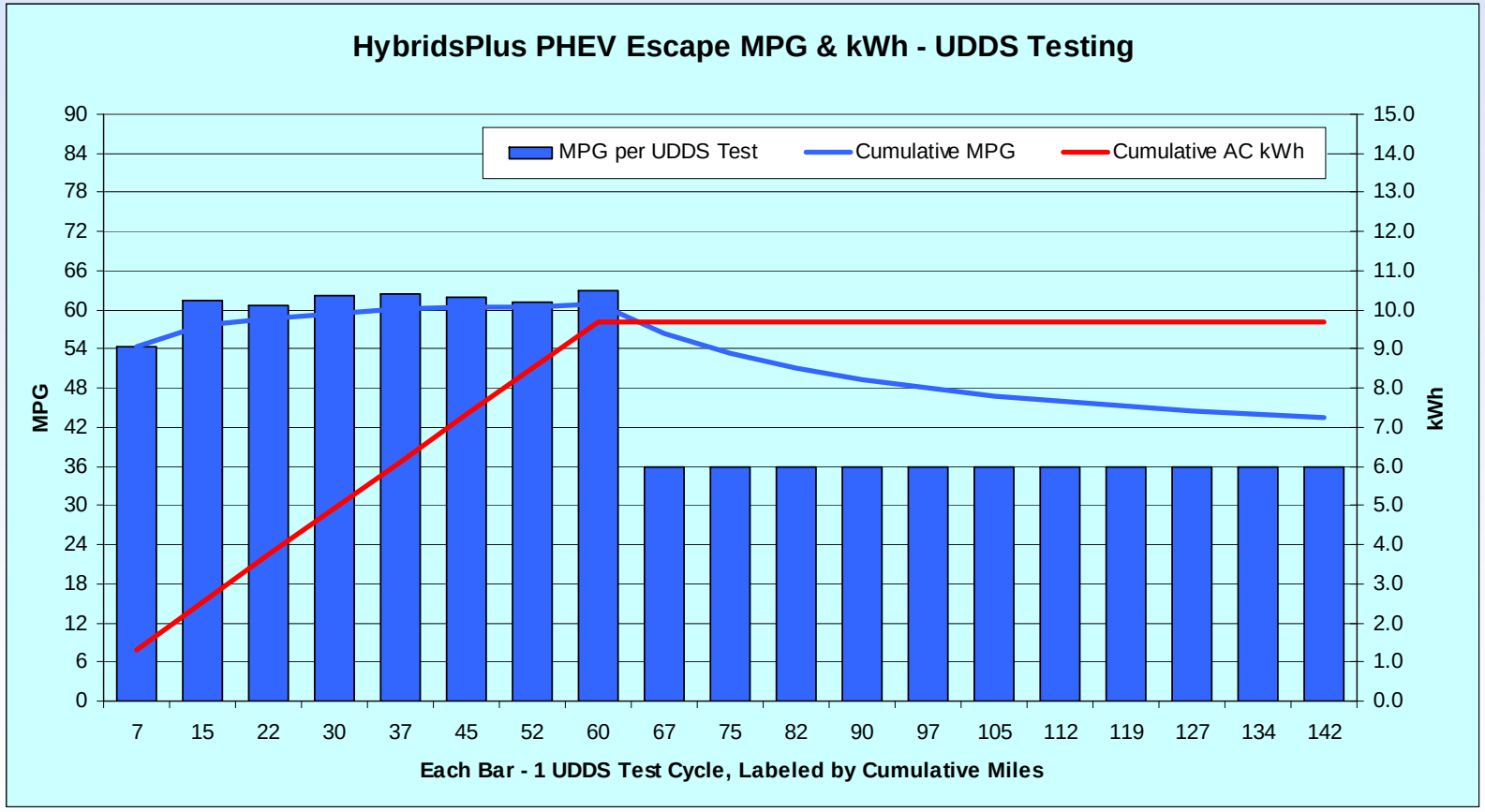
Electrovaya Escape – HWFETS Fuel Use

- **12 kWh Electrovaya (Li) and Escape packs – (AC kWh)**



Hybrids Plus Escape – UDDS Fuel Use

- **12 kWh Hybrids Plus pack (Li) – (AC kWh)**



Hybrids Plus Escape – HWFETS Fuel Use

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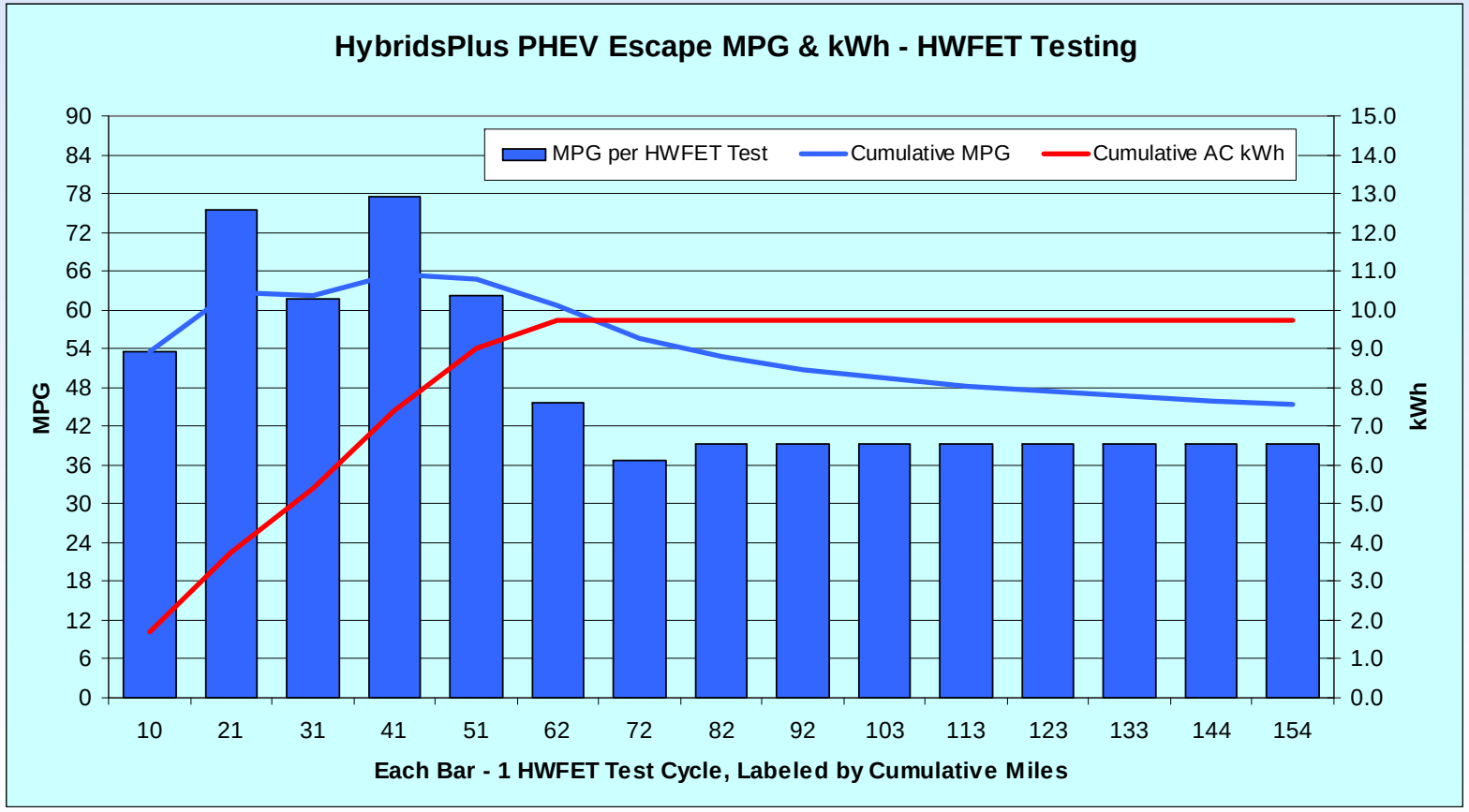


Renault Kangoo Test Results

- **First OEM series PHEV with 9.6 kWh (usable) Saft NiCad pack and 650cc gasoline engine**

Test Cycle	AC kWh per Mile	Miles per Gallon
Battery Only – UDDS	0.268	
Battery Only - HWFETS	0.155	
Battery Only @ Constant 45 mph	0.271	
Battery and Gas Cold UDDS	0.144	42.3
Battery and Gas Hot UDDS	0.110	39.4
Battery and Gas Hot HWFETS	0.042	40.9

PHEV Accelerated Testing

- Accelerated testing in Phoenix over 5,440 miles
- GPS units track distance, average and 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			

Hymotion Prius Gen I – 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	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

Hymotion Prius Gen II – 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	111.43	5.205	117.6
