

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

British Columbia PHEV Demonstration Workshop – AVTA's PHEV Testing and Demonstration Activities

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BC Hydro and Powertech Labs
Vancouver, British Columbia. October 2008**

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
- INL is a 890 square mile eastern Idaho based DOE multi-program laboratory with 3,600 staff
- 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, ~75 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



PHEV Questions

- Are PHEVs technically and economically feasible as a transportation option?
- What are the petroleum savings and electricity demands?
- Will fleets and the public adapt to plugging in (charging) PHEVs to maximize mpg?
- Is a two-fuel scenario a difficult transition?
- What are the charging infrastructure needs, including 110V versus 220V? Fast charging?
- V2Grid – economic benefit or liability to the vehicle operator?
- To answer these questions, the AVTA is testing and field demonstrating nine different PHEV models and charging infrastructure

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			VEHICLE TEST RESULTS		
Weights Design Curb Weight: 3037 Vehicle Test Weight: 3337 lbs GVWR: 3795 lbs GVWR F/R: 2333/2250 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: 3.2V Nominal System Voltage: 184.8V Nominal Pack Capacity: 4.7 kWh Measured Usable Capacity: 2.96 kWh Charge System: Input Voltages: 120V Required Breaker Currents: 15-Amp Charge Power Output: 1.2 kW Charge Plug Type: NEMA 5-15 Estimated 80% Charge Time: 4.4 hrs Estimated 100% Charge Time: 5.5 hrs	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 OFF¹ Cold Start Charge Depleting²: Fuel Economy: 146.72 MPG A/C kWh Consumed ³ : 1.47 kWh/mi Charge Depleting²: Average Fuel Economy: 167.2 MPG A/C kWh Consumed ³ : 1.48 kWh/mi Charge Sustaining⁴: Fuel Economy: 60.8 MPG Fuel Economy with A/C On^{1,2} Cold Start Charge Depleting²: Fuel Economy: 128.9 MPG A/C kWh Consumed ³ : 1.99 kWh/mi Charge Depleting²: Average Fuel Economy: 153.2 MPG A/C kWh Consumed ³ : 1.97 kWh/mi Charge Sustaining⁴: Fuel Economy: 46.5 MPG		

UDDS Fuel Economy ⁵			HWFET Fuel Economy ⁵		
Distance (miles)	Fuel Economy (mpg)	A/C Energy Consumed (kWh)	Distance (miles)	Fuel Economy (mpg)	A/C Energy Consumed (kWh)
10	154.8	1.65	10	87.48	1.30
20	160.3	3.31	20	95.27	2.64
40	117.4	3.58	40	86.11	3.92
60	99.40	3.58	60	75.79	3.92
80	88.88	3.58	80	70.52	3.92
100	83.71	3.58	100	67.36	3.92
200	72.26	3.58	200	61.05	3.92

TEST NOTES:
 1. Cumulative fuel economy over EPA standard urban drive cycle.
 2. Vehicle tested 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 conversion calculations.
 5. A/C on outdoor setting with full burner power.
 6. Cold start cumulative fuel economy values include cold start.
 7. A/C energy based on estimated charge efficiency.

This vehicle meets all EPA and California 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**

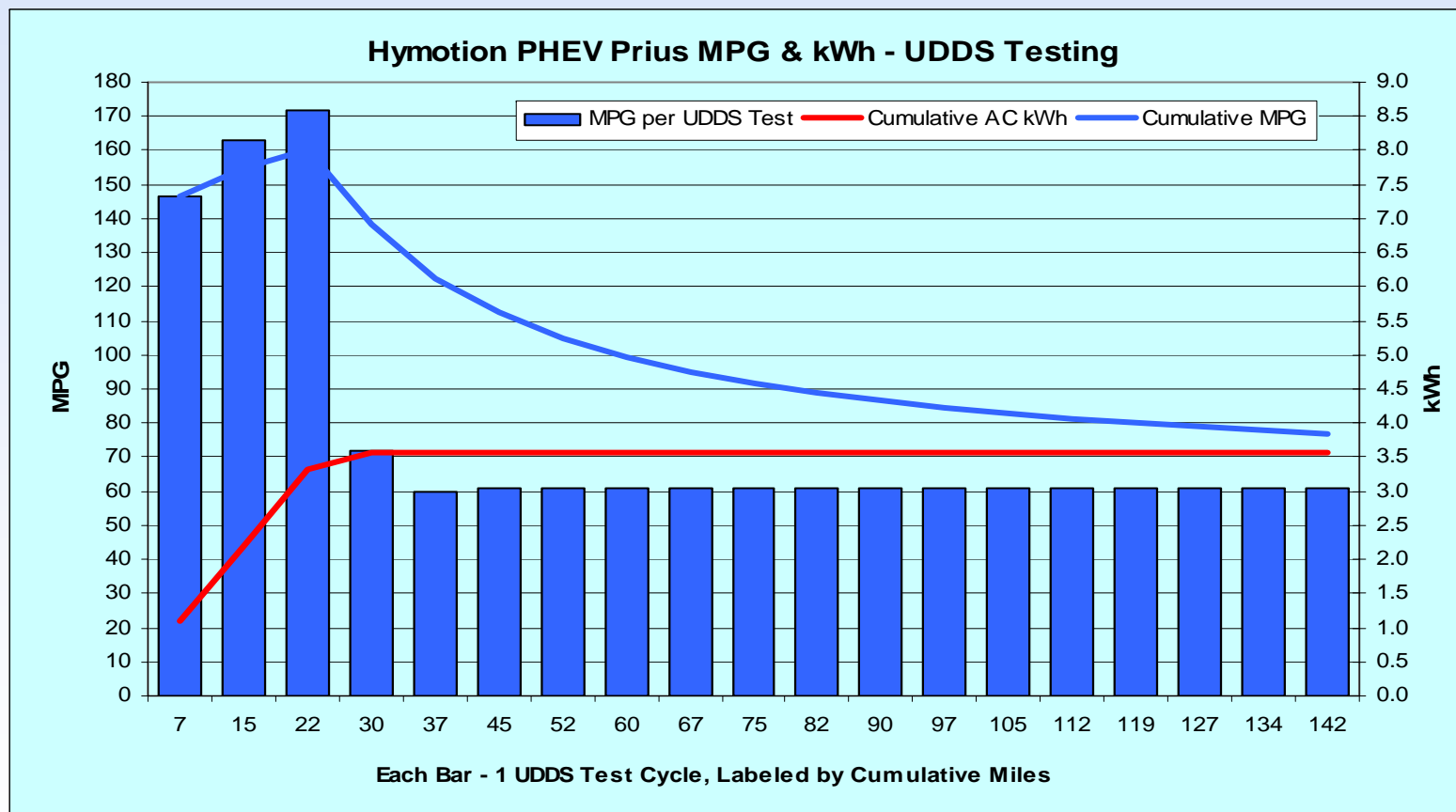
PHEV Baseline Performance Testing

- **EETEC conducts initial track testing near Phoenix, AZ**
 - Includes coastdown (determination of dynamometer coefficients), acceleration, top speed, braking, charging, and durability testing
- **Argonne 5-day dynamometer testing regime includes:**
 - Charge depleting and sustaining test cycles, as well as hot and cold starts
 - At least 26 UDDS (Urban Dynamometer Driving Schedule) and HWFEDS (Highway Fuel Economy Driving Schedule) dynamometer test cycles



