

U.S. Department of Energy - Vehicle Technologies Program 2008 Annual Merit Review

Advanced Vehicle Testing Activity (AVTA) - PHEV Evaluations and Data Collection

Vehicle Systems Merit Review

Jim Francfort – INL AVTA Principle Investigator

Lee Slezak – DOE Sponsor

February 2008, Bethesda, Maryland

AVTA Participants

- The Idaho National Laboratory (INL) supports the ATVA's overall execution, collects and analyzes the data, and disseminates the testing results
- The Clarity Group (Phoenix, AZ) provides track and onroad testing and technical support, Don Karner is the PI for the Clarity Group (d.b.a. Electric Transportation Engineering Corporation - ETEC)
- National Energy Technology Laboratory manages the Clarity Group contract
- Argonne National Laboratory performs dynamometer vehicle testing for the AVTA
- Public and private fleet test partners provide vehicle mission diversity and provide leveraged funding
- FY08 budget is \$9 million, with ~\$675k spent to date (\$7 million for PHEV Demonstration)

Historical Testing Accomplishments

- **Full-size electric vehicles (started early 1990's)**
 - 40 EV models, 5+ million test miles
- **Neighborhood electric vehicles (ongoing)**
 - 15 NEV models, 200,000 test miles
- **Urban electric vehicles**
 - 3 models, 1 million test miles
- **100% Hydrogen and HCNG internal combustion engine (HICE) vehicles (ongoing)**
 - 6 models, 400,000 test miles
- **Hybrid electric vehicles (ongoing)**
 - 13 HEV models, 3.5 million test miles
- **Testing methods and procedures continue to evolve to match vehicle technology advancements**

AVTA's PHEV Testing Objectives

- **Provide benchmark Plug-in Hybrid Electric Vehicle (PHEV) data to technology modelers, target setters, and research and development programs**
- **Assist early-adapter fleet managers in making informed vehicle purchase, deployment and operating decisions**
 - **Document the performance of PHEVs in test-track, dynamometer, accelerated, and real-world applications**
 - **Reduce the uncertainties about vehicle and battery performance and life**
 - **Document fuel (petroleum and electricity) use over various distances**
 - **Document charging infrastructure requirements, use, performance and costs**
 - **Document operator influence on charging times, patterns, and frequencies**

AVTA's PHEV Testing Objectives – cont'd

- Collect onboard vehicle operations data via data loggers
- Collect vehicle maintenance costs
- Document real-world PHEV life-cycle costs
- Continue to use established testing facilities and fleet-testing relationships to maximize knowledge and value to DOE



FY07 Testing Accomplishments

- **Developed 400-page PHEV testing specifications and procedures document that incorporated comments from other national laboratories, industry and other stakeholders**
- **Obtained and benchmarked one PHEV from an OEM and two from PHEV conversions companies (only available) by performing:**
 - **Baseline performance track and laboratory tests**
 - **Initiated accelerated onroad tests**
- **Performed due diligence on PHEV models to determine suitability as test candidates**

FY07 Testing Accomplishments - cont'd

- **Initiated cooperative testing agreements that provide access to non-DOE owned PHEVs operating in demonstration fleets. Partners include:**
 - **New York State Energy Research Development Agency (NYSERDA)**
 - **City of Seattle, King County, Port of Seattle, Puget Sound Clean Air Agency**
 - **Tacoma Power**
 - **National Rural Electric Cooperative Association**
 - **PHEV conversion companies**
 - **Hymotion**
 - **EnergyCS**

Baseline Performance Testing

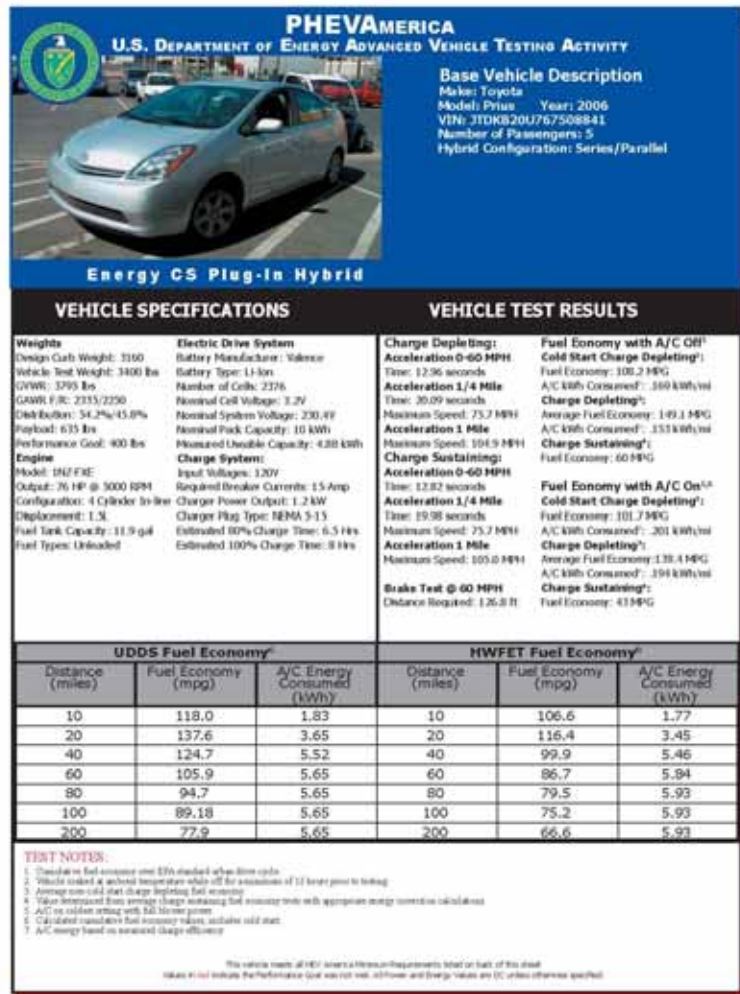
- Initial track testing conducted near Phoenix
 - Testing includes coastdown (determination of dynamometer coefficients), acceleration, top speed, charging, & durability tests
- Five day dynamometer testing regime performed at Argonne
 - Testing includes at least 26 drive cycle tests
 - Charge depleting & sustaining test cycles
 - UDDS & HWFED cycles reported
 - Includes air conditioning (A/C) off & on cycles



RESS Baseline Performance Testing

- If vehicle option, conduct Rechargeable Energy Storage System (RESS) only testing with & without the air conditioning (A/C):
 - Day 1, RESS Only mode – A/C off
 - UDDS, UDDS, HWFEDS, HWFEDS
 - UDDS, UDDS, HWFEDS, HWFEDS
 - Repeat as able, then charge traction battery
 - Day 2, RESS Only mode – A/C on
 - UDDS, UDDS, HWFEDS, HWFEDS
 - UDDS, UDDS, HWFEDS, HWFEDS
 - Repeat as able