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	In testing		
100	2	8	12	6	600	26.48	10.91	56.5
200	2	18	12	3	600	16.01	10.41	57.7
Total	2540	3100	1404	167	5,440	Weighted Average		

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	15	600	25.00	14.29	42.7
40	2	2	12	5	600	31.52	11.05	56.1
40	0	4	12	5	600	32.44	11.36	55.5
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		66.1

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

Renault Kangoo – Accelerated Testing

Cycle	Urban	Highway	Charge	Reps	Total	Electricity		Gasoline	
(mi)	(10 mi)	(10 mi)	(hr)	(N)	(mi)	AC kWh	Mi/kWh	Gals	MPG
10	1	0	4	60	600	359.60	1.7	0	
20	1	1	8	30	600	131.96	4.6	0	
40	4	0	12	5	200	35.18	5.6	0	
40	2	2	12	5	200	33.22	6.0	0	
40	0	4	12	5	200	28.60	7.0	0	
60	2	4	12	10	600	57.96	10.4	13.3	45.1
80	2	6	12	8	640	44.62	14.4	16.6	38.6
100	2	8	12	6	600	Deleted*			
200	2	18	12	3	600	Deleted*			
Total	1560	1480	876	123	3,040				

*** Testing ended when gasoline engine and inverter failed. Each total distance slightly greater than 600 miles.**

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	Testing		
20	1	1	8	30	600	163.29	13.51	45.7
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		