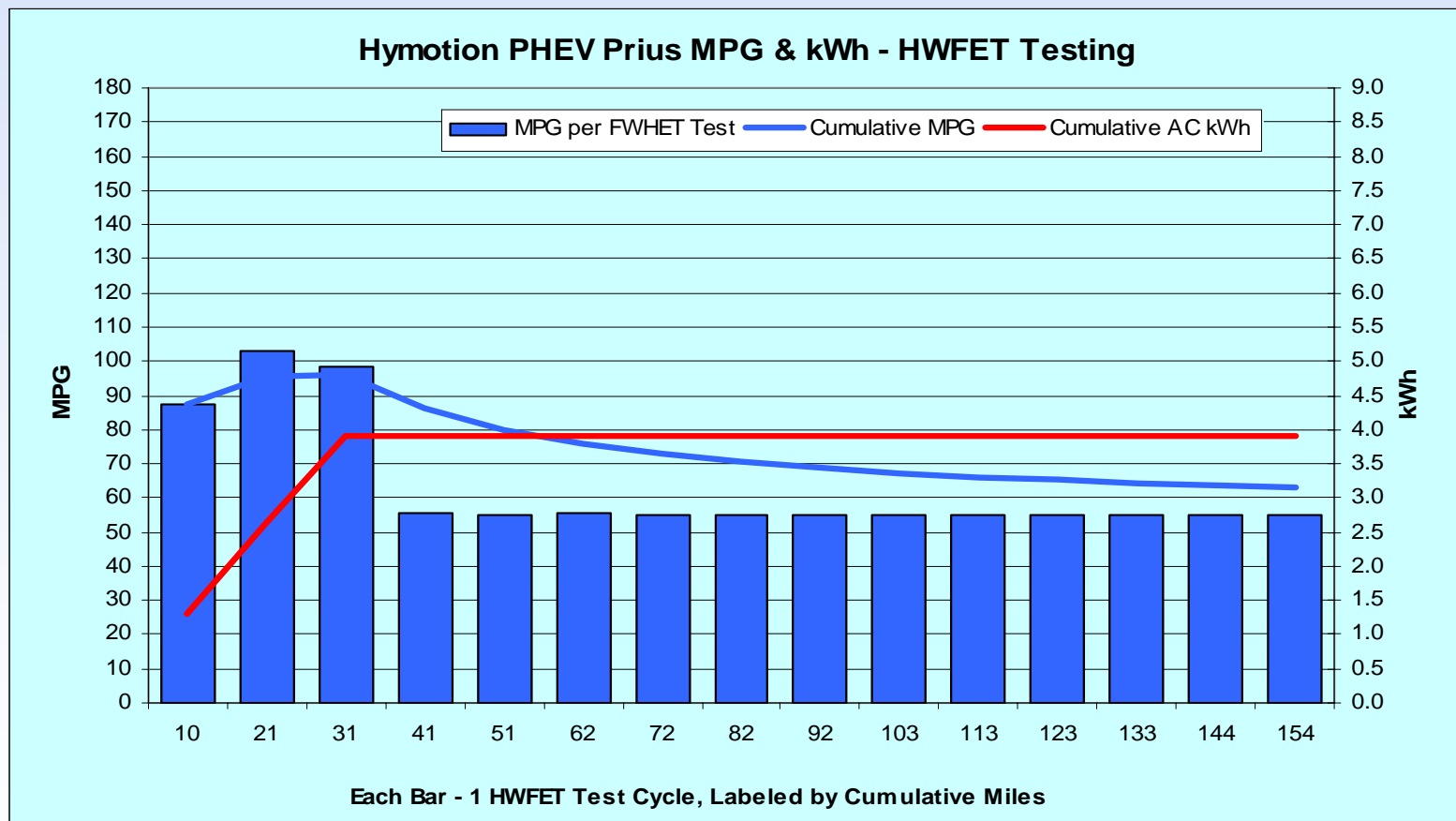
Hymotion Prius – UDDS Fuel Use

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



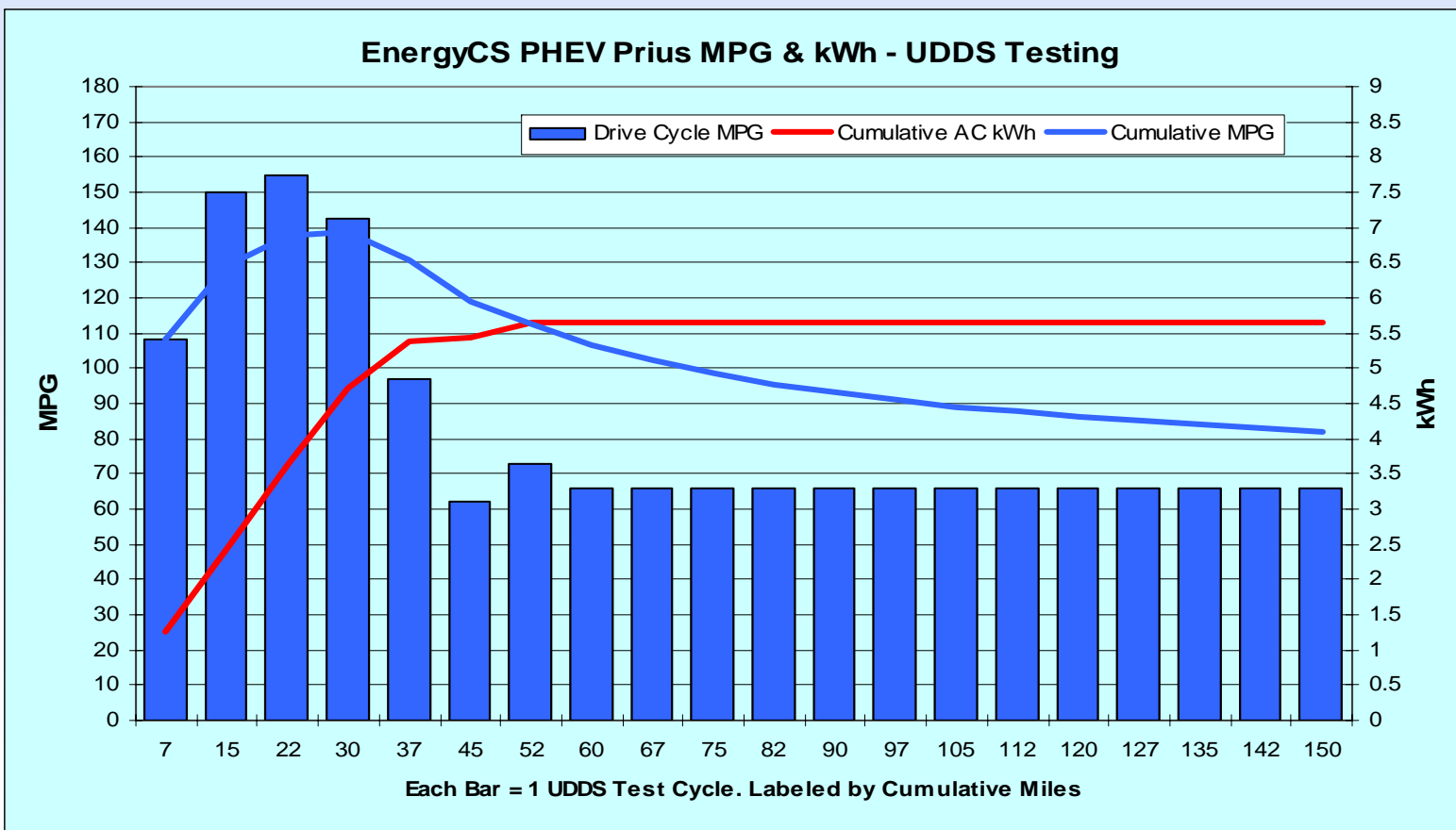
Hymotion Prius – HWFETS Fuel Use

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



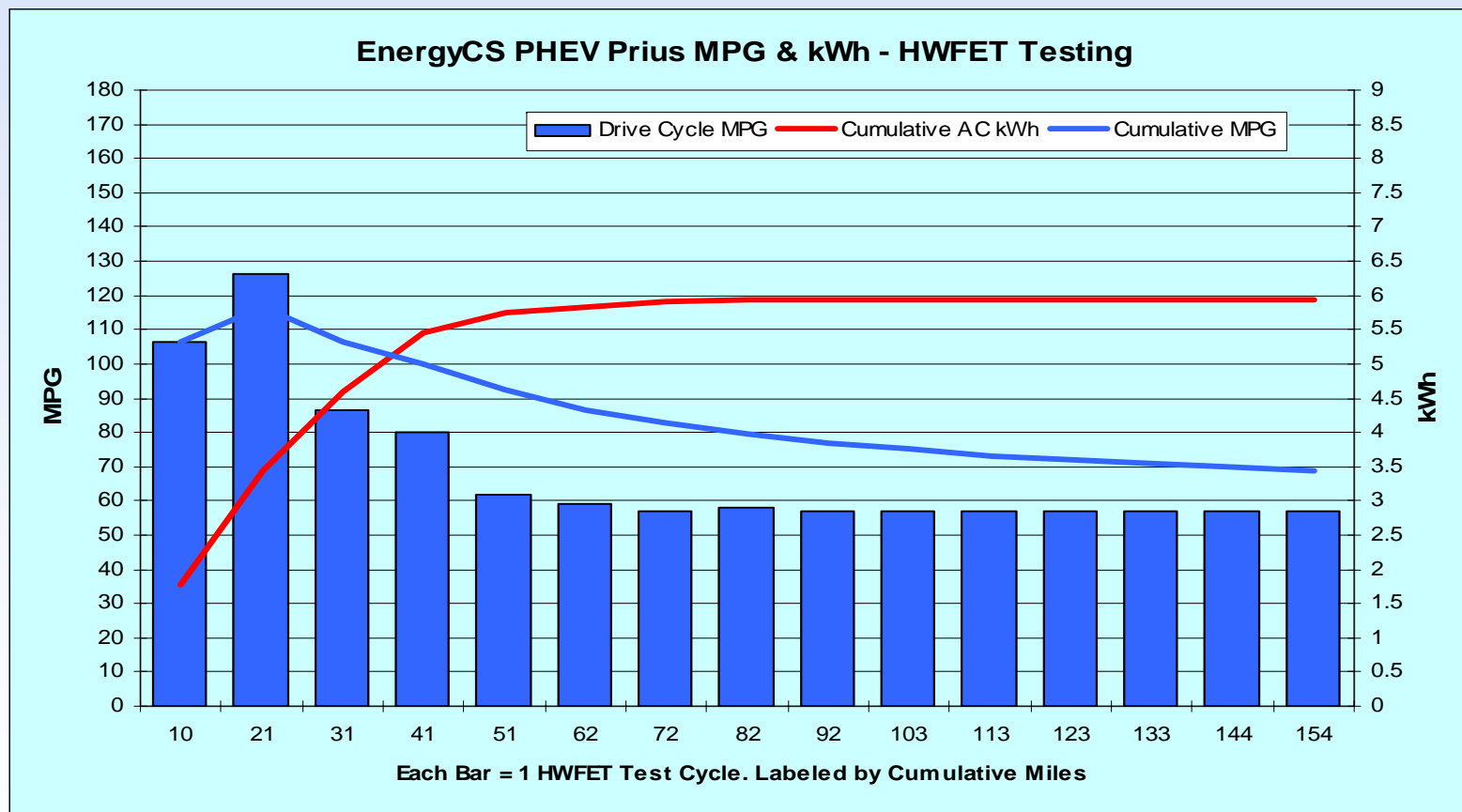
EnergyCS Prius – UDDS Fuel Use

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



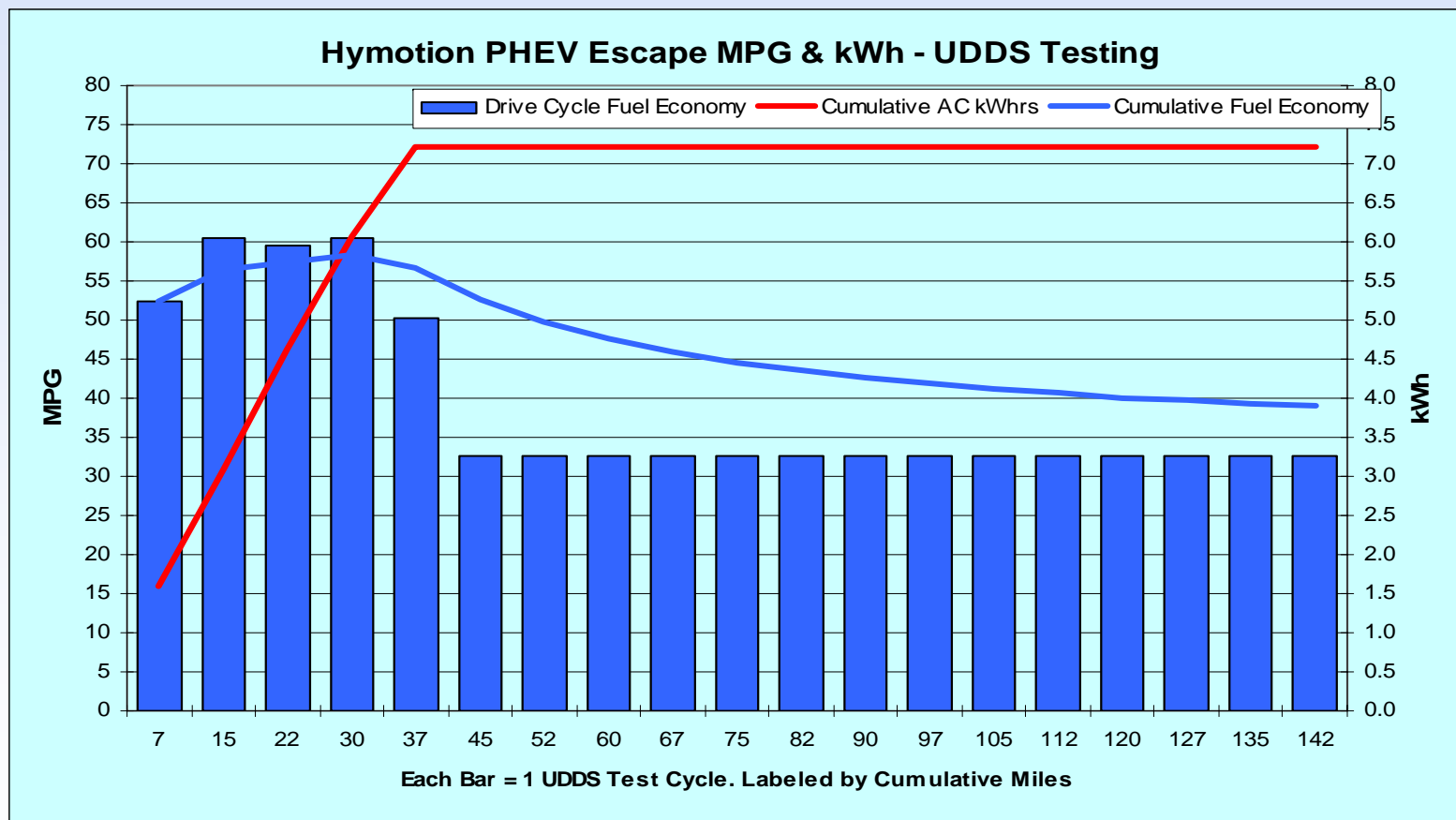
EnergyCS Prius – HWFETS Fuel Use

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