FY07 Testing Results



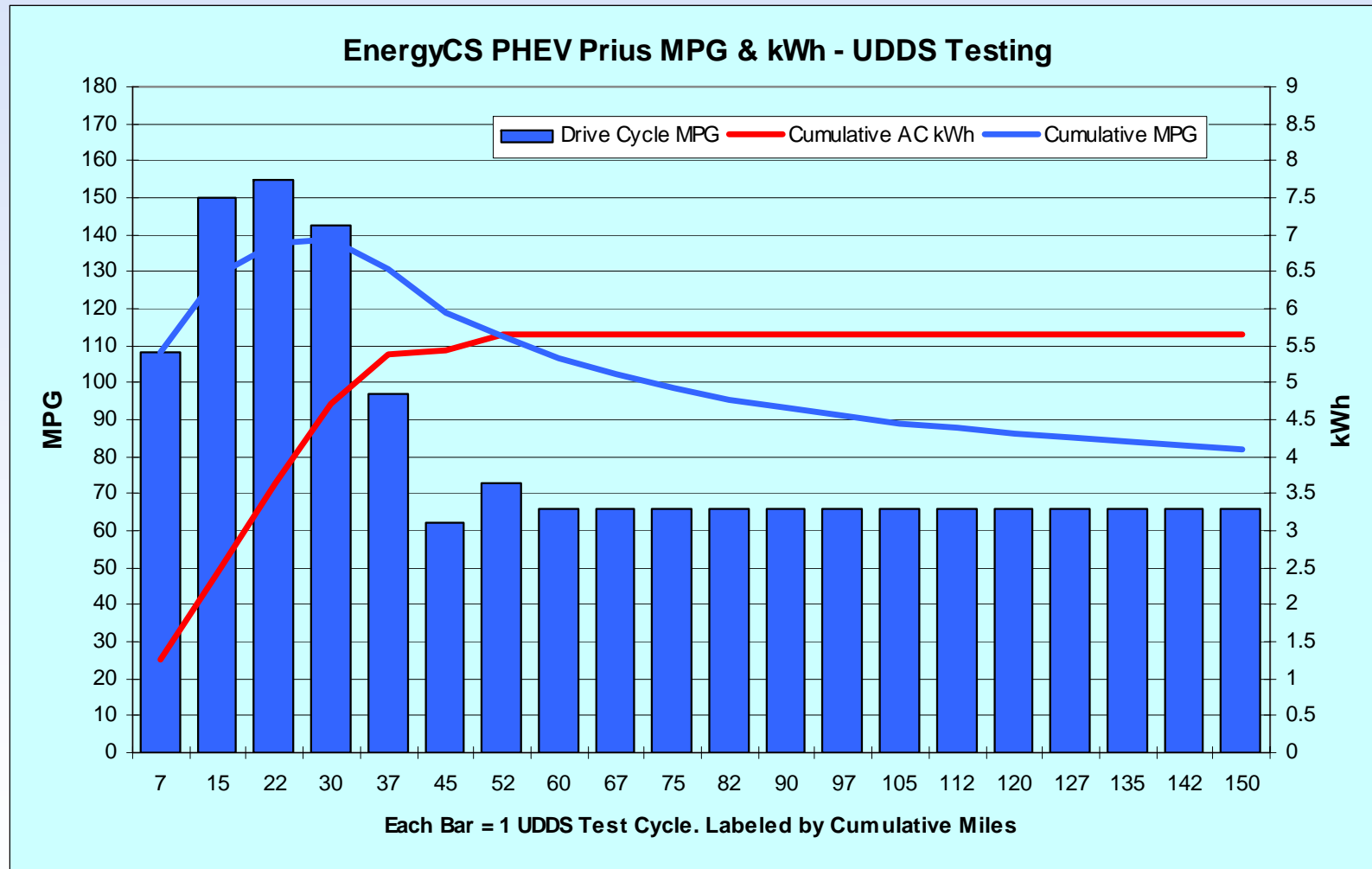
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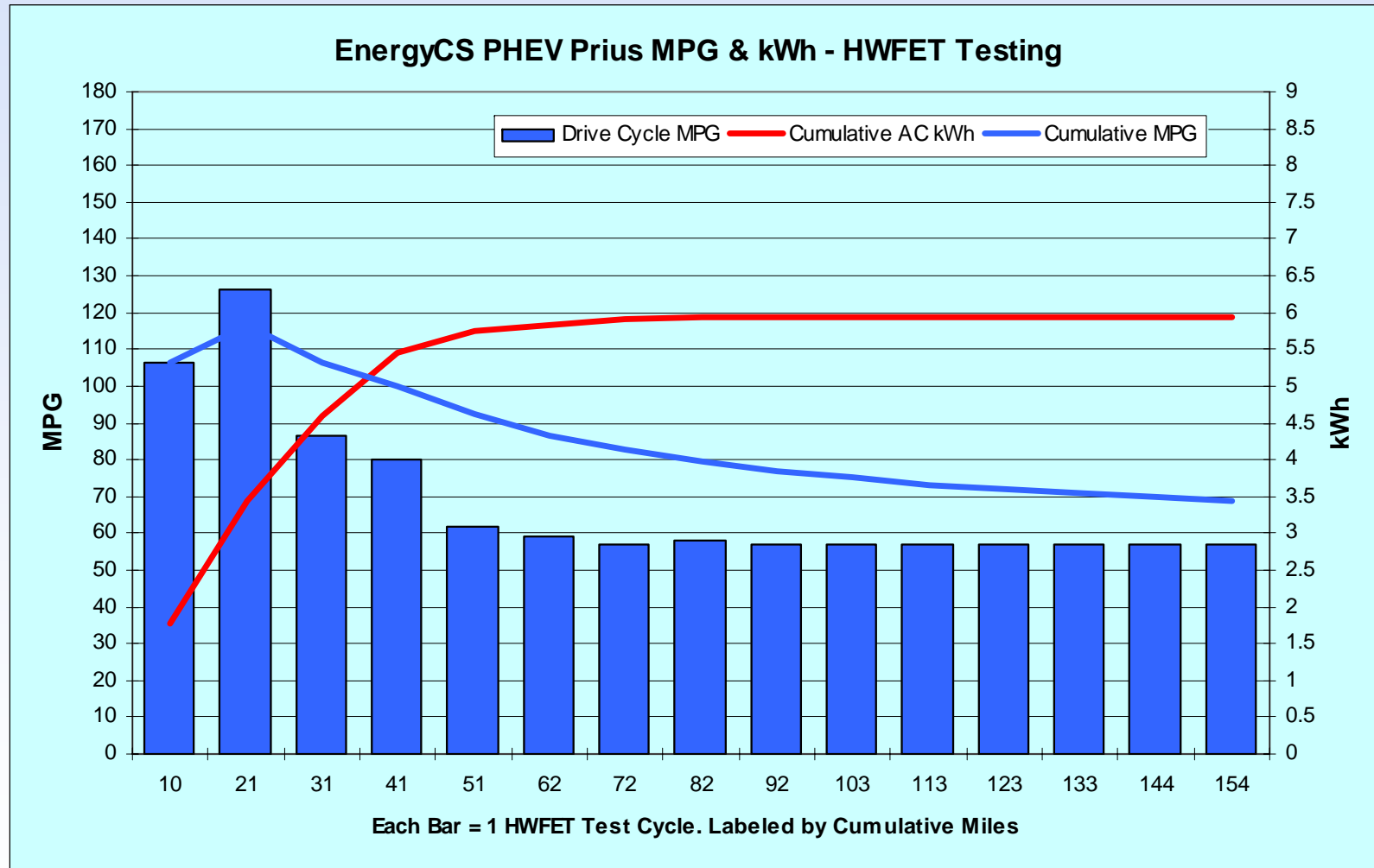
FY07 EnergyCS Prius – UDDS Fuel Use

- 9 kWh Valence lithium pack – AC kWh



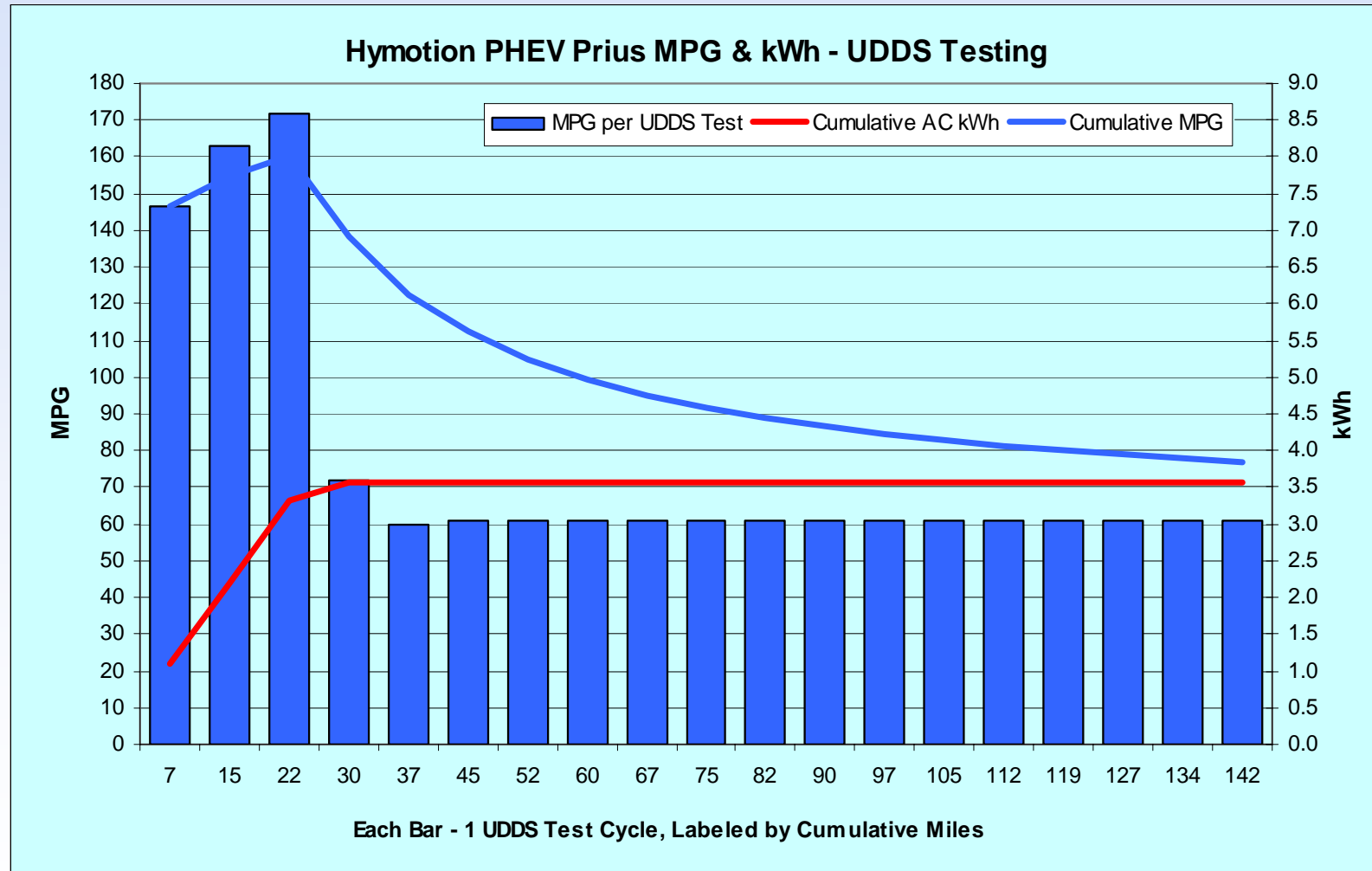
FY07 EnergyCS Prius – HWFET Fuel Use

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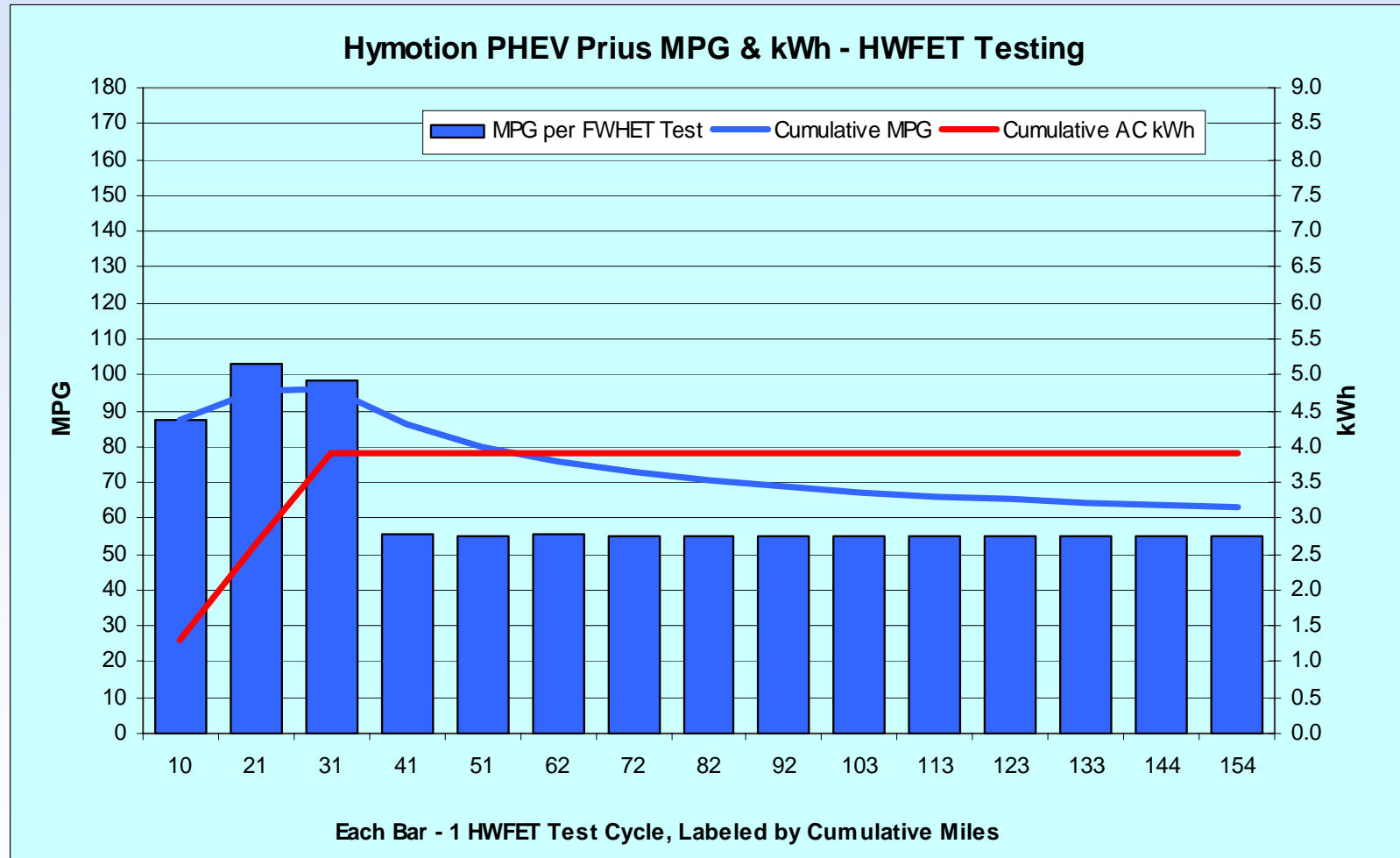
FY07 Hymotion Prius – UDDS Fuel Use