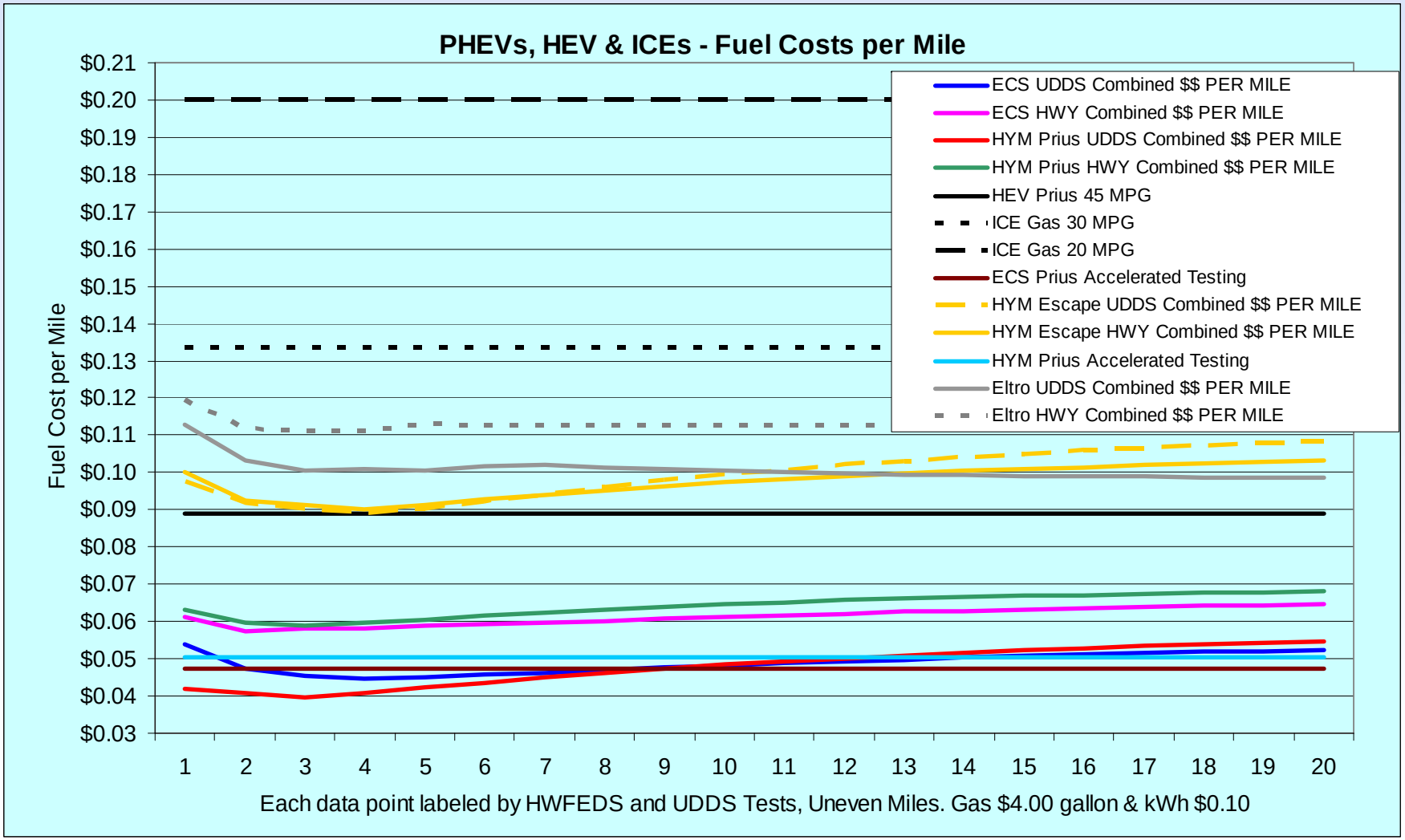
Each total distance slightly greater than 600 miles. HEV version = 27 mpg

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	In testing		
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	55.84	20.73	29.8
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	13.31	19.01	30.9
Total	2340	3100	1344	162	5440	Weighted Average		

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

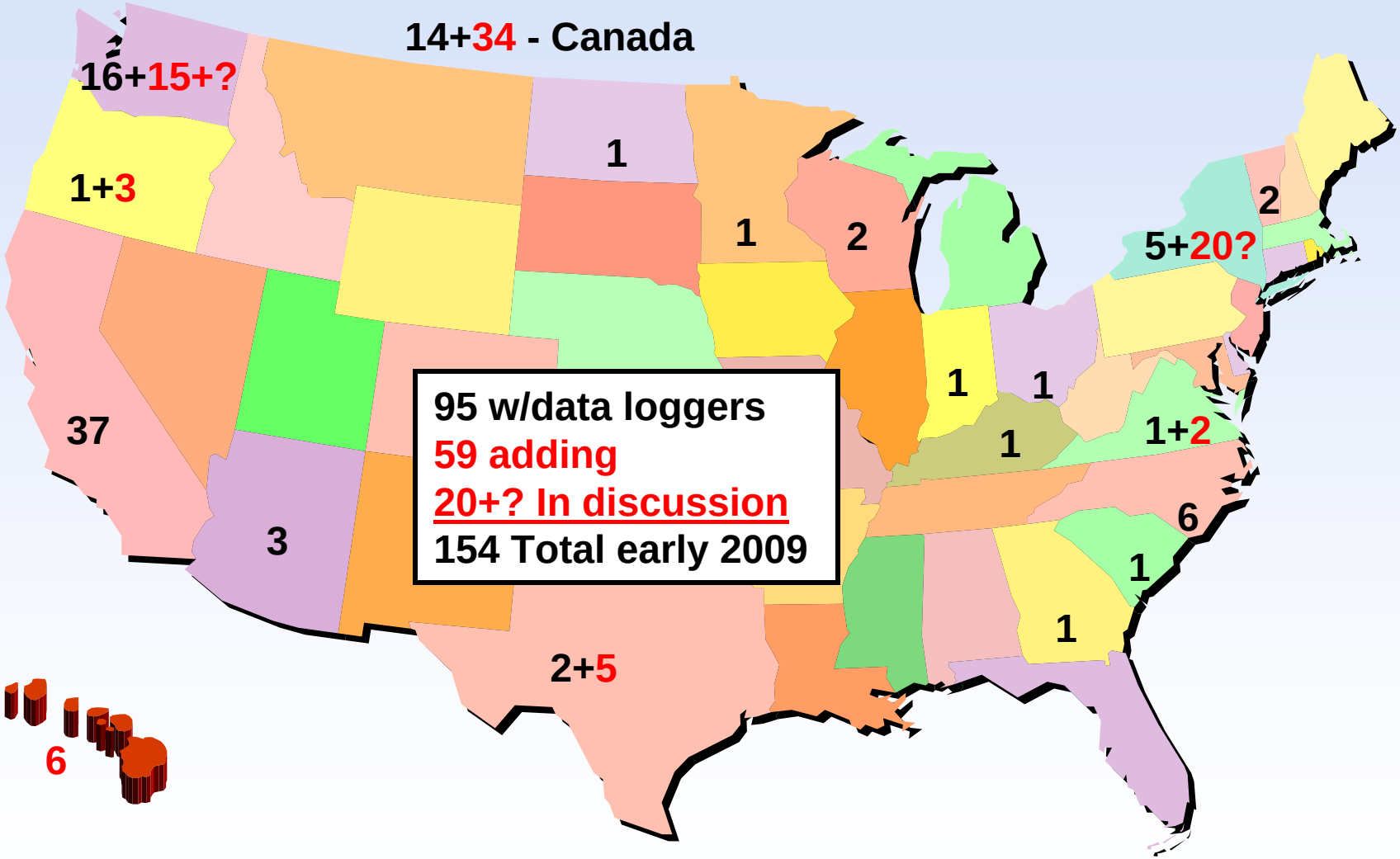
PHEV Vs. HEV and ICE Fuel Costs per Mile