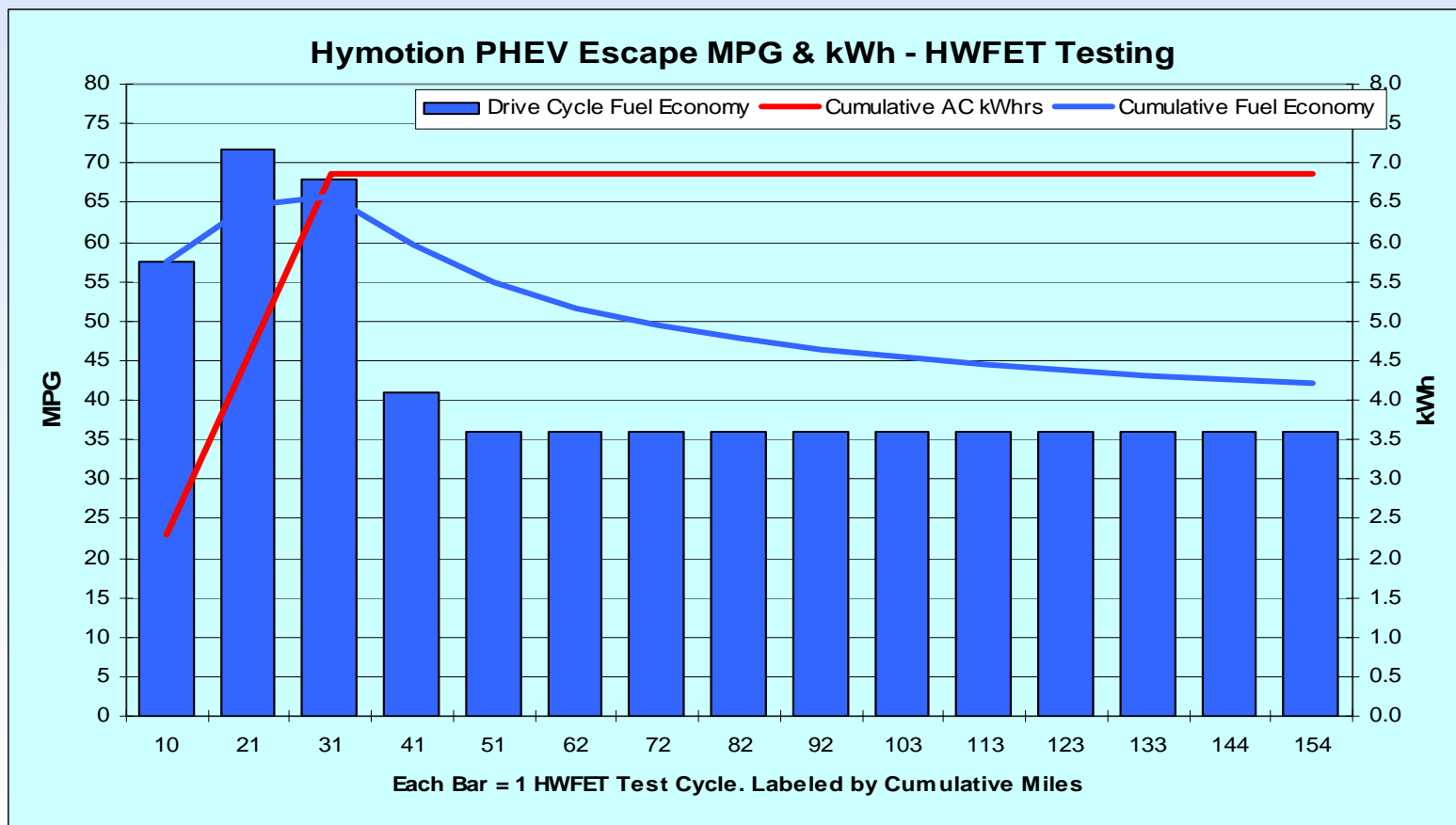
Hymotion Escape – UDDS Fuel Use

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



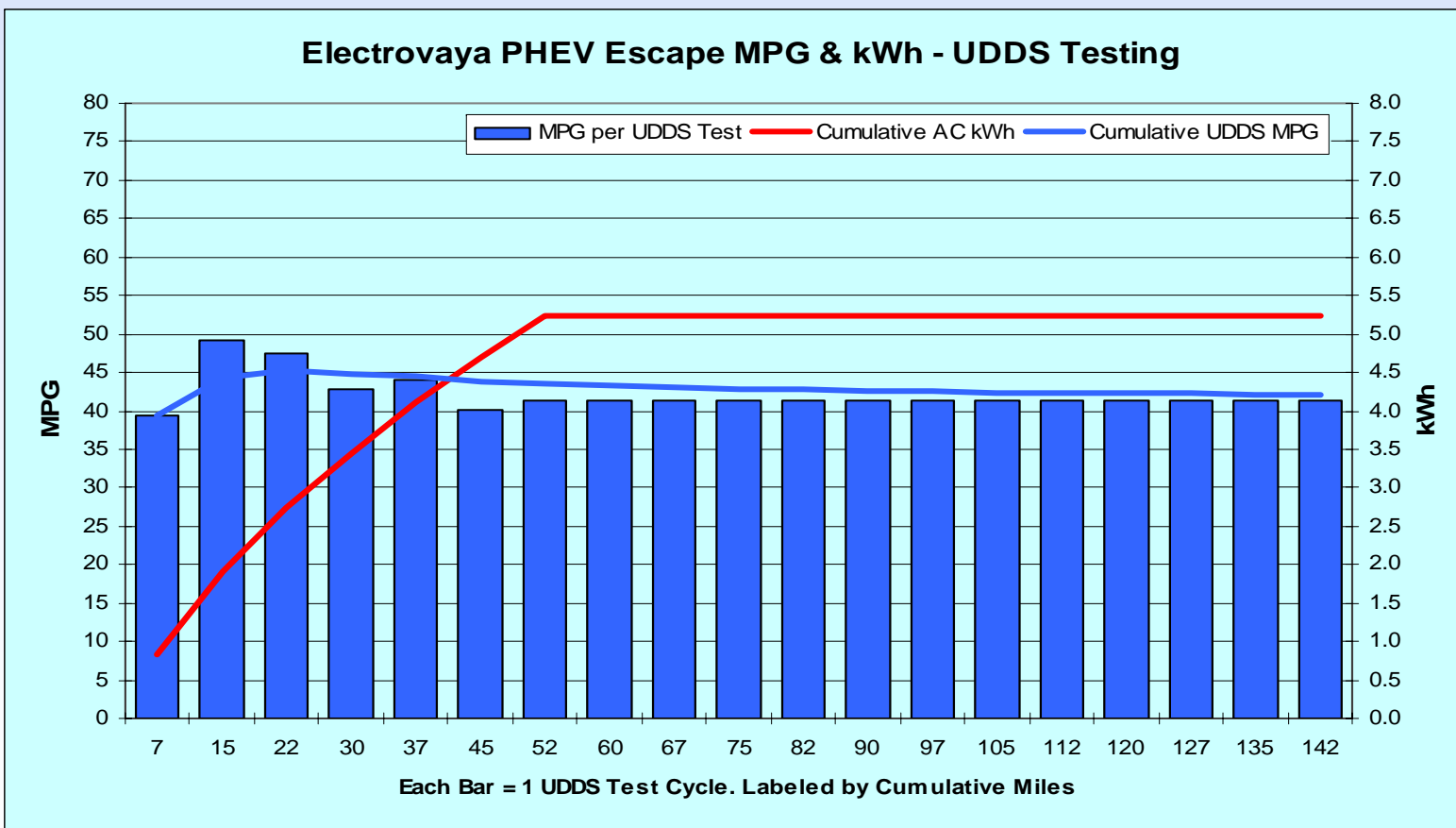
Hymotion Escape – HWFETS Fuel Use

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



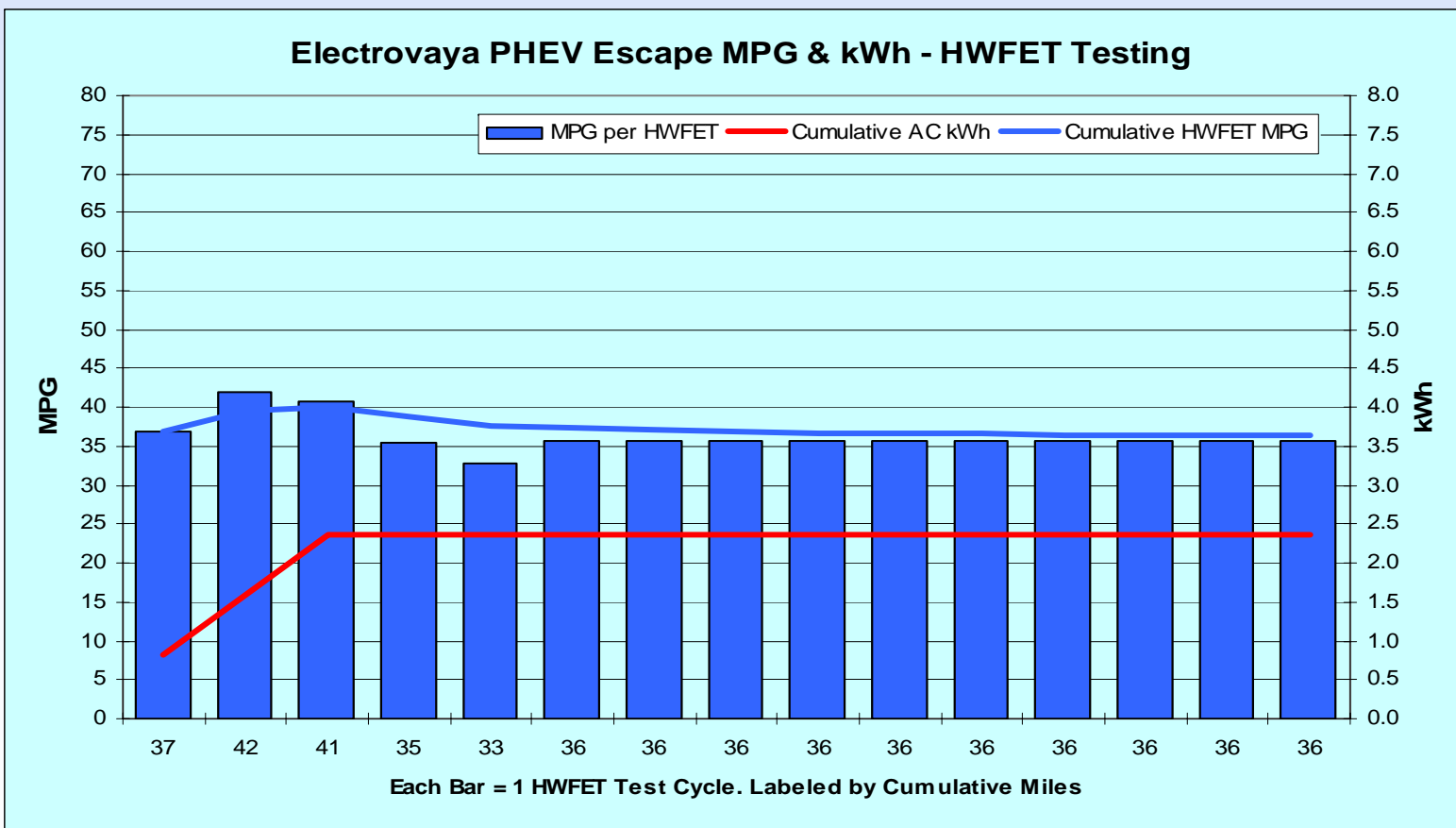
Electrovaya Escape – UDDS Fuel Use

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



Electrovaya Escape – HWFETS Fuel Use

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