- 5 kWh A123 lithium & Prius packs – AC kWh

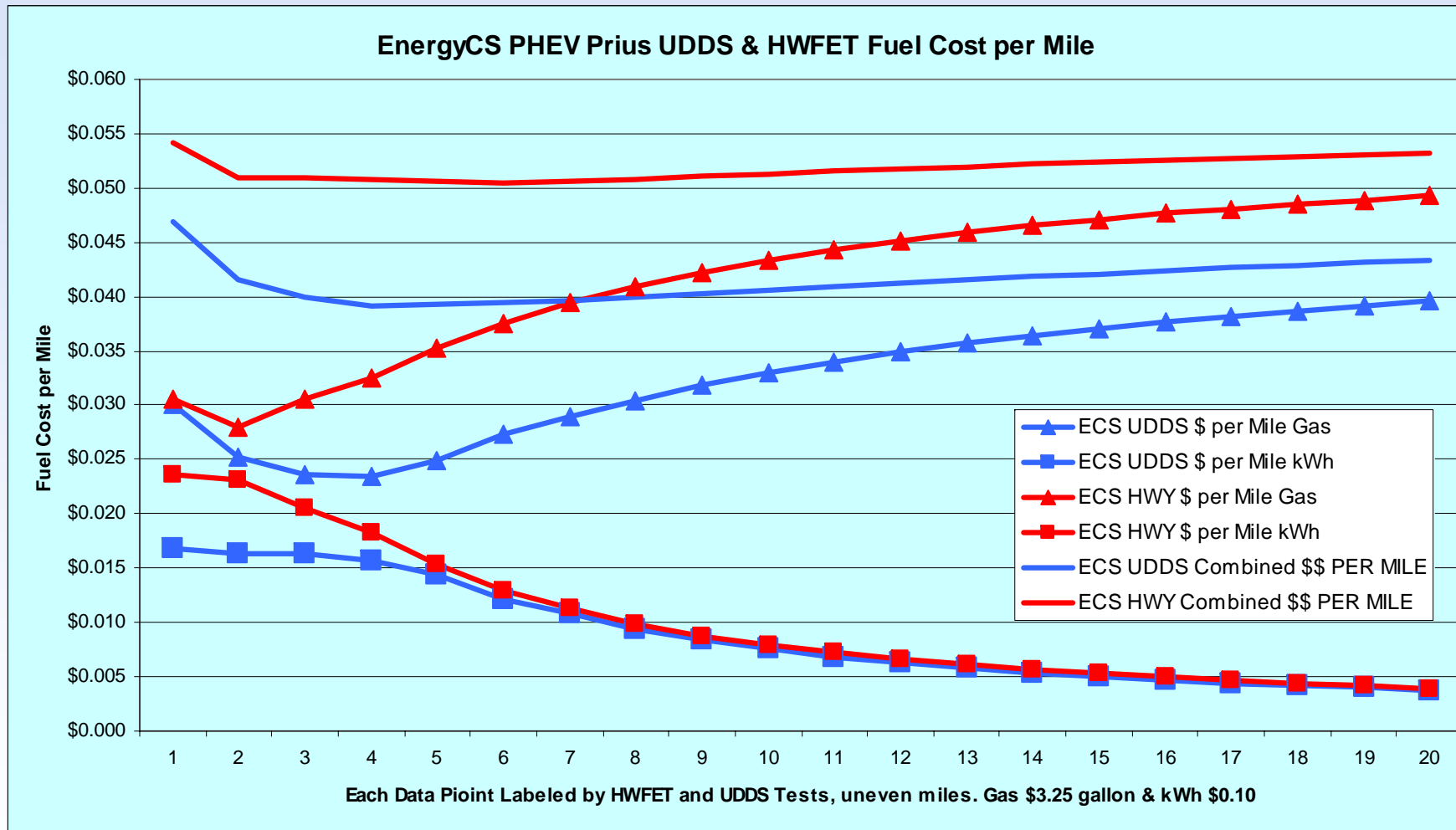


FY07 Hymotion Prius – HWFET Fuel Use

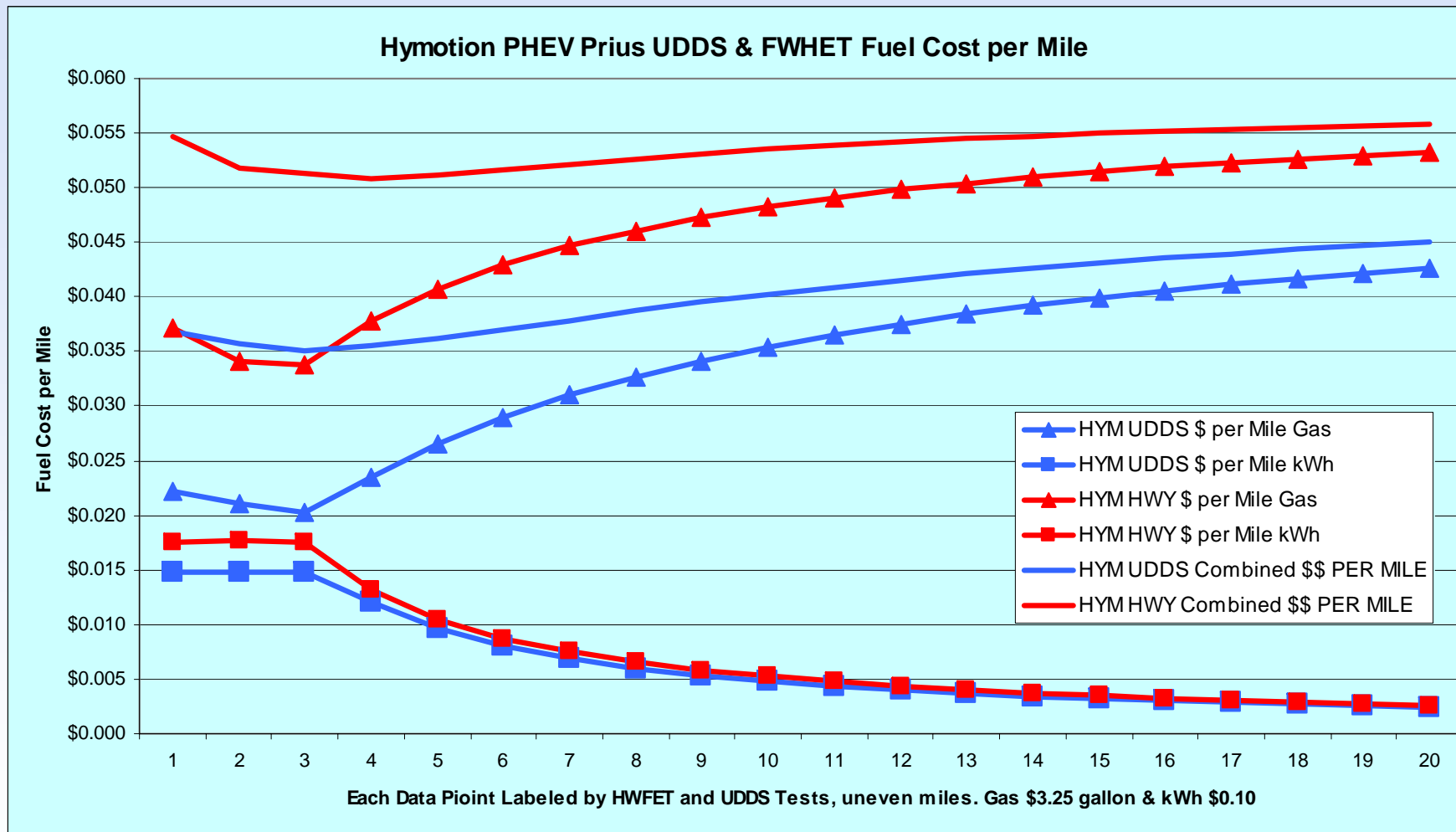
- 5 kWh A123 lithium & Prius packs – AC kWh