Onroad Demonstration and Data Collection Partners

- ~75 Testing partners in the U.S. and Canada, including:
  - 36 Electric utilities (some via NRECA)
  - 6 City governments
  - 2 County governments
  - 2 State governments
  - 8 Universities and colleges
  - 2 Clean air agencies
  - 7 Private companies and advocacy organizations
  - 3 Governments of Canadian provinces
  - 2 Sea ports and U.S. military organizations
  - 2 PHEV conversion companies

PHEVs and Demonstration Locations



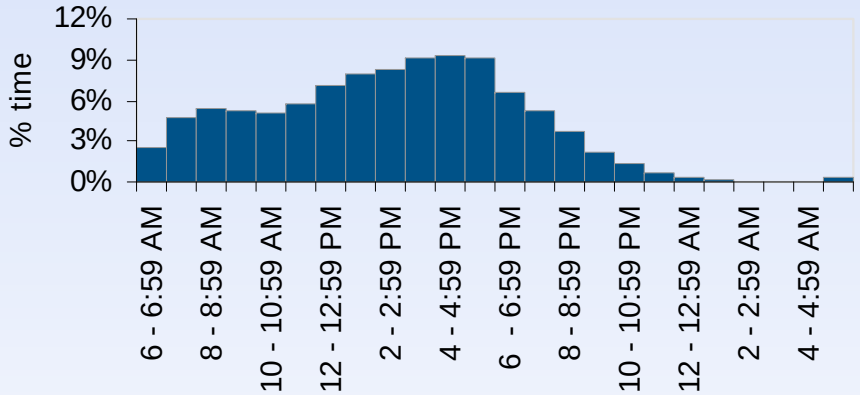
Off-board Charging Patterns

Average number of charging events per vehicle per month	20
Average number of charging events per vehicle per day when vehicle driven	0.7
Average number of trips between charging events	3.9
Average distance driven between charging events (mi)	34.0
Average duration of charging event (hr)	2.4
Average energy per charging event (DC kWh)	1.8
Average charging energy per vehicle per month (DC kWh)	35.3