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 mpg	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 – 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

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*	Testing		
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		

*Software updated and cells replaced. Rerun. 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		

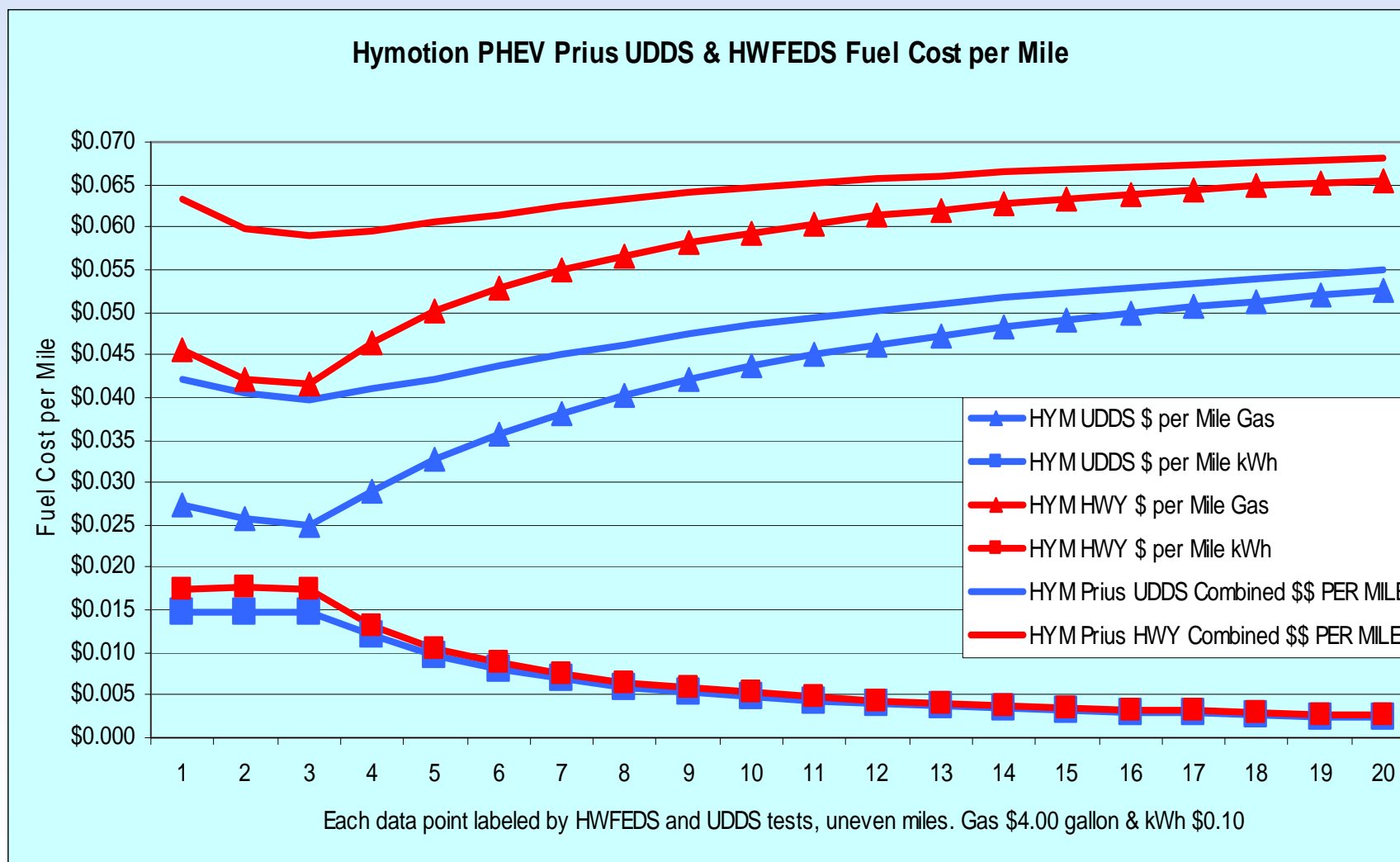
Each total distance slightly greater than 600 miles. HEV version = 27 mpg