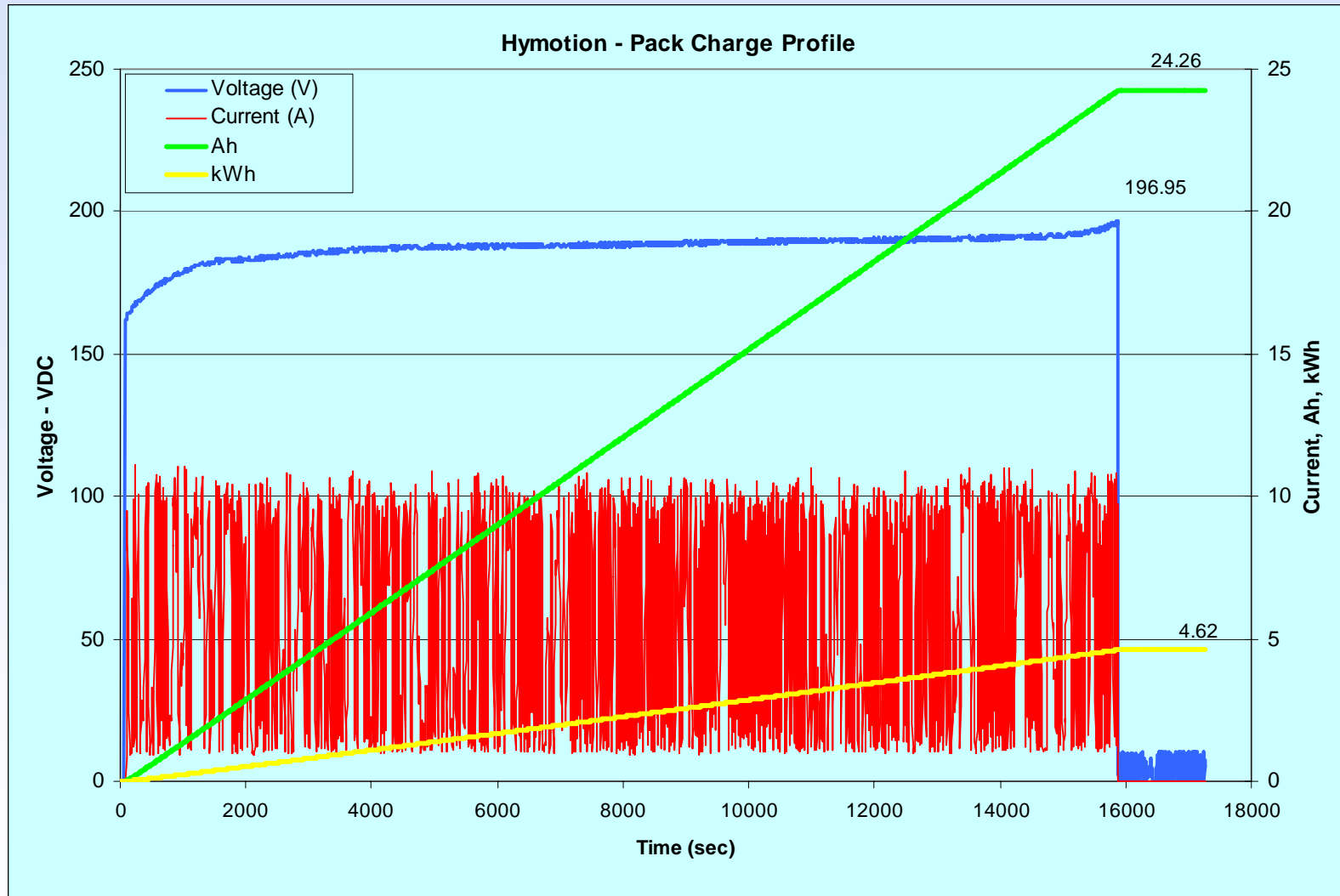
FY07 EnergyCS Prius – Fuel Costs



FY07 Hymotion Prius – Fuel Costs

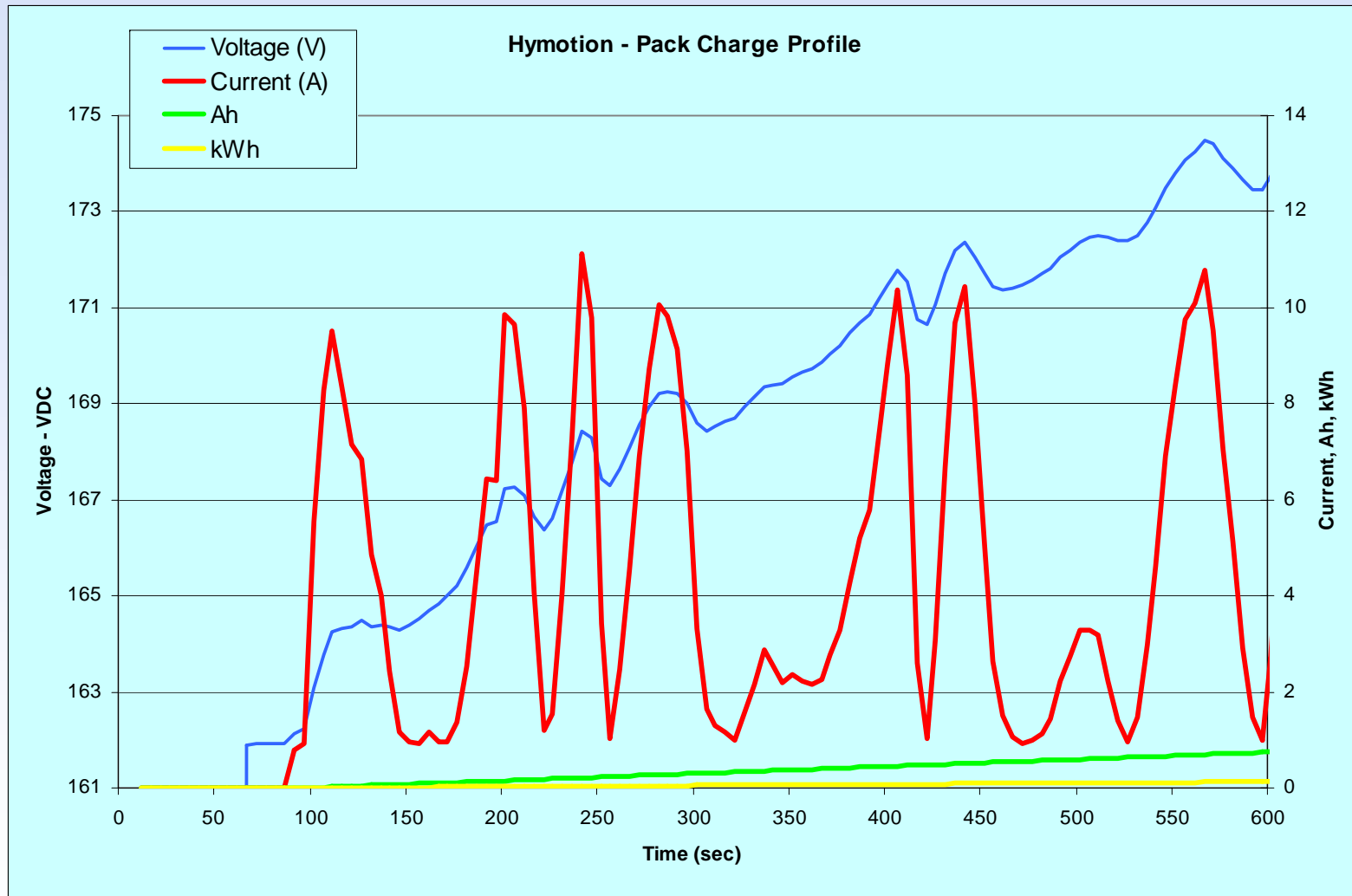


FY07 Hymotion Battery Charge Profile



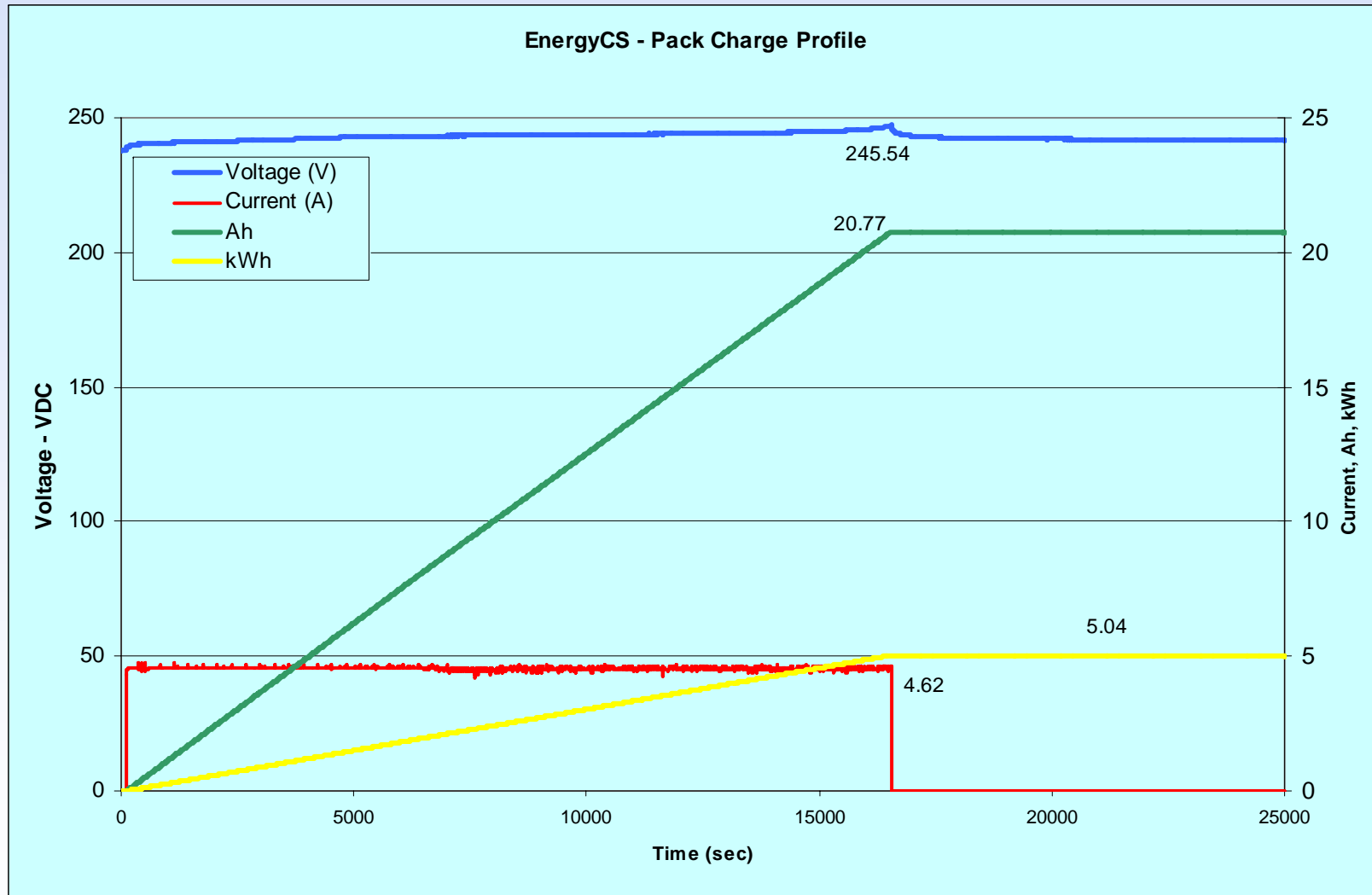
A123 Systems Lithium Ion Battery - DC kWh