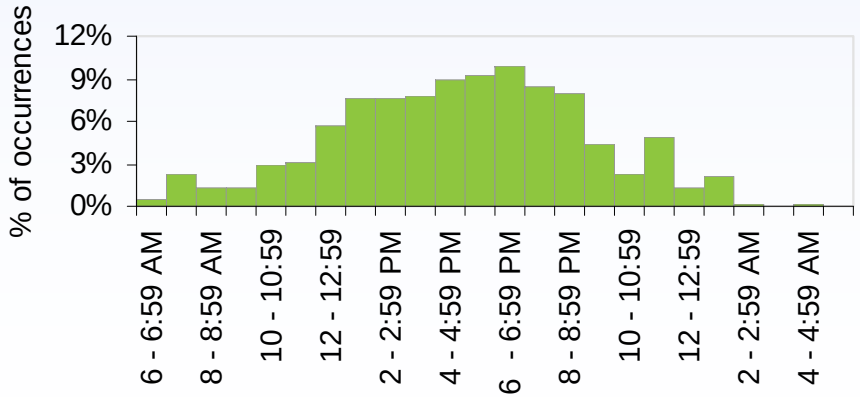
Off-board Charging Patterns

- **28 Hymotion Priuses, Jan – Jun 2008**

Time of Day When Driving



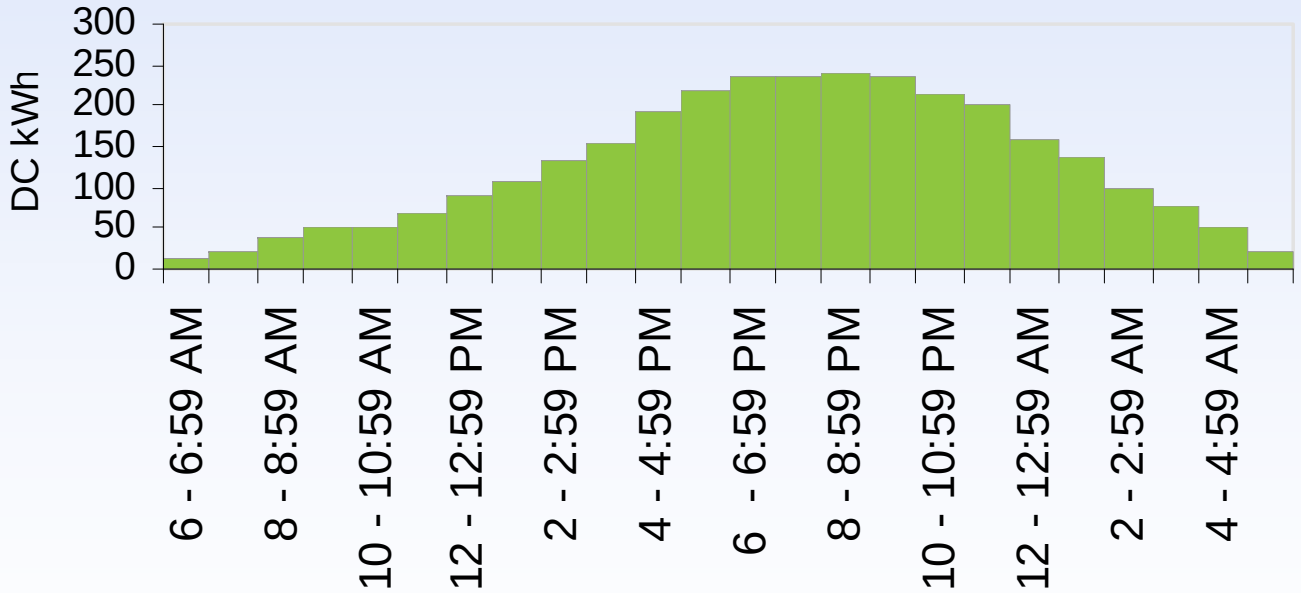
Time at the Start of Charging Events



Off-board Charging Patterns

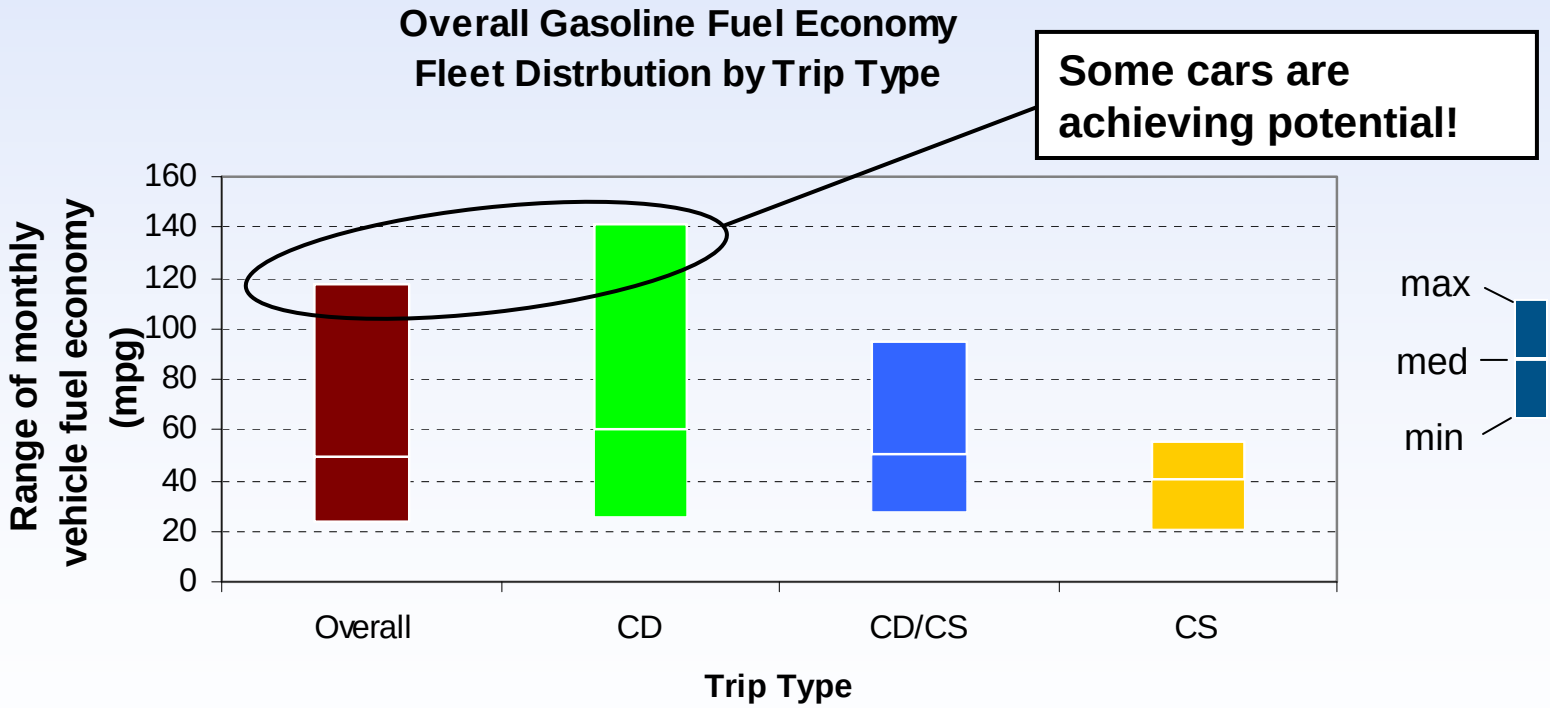
- **28 Hymotion Priuses, Jan – Jun 2008**

Energy Consumed vs. Time of Day When Charging



PHEV Fleet Performance

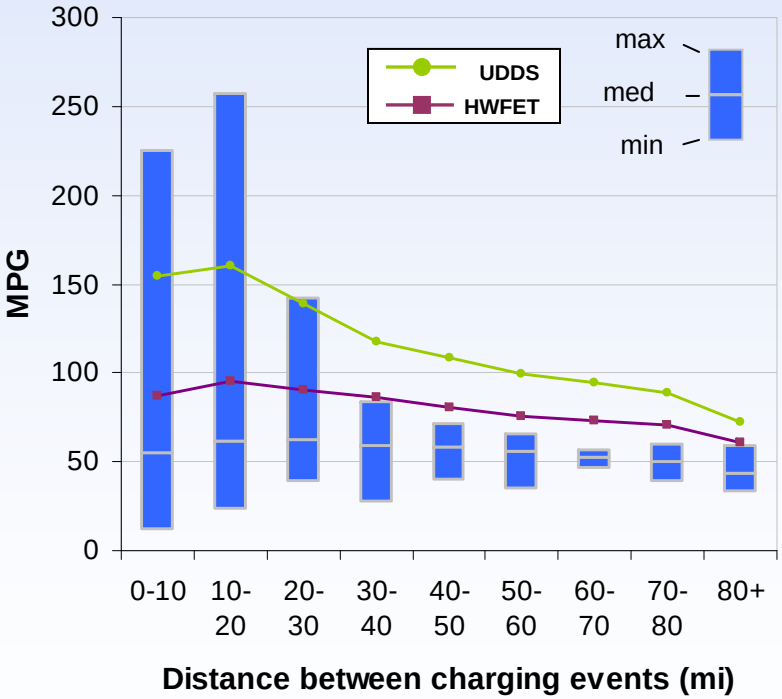
- **28 Hymotion Priuses, Jan – Jun 2008**
- **Range of monthly vehicle fuel economy results:**