Electrovaya Escape – Accelerated Testing

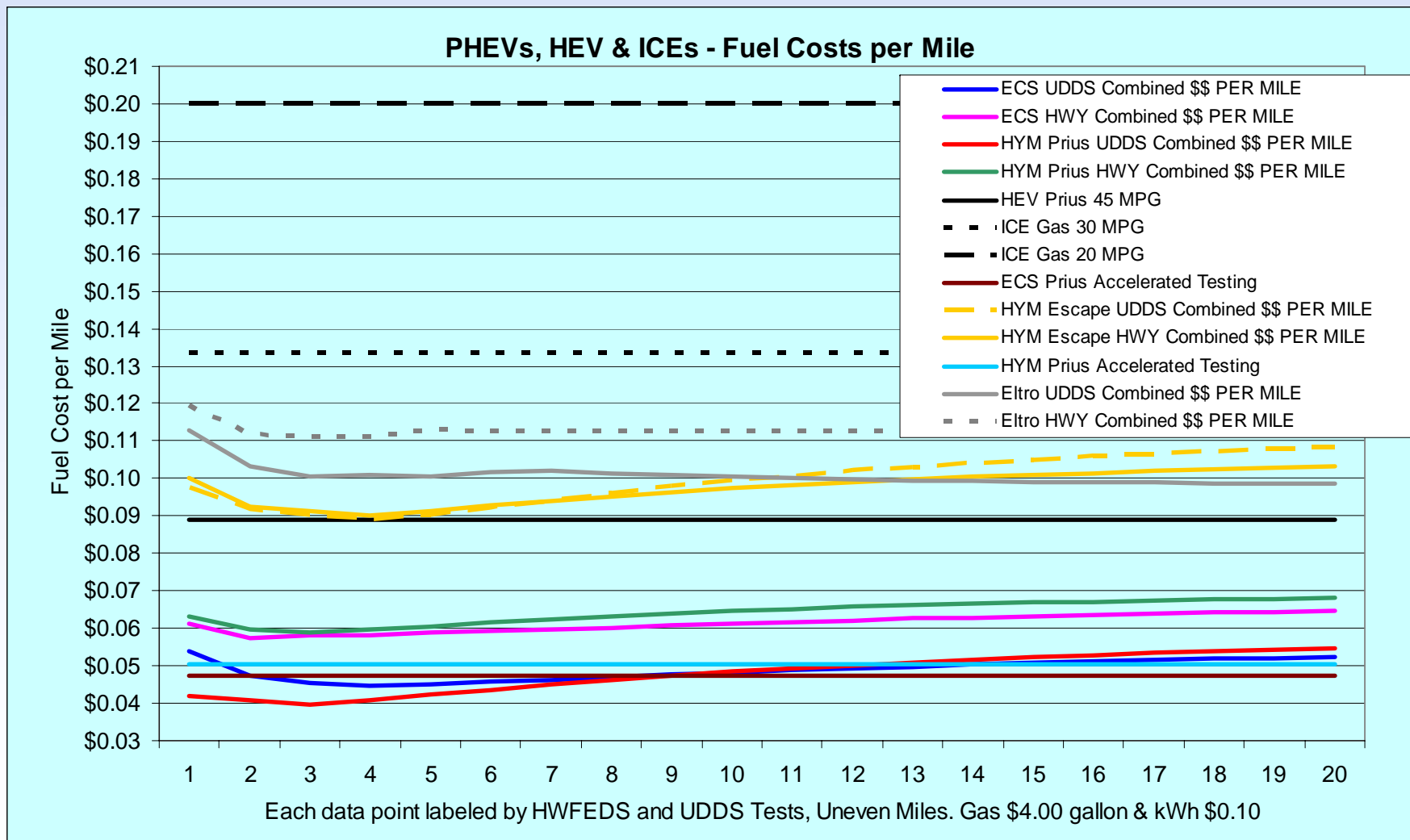
Cycle	Urban	Highway	Charge	Reps	Total	Electricity	Gasoline	
(mi)	(10 mi)	(10 mi)	(hr)	(N)	(mi)	AC kWh	Gals	MPG
10	1	0	4	60	600			
20	1	1	8	30	600			
40	4	0	12	15	600	71.3	16.42	37.3
40	2	2	12	15	600	69.8	14.34	43.1
40	0	4	12	15	600	55.84	20.73	29.8
60	2	4	12	10	600	44.79	16.64	37.3
80	2	6	12	8	640	42.72	16.30	40.8
100	2	8	12	6	600	20.85	21.17	29.2
200	2	18	12	3	600			
Total	2340	3100	1344	162	5440	Weighted Average		