FY07 Hymotion Cell Charge Profile



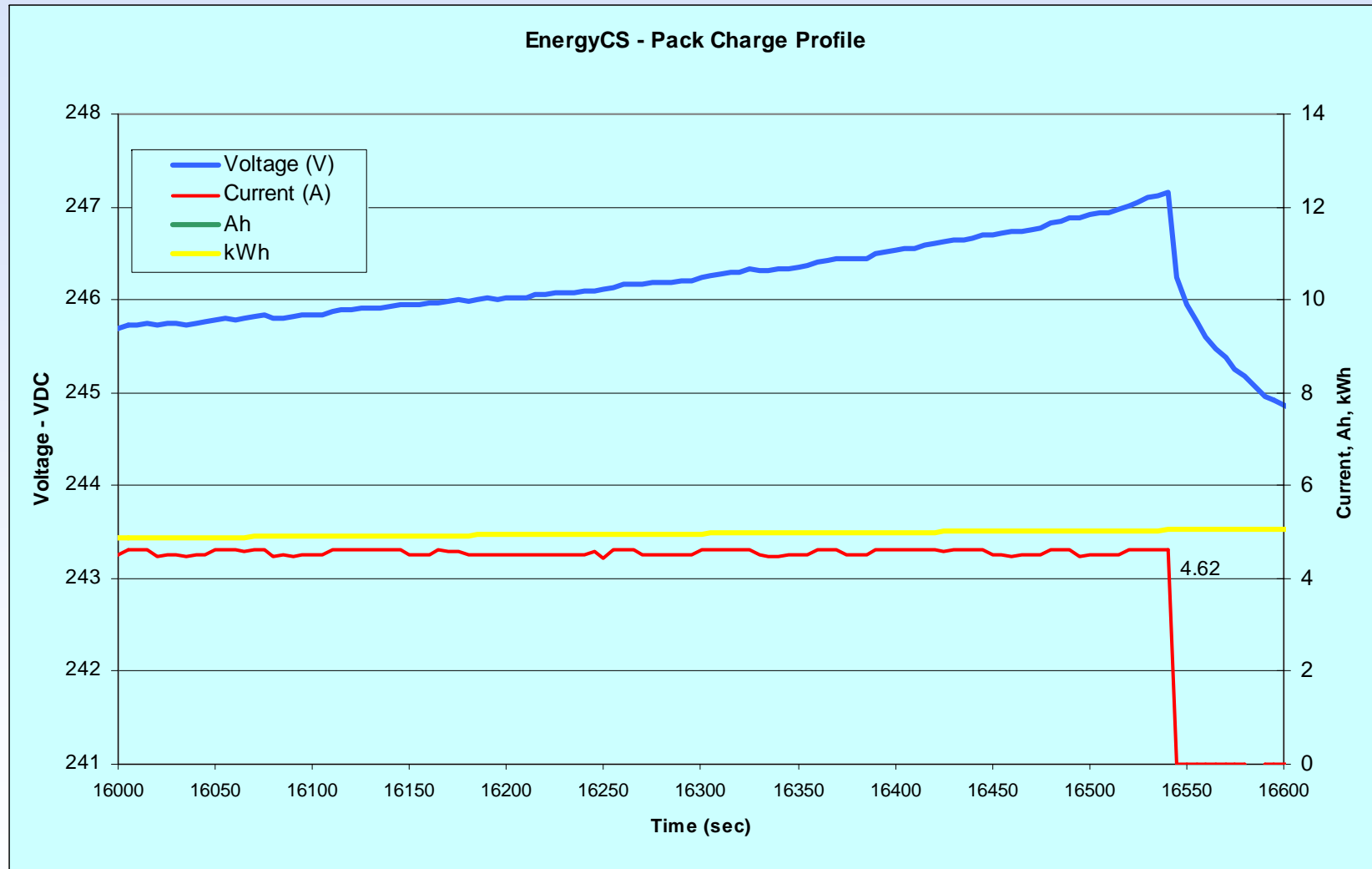
A123 Systems Lithium Ion Battery – DC kWh

FY07 EnergyCS Battery Charge Profile



Valence Lithium Ion Battery – DC kWh

FY07 EnergyCS Cell Charge Profile



Valence Lithium Ion Battery – DC kWh

FY07 Kangoo Test Results

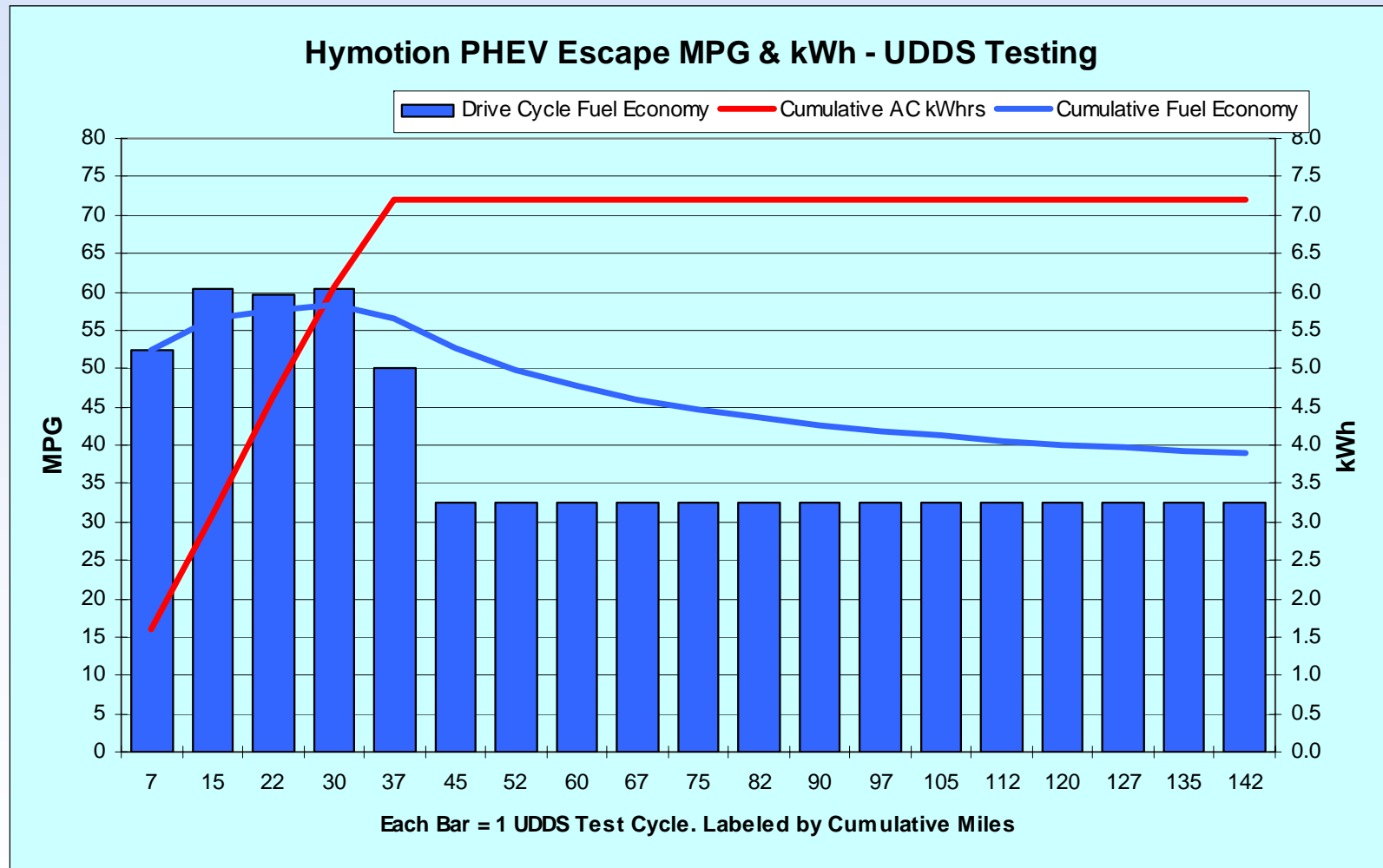
- Renault Kangoo – Series PHEV with 9.6 kWh (usable) Saft NiCad pack & 650cc gasoline engine

Test Cycle	AC kWh per Mile	Miles per Gallon
Battery Only - UDDS	0.268	
Battery Only - HWFET	0.155	
Battery Only @ Constant 45 mpg	0.271	
Battery & Gas Cold UDDS	0.144	42.3
Battery & Gas Hot UDDS	0.110	39.4
Battery & Gas Hot HWFET	0.042	40.9