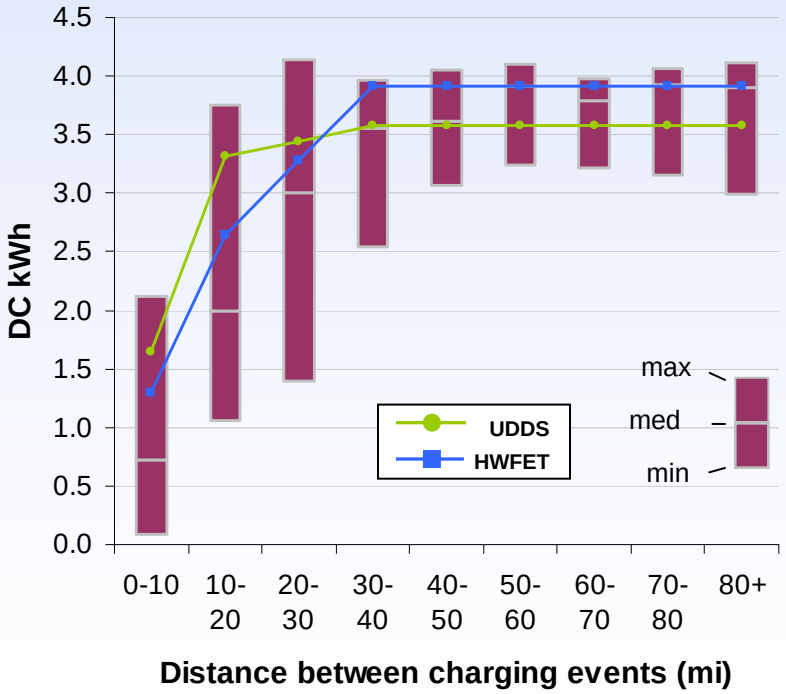
Fleet Fuel and Electricity Between Charging Events

23 Hymotion Priuses, Jan – Jul 2008

MPG vs. Distance Driven Between Charging Events



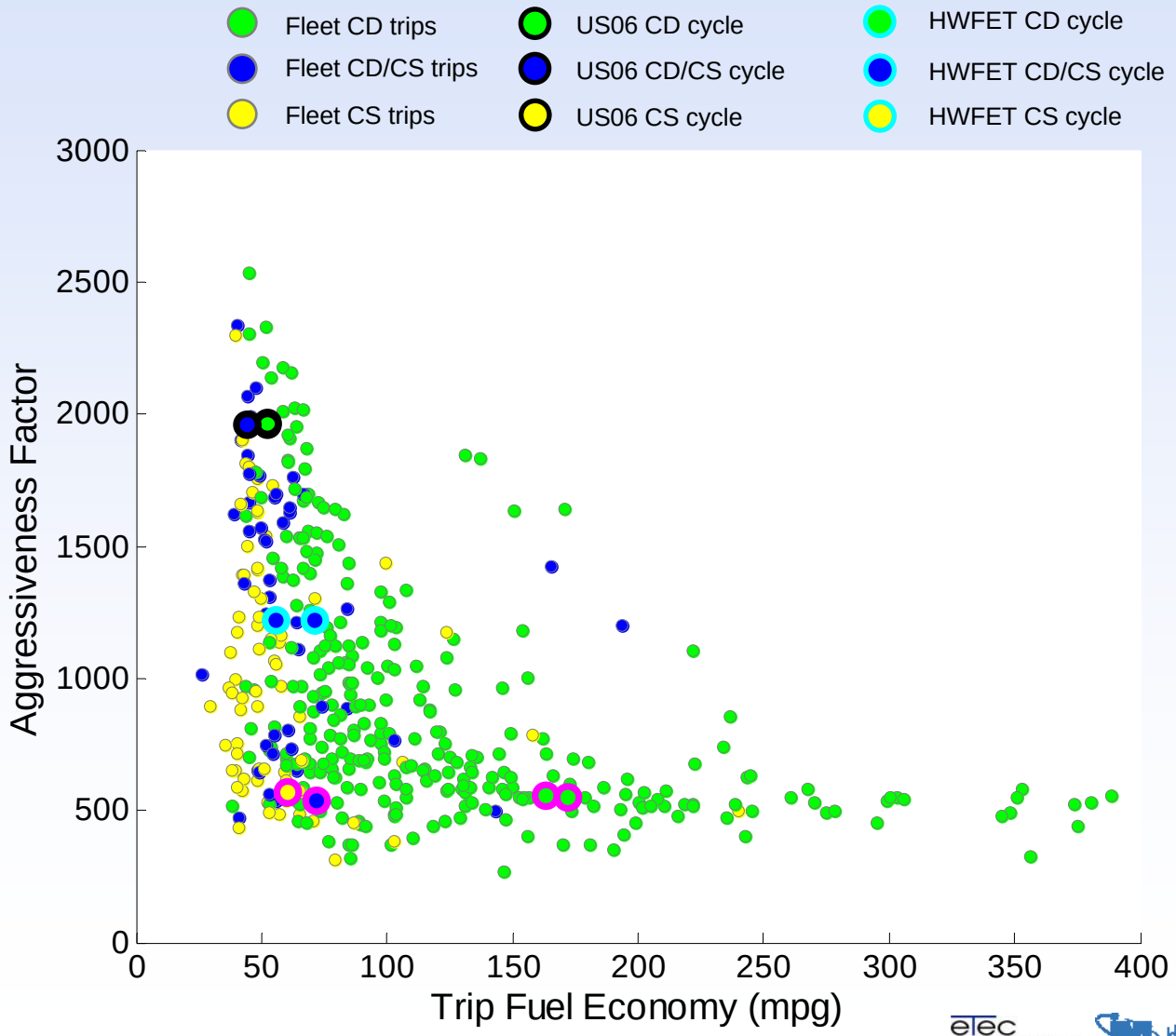
DC kWh vs. Distance Driven Between Charging Events