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

Hymotion Prius – Fuel Costs



PHEV Vs. HEV and ICE Fuel Costs per Mile

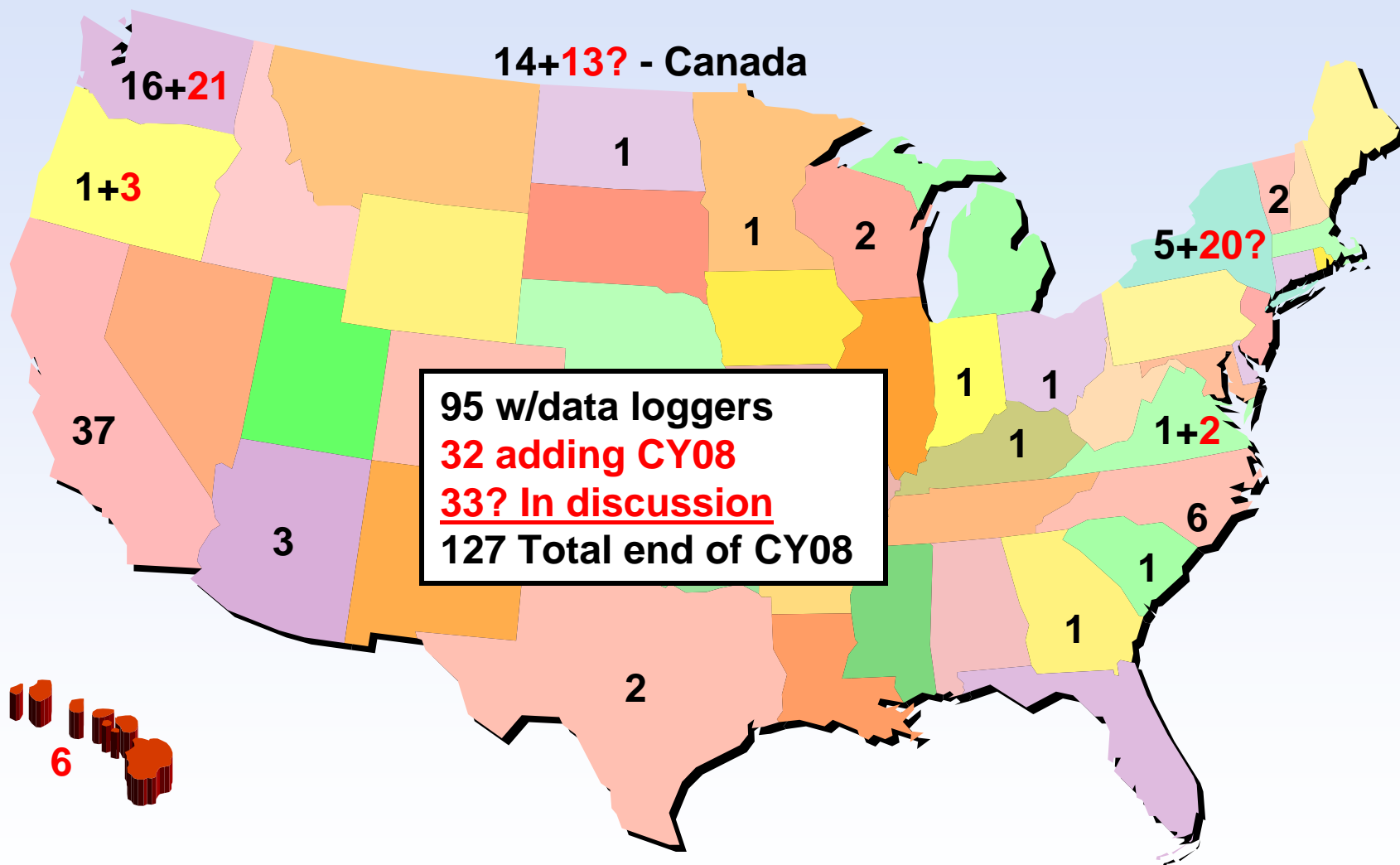


Onroad Demonstration and Data Collection Partners

- **~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



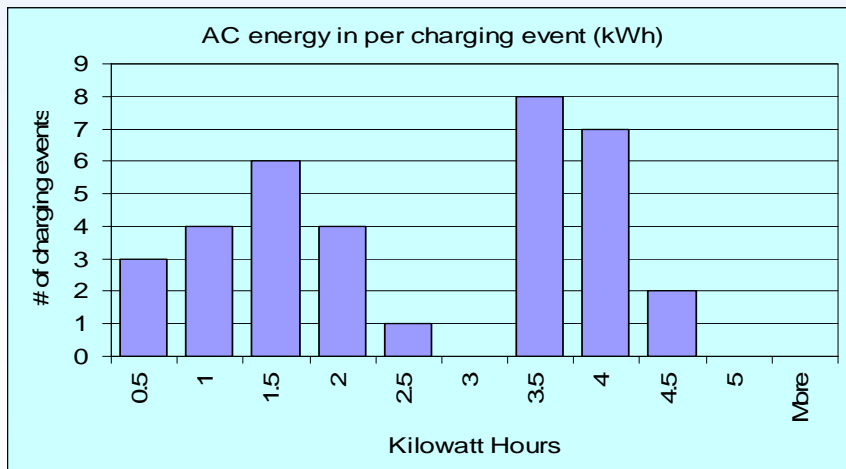
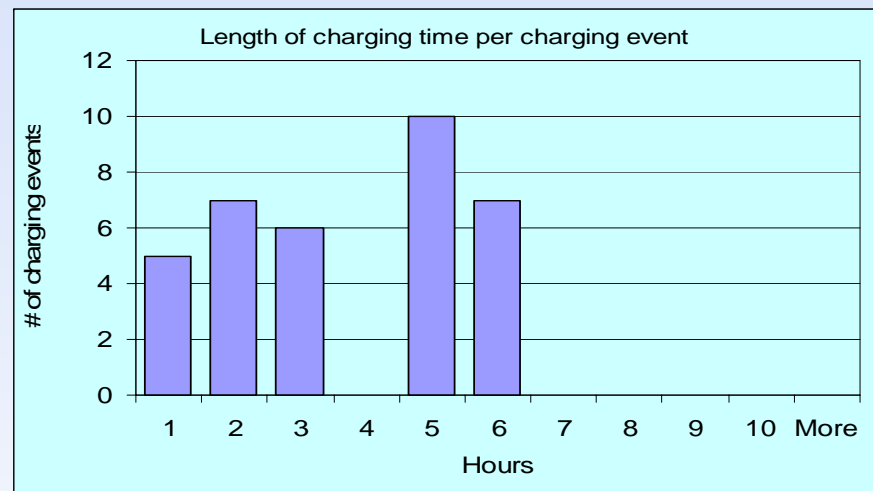
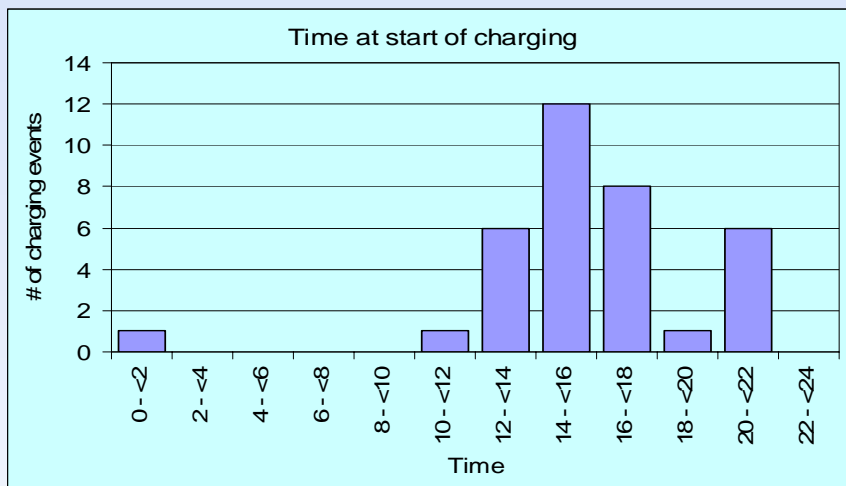
Hymotion Joint Data Collection

- 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



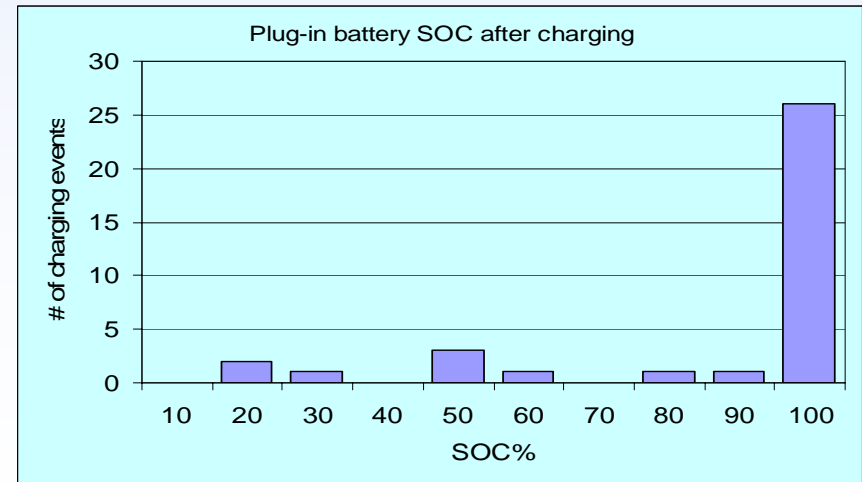
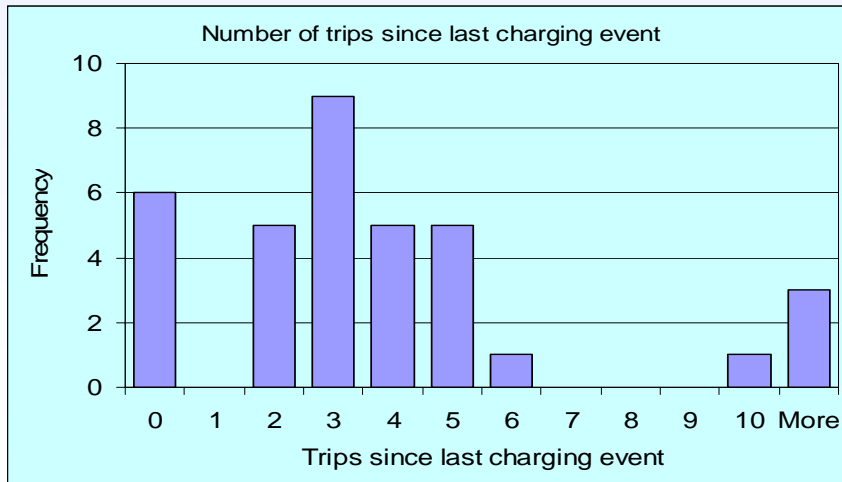
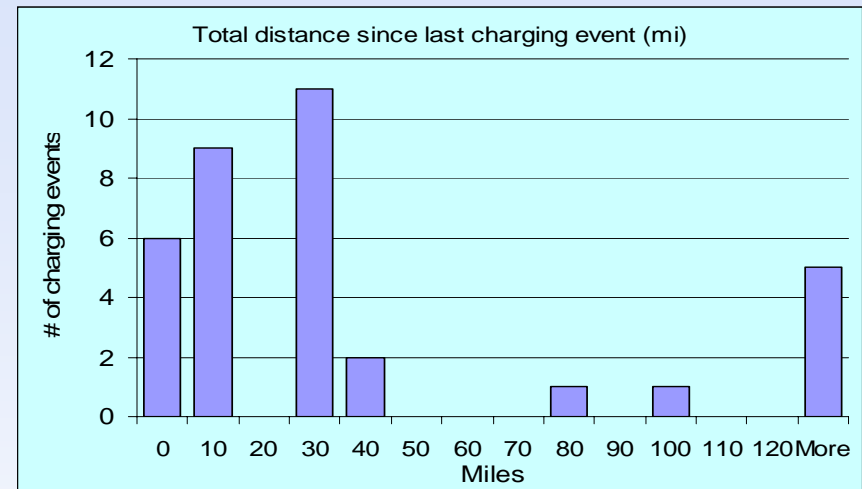
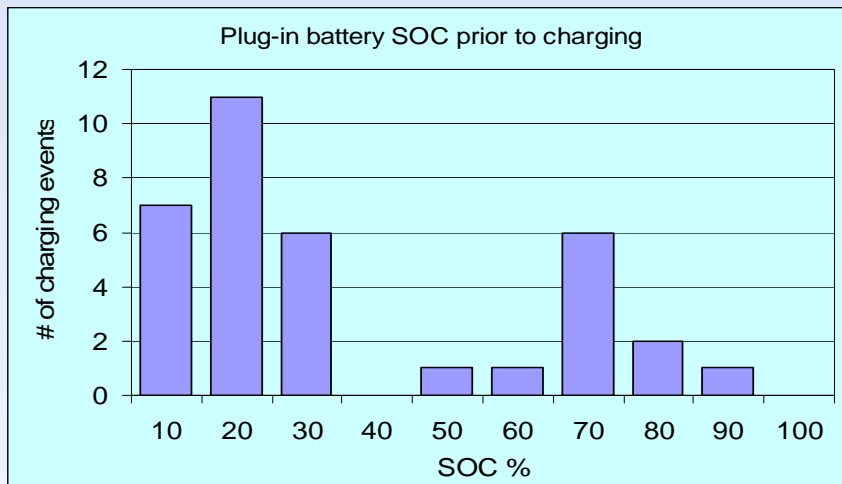
Single Hymotion Prius Charging Profiles