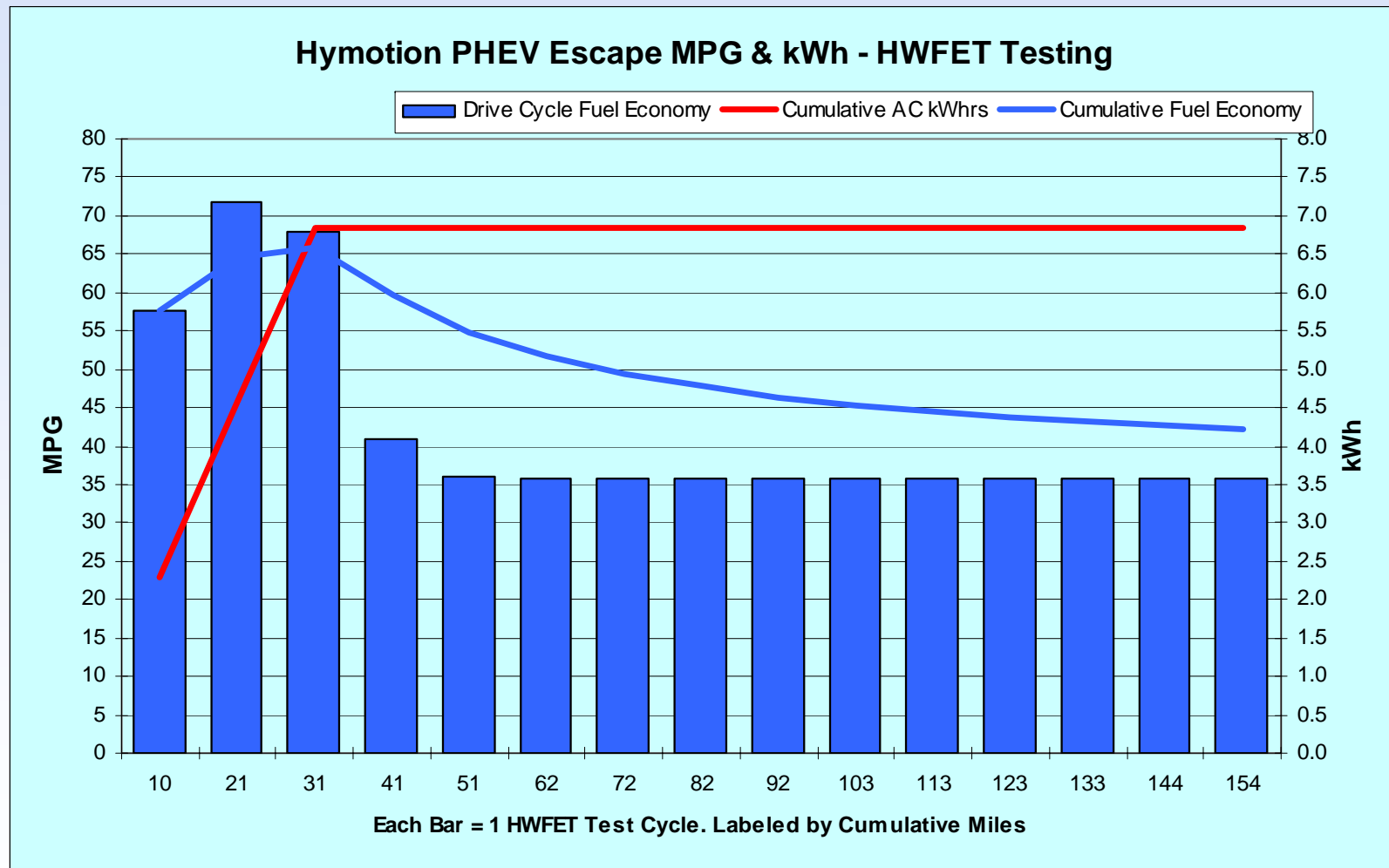
FY08 Hymotion Escape – UDDS Fuel Use

- 8.5 kWh A123 lithium & Prius packs – AC kWh

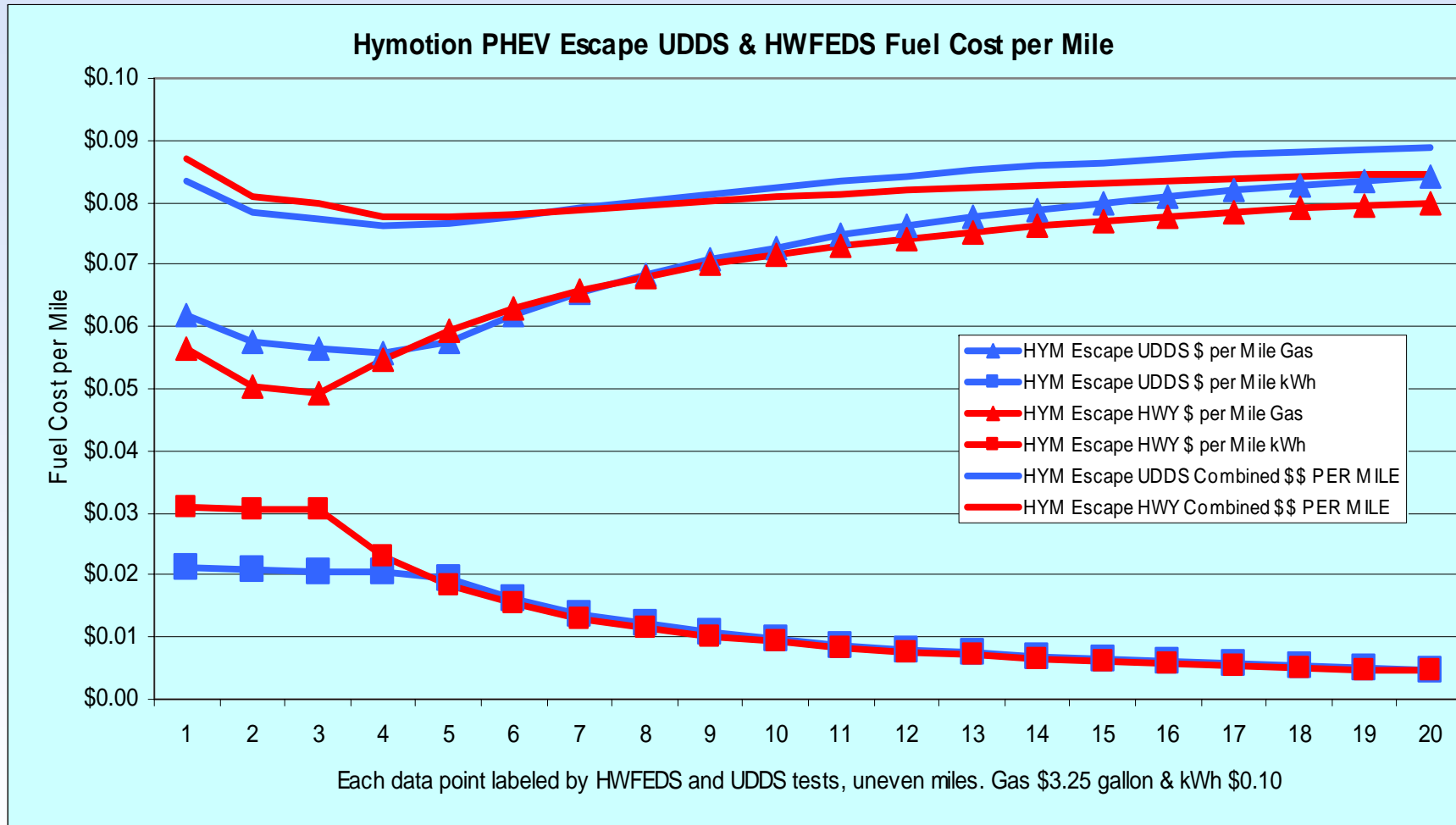


FY08 Hymotion Escape – HWFET Fuel Use

- 8.5 kWh A123 lithium & Prius packs – AC kWh



FY08 Hymotion Escape – Fuel Costs



FY08 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 1,344 hours of charging - can not be economically performed on a dynamometer**
- **Not as controlled as dynamometer, but compliments controlled dynamometer testing by allowing a broader view of fuel use over many more miles and charging events**
- **Test PHEV batteries at completion of accelerated testing and at 25k, 50k and ? miles**

FY08 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			

FY08 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	125.6
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	5.78	105.8
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	1740	2500	984	132	4840	Weighted Average		81.7

* Being rerun to 600 miles

FY08 Hymotion Prius – Accelerated Testing

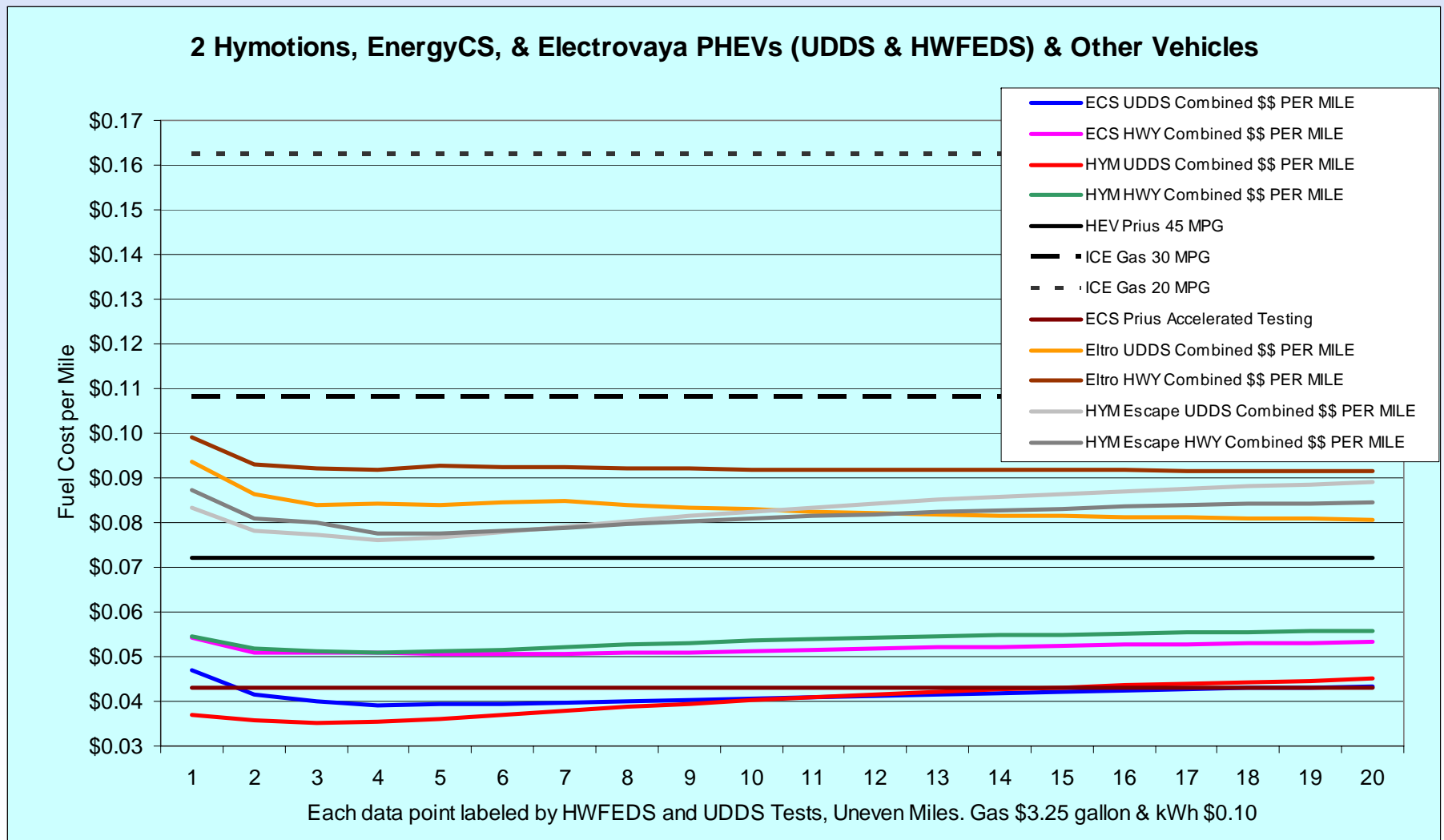
Cycle	Urban	Highway	Charge	Reps	Total	Electricity	Gasoline	
(mi)	(10 mi)	(10 mi)	(hr)	(N)	(mi)	kWh	Gals	MPG
10	1	0	4	60	600			
20	1	1	8	30	600	122.02	5.37	115.9
40	4	0	12	5	200*	29.84	1.87	108.9
40	2	2	12	5	600	87.22	5.78	106.8
40	0	4	12	5	600	79.82	8.54	73.1
60	2	4	12	10	600			
80	2	6	12	8	640	43.99	11.36	58.34
100	2	8	12	6	600	35.98	8.43	73.23
200	2	18	12	3	600	15.0	8.43	54.82
Total	1740	2500	984	132		Weighted Average		70.6