(EV-only segments not included)

Aggressiveness vs. MPG

Aggressiveness factor = trip mean(veh speed * accel pedal position)

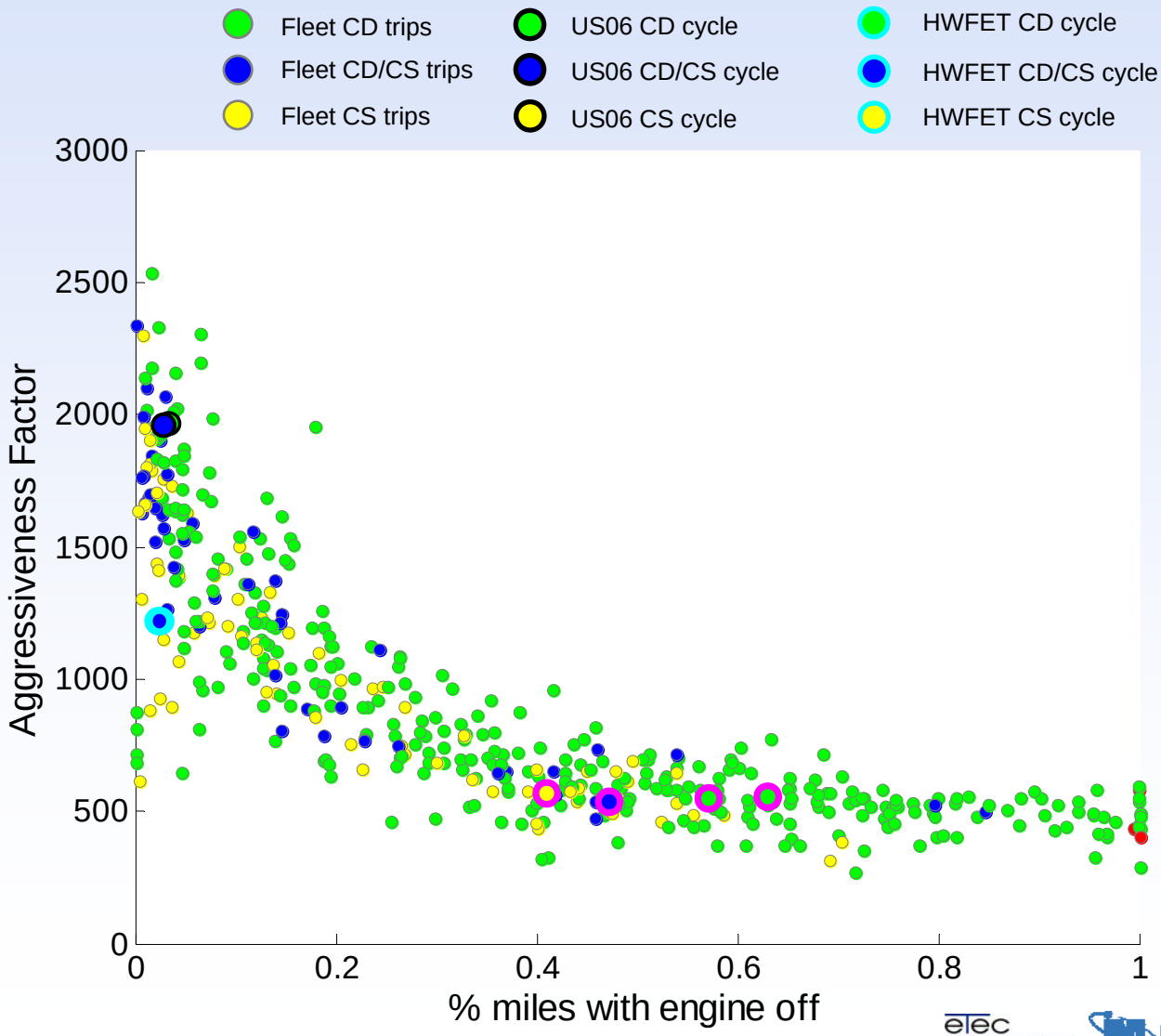


Random trips from Prius fleet with no A/C, distance > 3 miles, from Apr – Jun

First 2 miles of each trip removed to exclude cold starts

Aggressiveness vs. % EV miles

Aggressiveness factor = trip mean(veh speed * accel pedal position)



Random trips from Prius fleet with no A/C, distance > 3 miles, from Apr – Jun

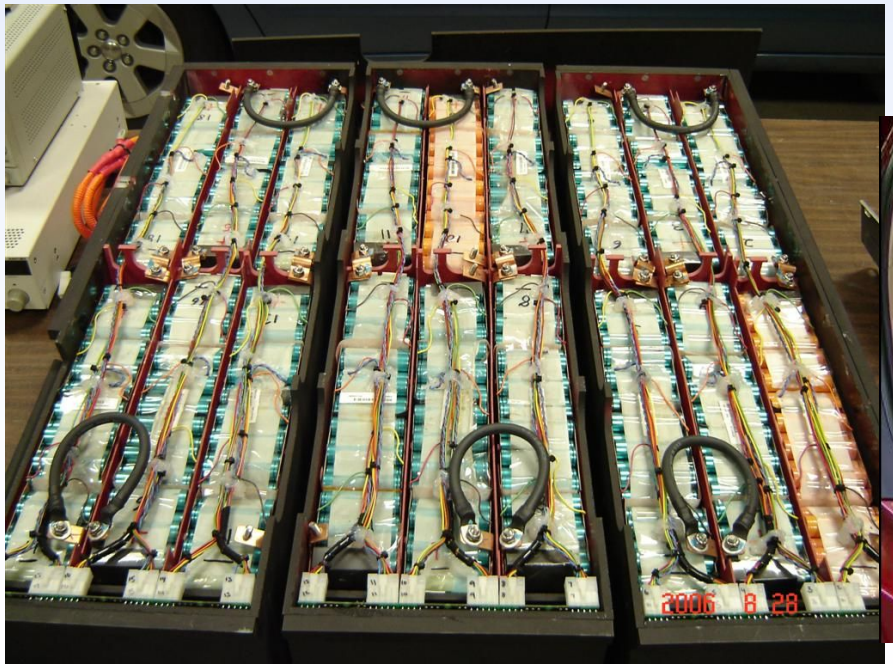
First 2 miles of each trip removed to exclude cold starts