- 3 months, 2212 miles, 35 charges



Single Hymotion Prius Charging Profiles

- 3 months, 2212 miles, 35 charges



26 Hymotion Prius - January thru May 2008

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

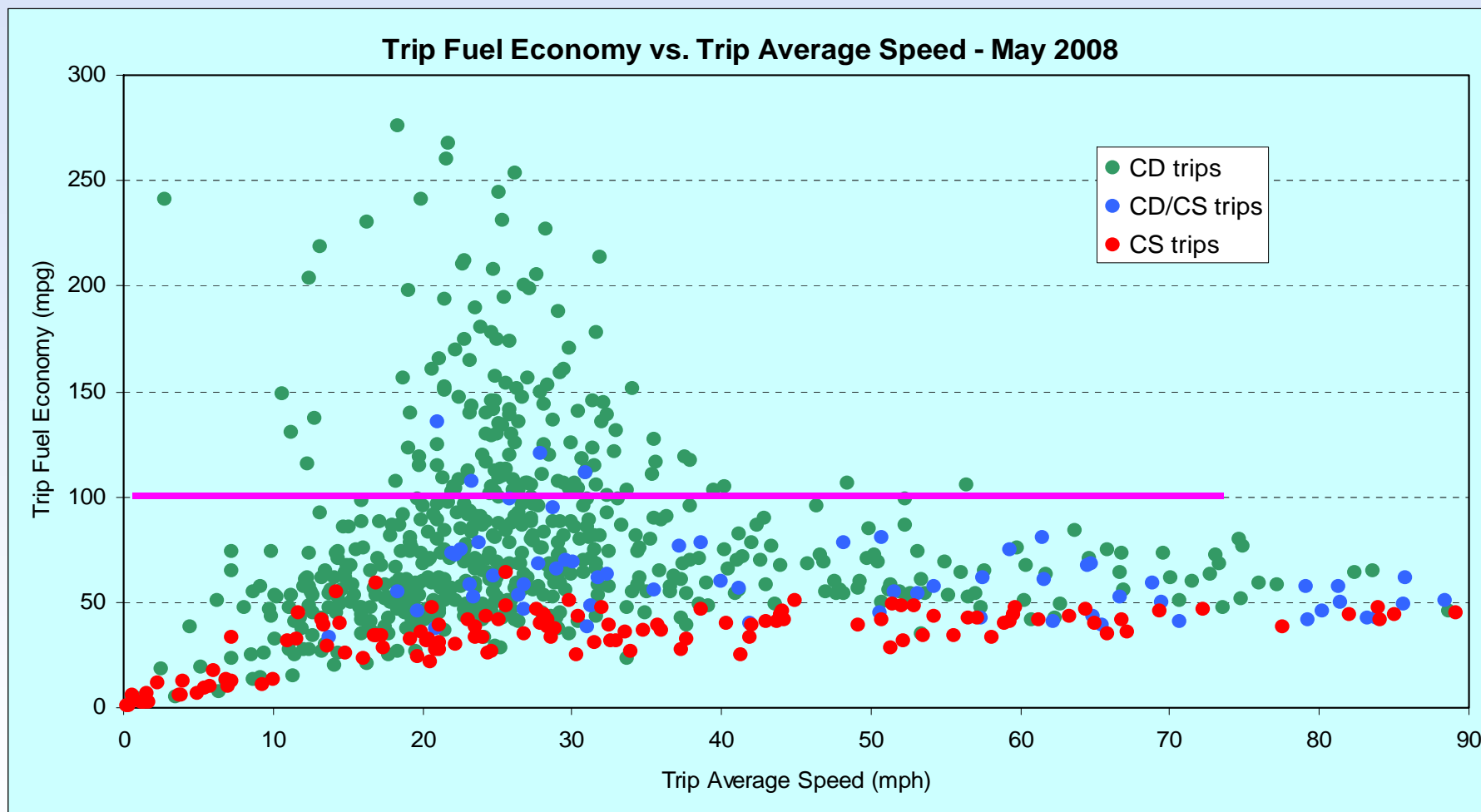


13 Hymotion Prius in May 2008 - MPG

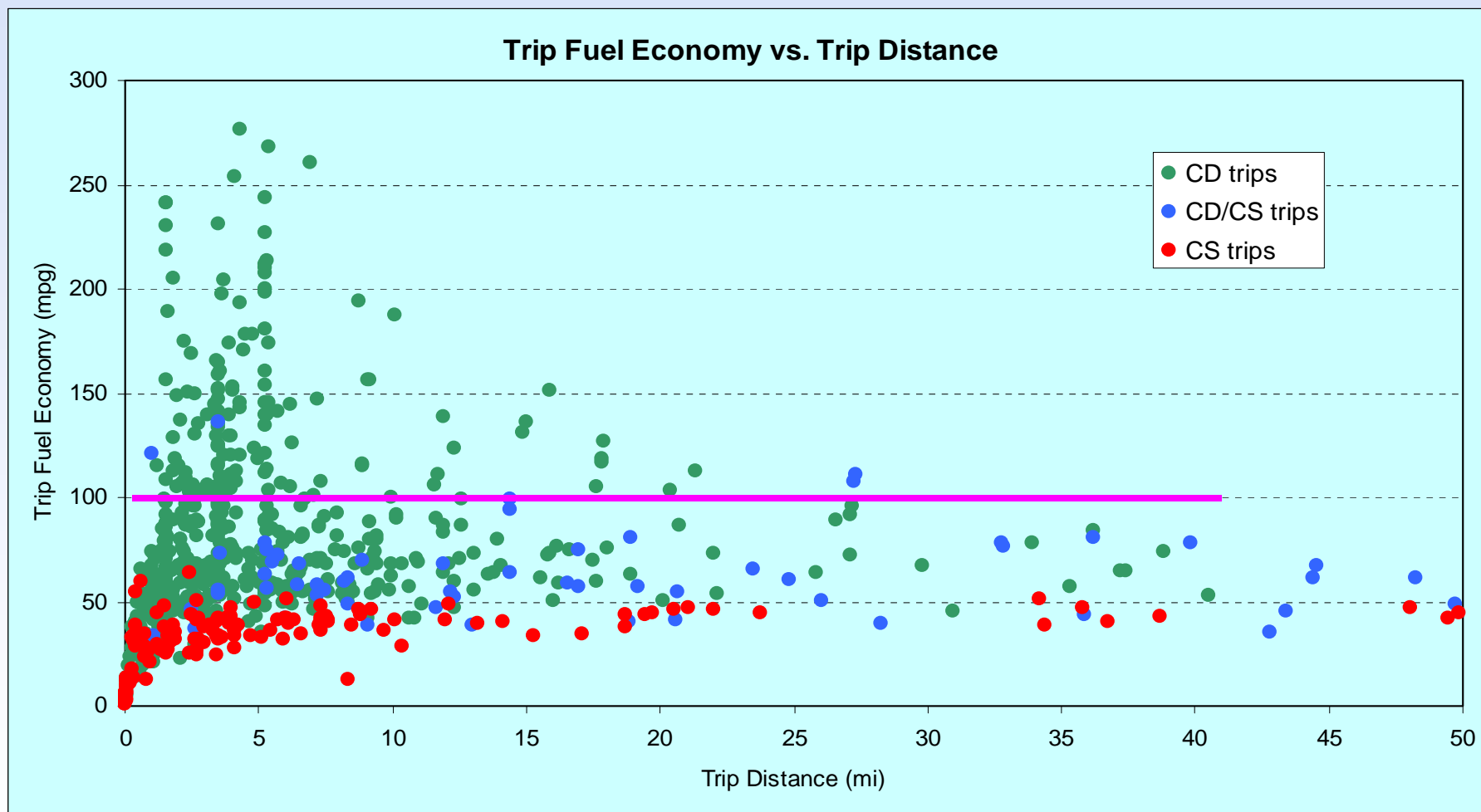
- Below averages do NOT tell the whole PHEV energy use potential – see following slides