* Being rerun to 600 miles

FY08 Renault Kangoo – Accelerated Testing

Cycle	Urban	Highway	Charge	Reps	Total	Electricity		Gasoline	
(mi)	(10 mi)	(10 mi)	(hr)	(N)	(mi)	kWh	Mi/kWh	Gals	MPG
10	1	0	4	60	600	359.60	1.67	0	-
20	1	1	8	30	600	131.96	4.55	0	-
40	4	0	12	5	200	35.18	5.59	0	-
40	2	2	12	5	200	33.22	6.02	0	-
40	0	4	12	5	200	28.60	6.99	0	-
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	1740	2500	984	132	4,240	Weighted Average			

FY07 / FY08 PHEV Fuel Costs per Mile



FY08 PHEV Onroad Demonstrations and Data Collection Activities



FY08 Hymotion Joint Data Collection

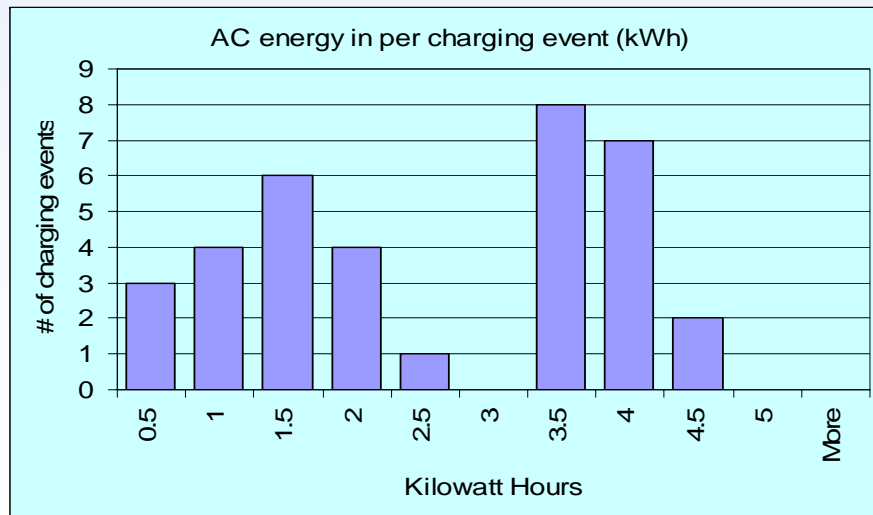
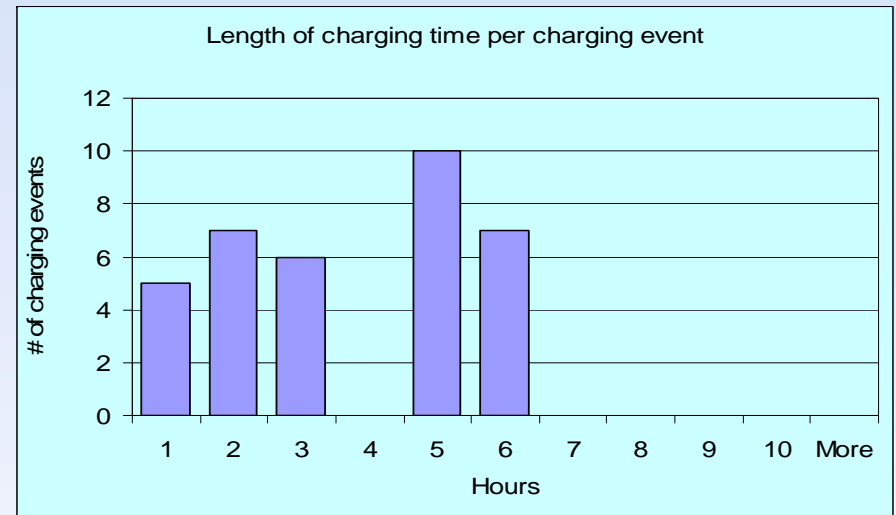
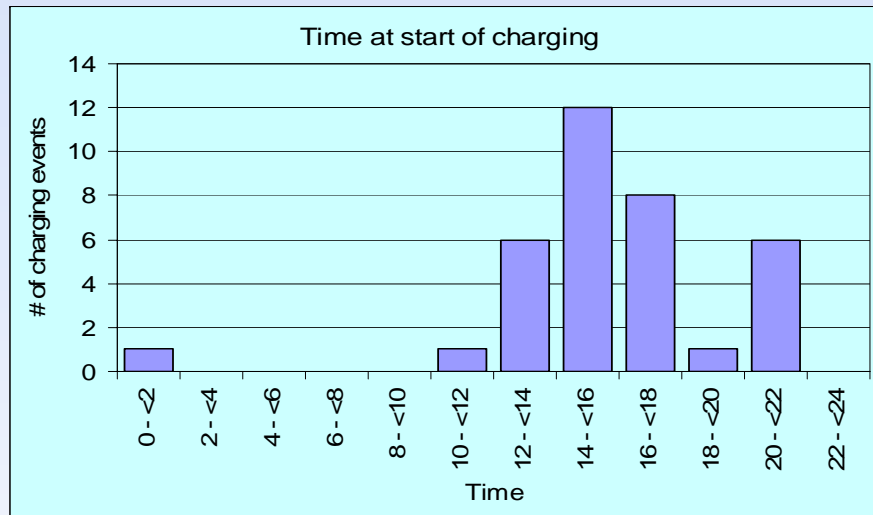
- **Kvaser data loggers installed on 45 PHEVs in North America fleets, will include 100 vehicles by end of 2008**
- **Onboard data includes performance, fuel use, and charging and driving profiles (up to 45 parameters)**
- **Offboard data includes fuel use, maintenance and mission description**
- **Fleet testing agreement requires the INL to:**
 - **On a monthly basis, collect data from fleets via INL ftp site or regular mail**
 - **Perform AVTA, operating fleet, and Hymotion required data reduction and analysis**
 - **Report testing results monthly**
- **To date, 96% of 26 North American fleets with data loggers installed have agreed to participate**

FY08 Hymotion Joint Data Collection – cont'd

- **Participates include electric utilities, water agencies, universities, county and provincial governments, and a private company in geographically diverse regions:**
 - **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 (5 fleets), Oregon**
- **New battery version available 1st half 2008, currently in crash testing; will maintain SULEV certification**

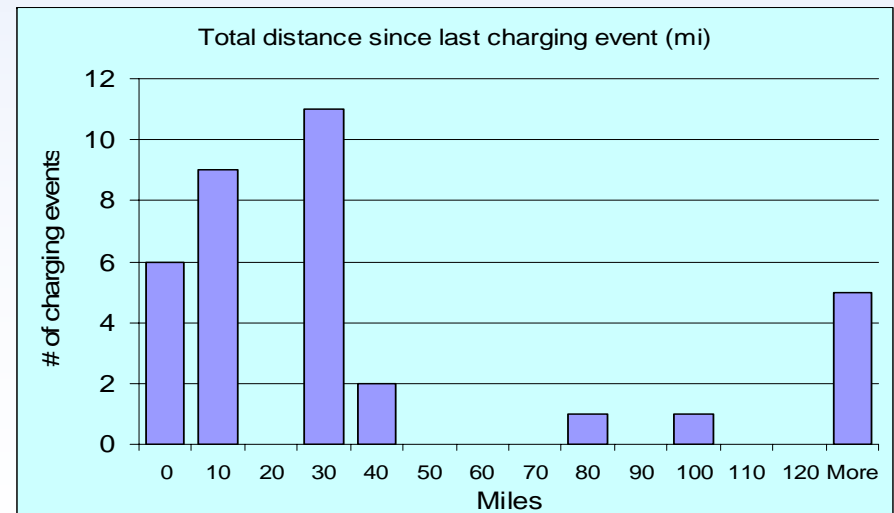
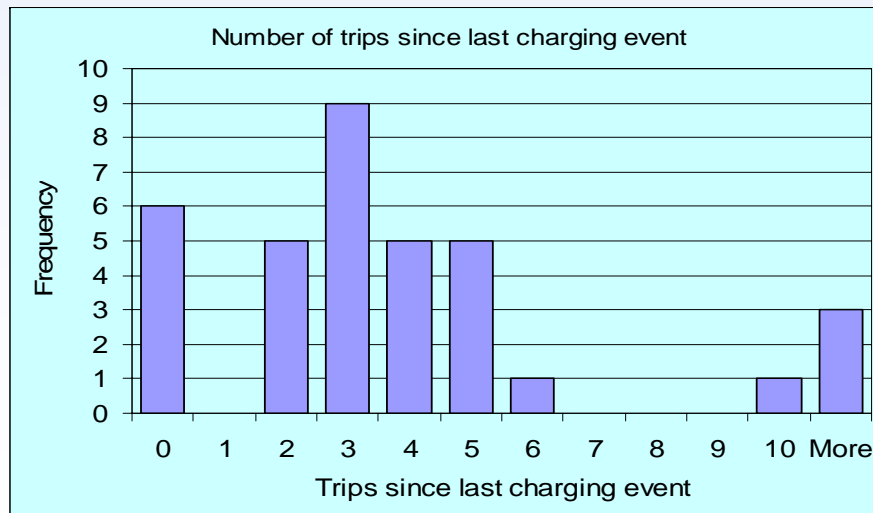
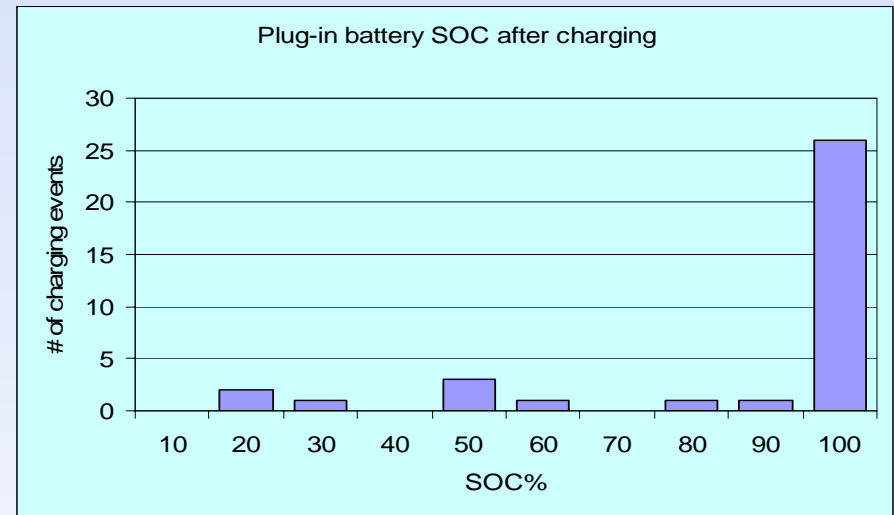
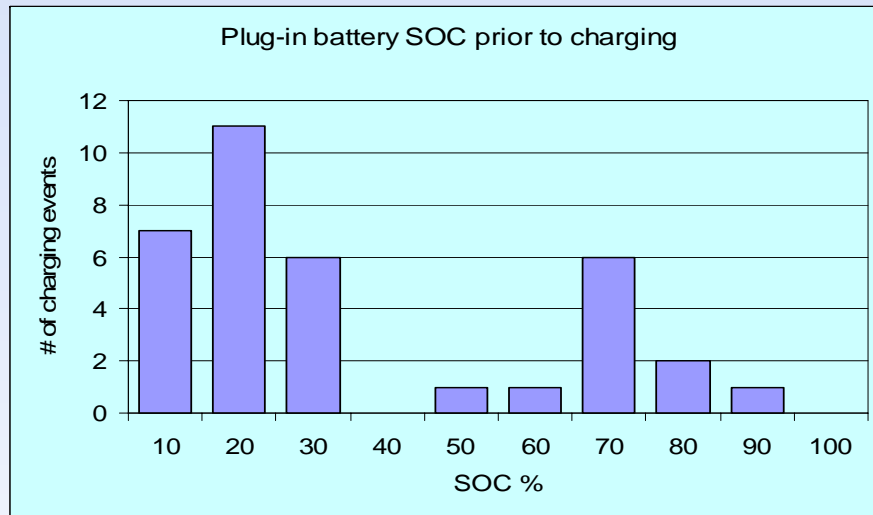
FY08 Hymotion Prius Charging Profiles