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

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)**



NYSERDA Testing Partnership

- **AVTA is testing New York State Energy Research and Development Agency's PHEV conversions, stated 2007**
- **Fleet testing of ~20 PHEVs CY08/09**

Model	Baseline Testing	Accelerated Testing
EnergyCS Prius	Completed	Completed
Hymotion Prius	Completed	Completed
Hymotion Escape	Completed	Ongoing
Electovaya Escape	Completed	Ongoing
HybridsPlus Escape	Ongoing	Ongoing

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, nine vehicles converted to date

- 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 demonstrations 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

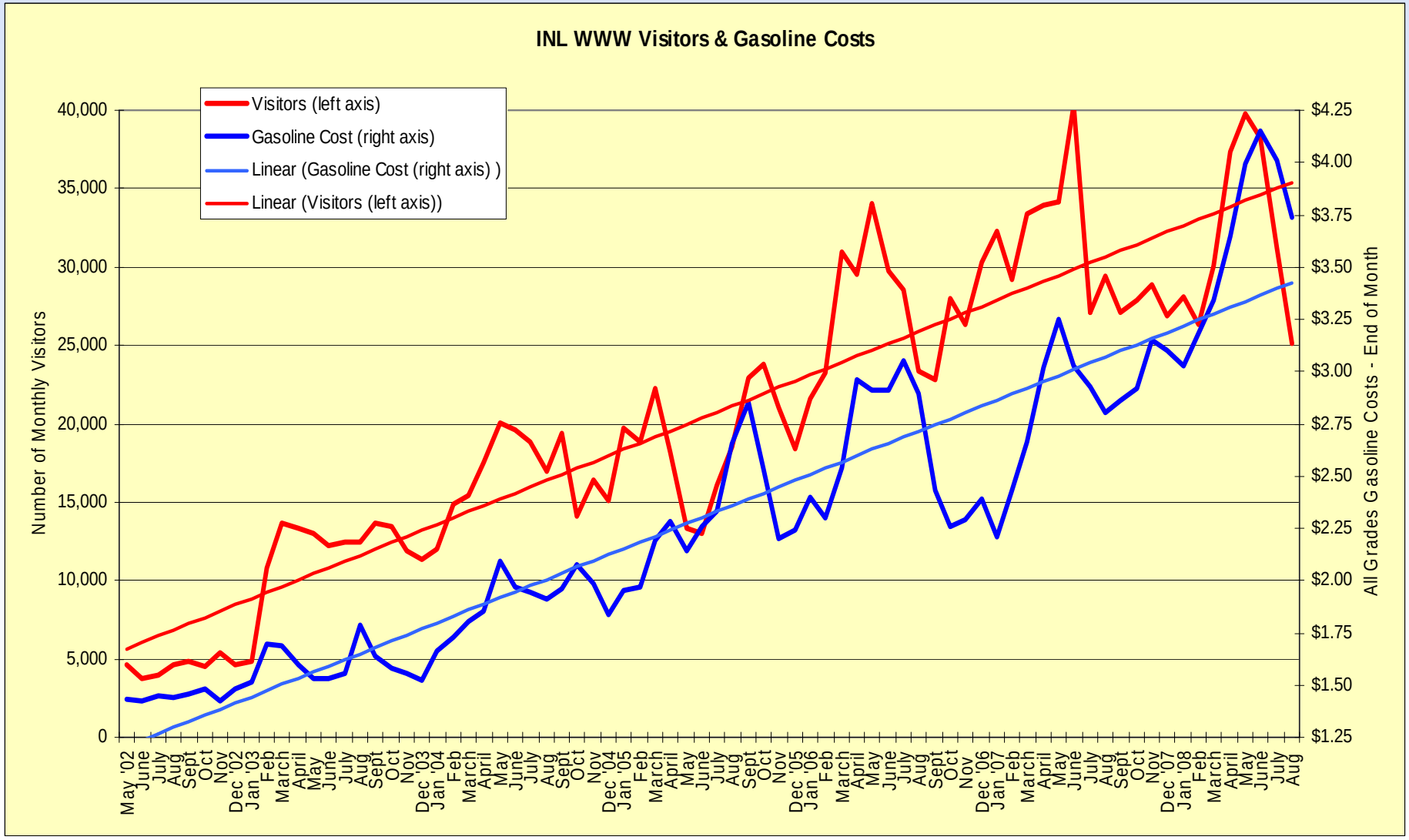
Fleet Demonstration Partners – cont'd

- Washington State
  - Various groups across the state planning total of 14 Hymotion Priuses
  - Started 4/2008; 6 conversion installations this week
- 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
- National Rural Electric Cooperative Association
  - 10 Prius and Escape PHEVs from Hymotion, EnergyCS, and Hybrids Plus operated by rural electric coop utilities, 6 converted to date, started 2007
- Hawaii, with 6 Hymotion Prius on Maui and Oahu
  - Planned start 1/2009
- Vancouver, British Columbia
  - Planning 34 conversions with V2Green data loggers

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. Winter 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 TADA PHEV solicitation**
- **Will consider other suitable PHEV conversions for vehicle/battery testing**

AVTA Webpage Use and Gasoline Costs



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Additional Information

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

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