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	

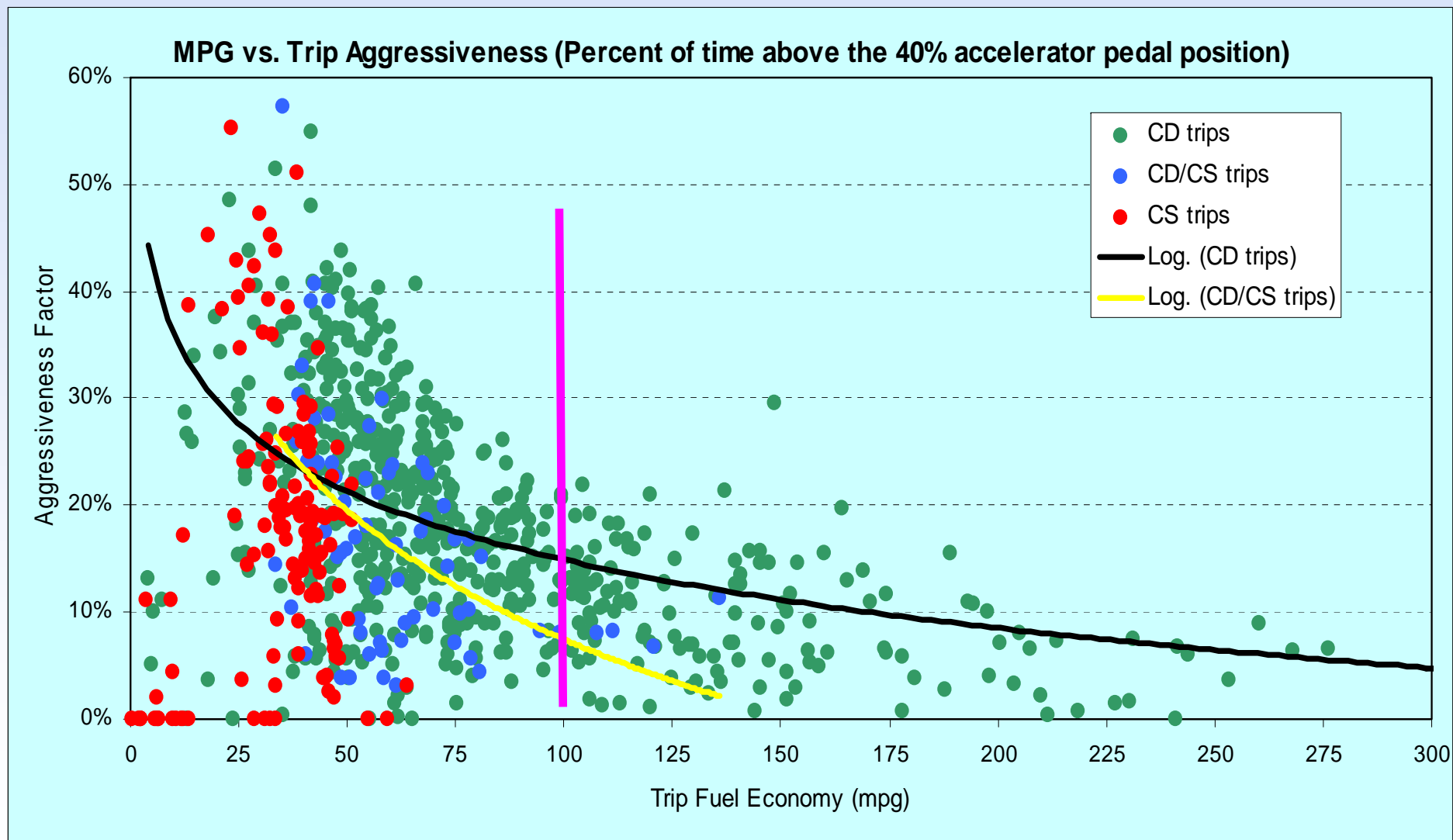
13 Hymotion Prius MPG Vs. Speed



13 Hymotion Prius MPG Vs. Distance



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
Electrovaya Escape	Ongoing	Ongoing
HybridsPlus Escape	Ongoing	Ongoing



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, nine vehicles converted to date, remainder October 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 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-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 Oct. 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

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

Charging Infrastructure

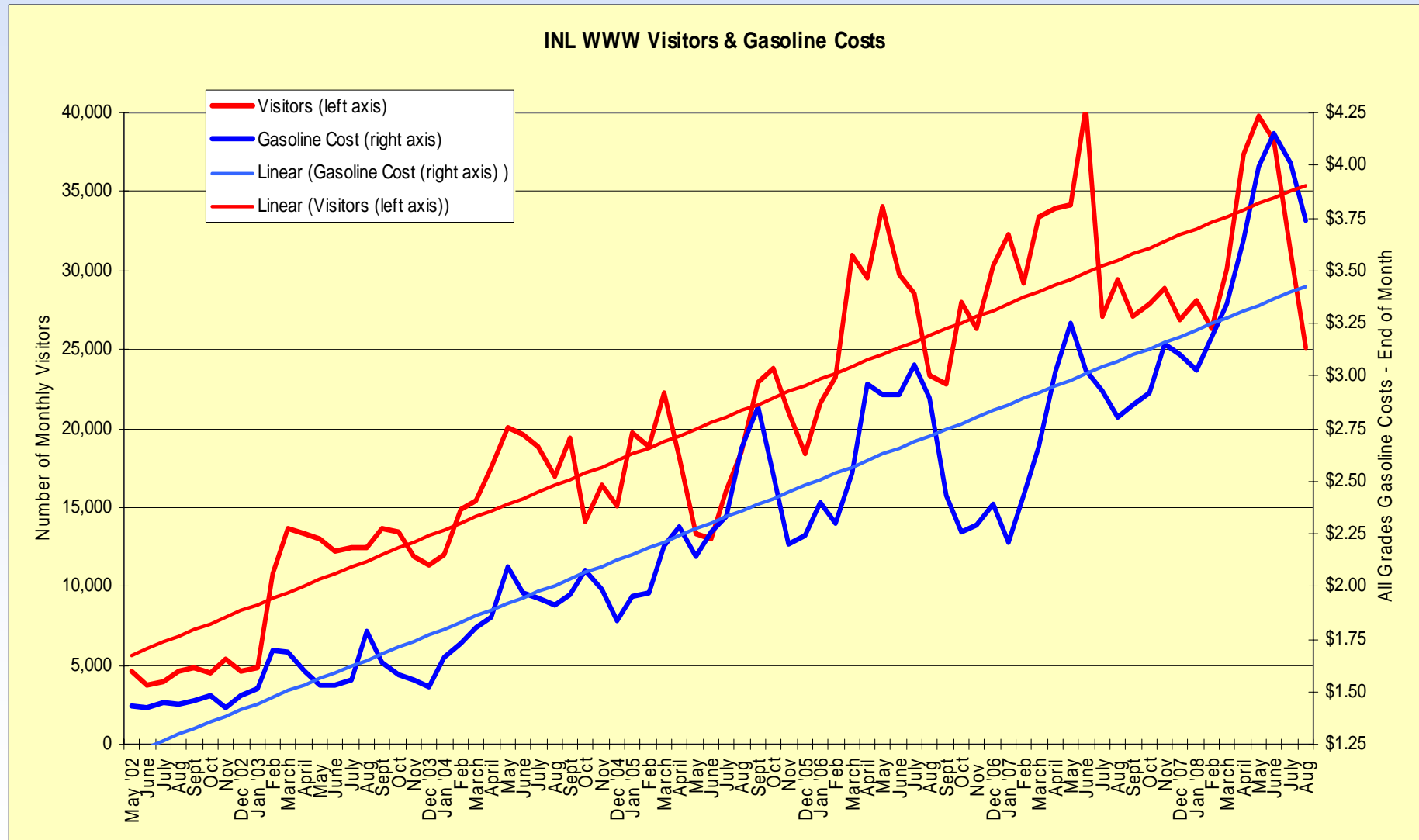
- National Electric Code requires
 - Dedicated branch circuit
 - GFCI (ground fault circuit interrupt)
 - “EV” extension cord
 - Unique connector “plug”
- NEC being updated



PHEV Market Status - Converters

- **Hymotion: ~125 Prius (\$9995) and 5 Escapes**
 - Prius only battery production ramp-up now, replacing all 67 Version 1 batteries. Recall most Escapes
 - Prius crash-tested and obtaining CARB certification
 - Conversions and warranty work in Boston, D.C., L.A., Minneapolis, San Francisco and Seattle
- **Hybrids Plus: ~35 Prius and Escapes, (\$21,600 to \$36,150). Some operational issues**
- **EnergyCS: ~30 Prius (~\$40,000). Some operational issues with early batteries**
- **Cal Cars: 8 Prius, believed to be all lead acid**
- **Green Car Company: 3(?) Manzanita lead acid Prius conversions (\$12,000). Some operational issues. Doing Hymotion conversions**
- **Electrovaya: 2(?) Escapes. Some operational issues**
- **Various single conversion “companies”**

AVTA Webpage Use and Gasoline Costs



Acknowledgement

This work is supported by the U.S. Department of Energy's Vehicle Technologies Program

Additional Information

**<http://avt.inl.gov>
or**

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

INL/MIS-08-14927