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



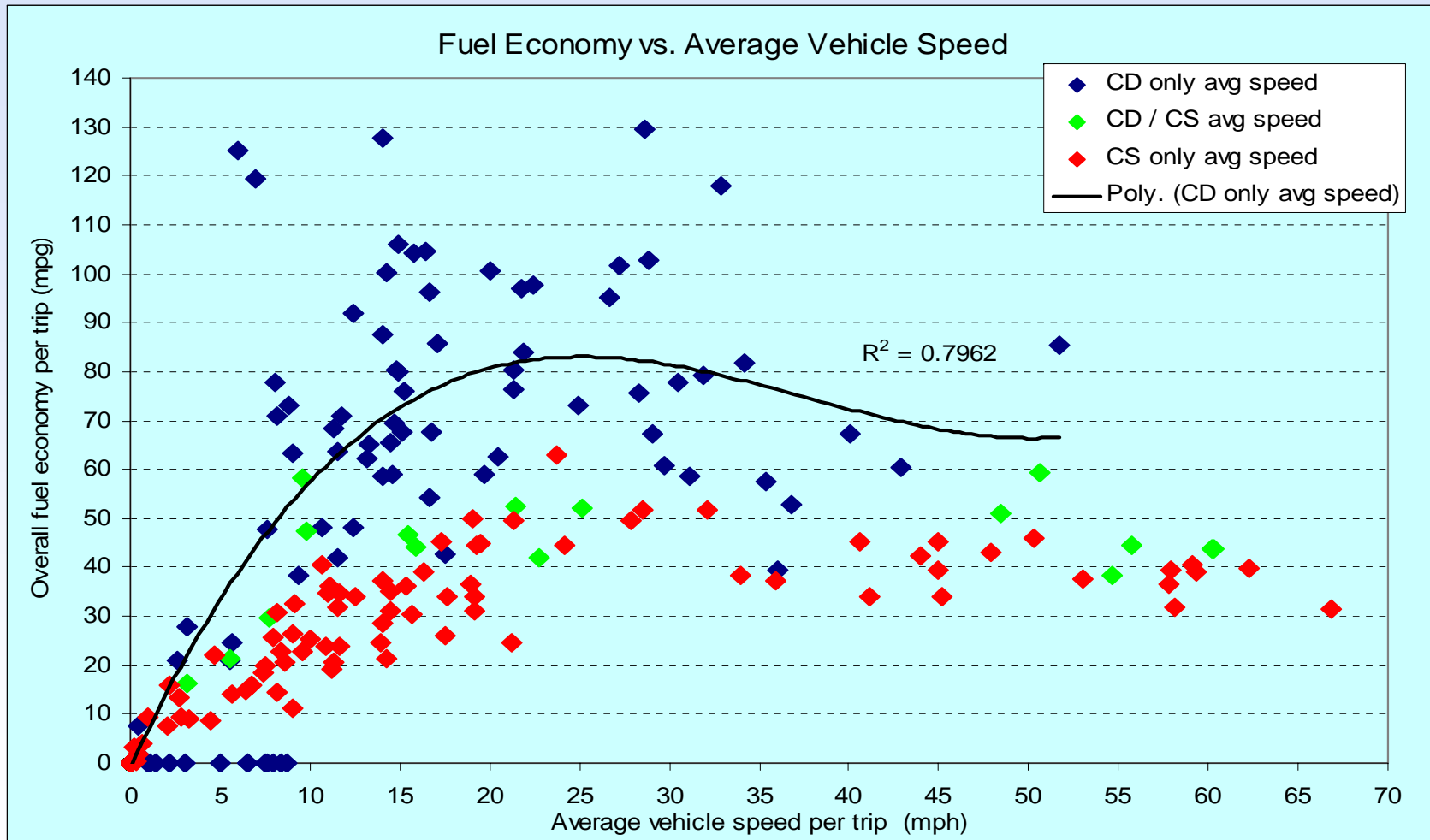
FY08 Hymotion Prius Charging Profiles

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



FY08 Hymotion Prius MPG Vs. Speed

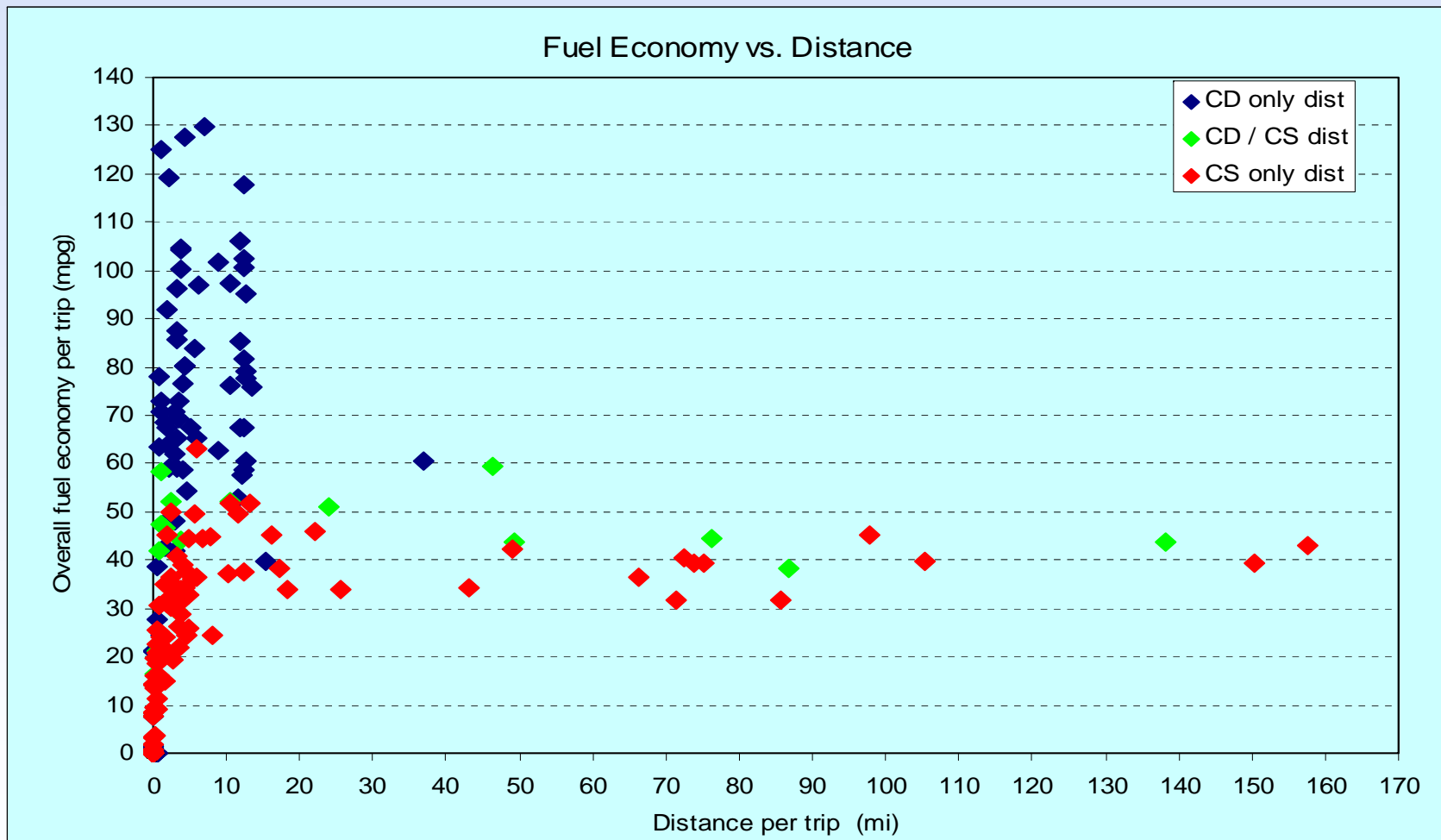
- 3 months, 2212 miles (single PHEV)



CD – charge depleting, S - sustaining

FY08 Hymotion Prius MPG Vs. Trip Distance

- 3 months, 2212 miles (single PHEV)



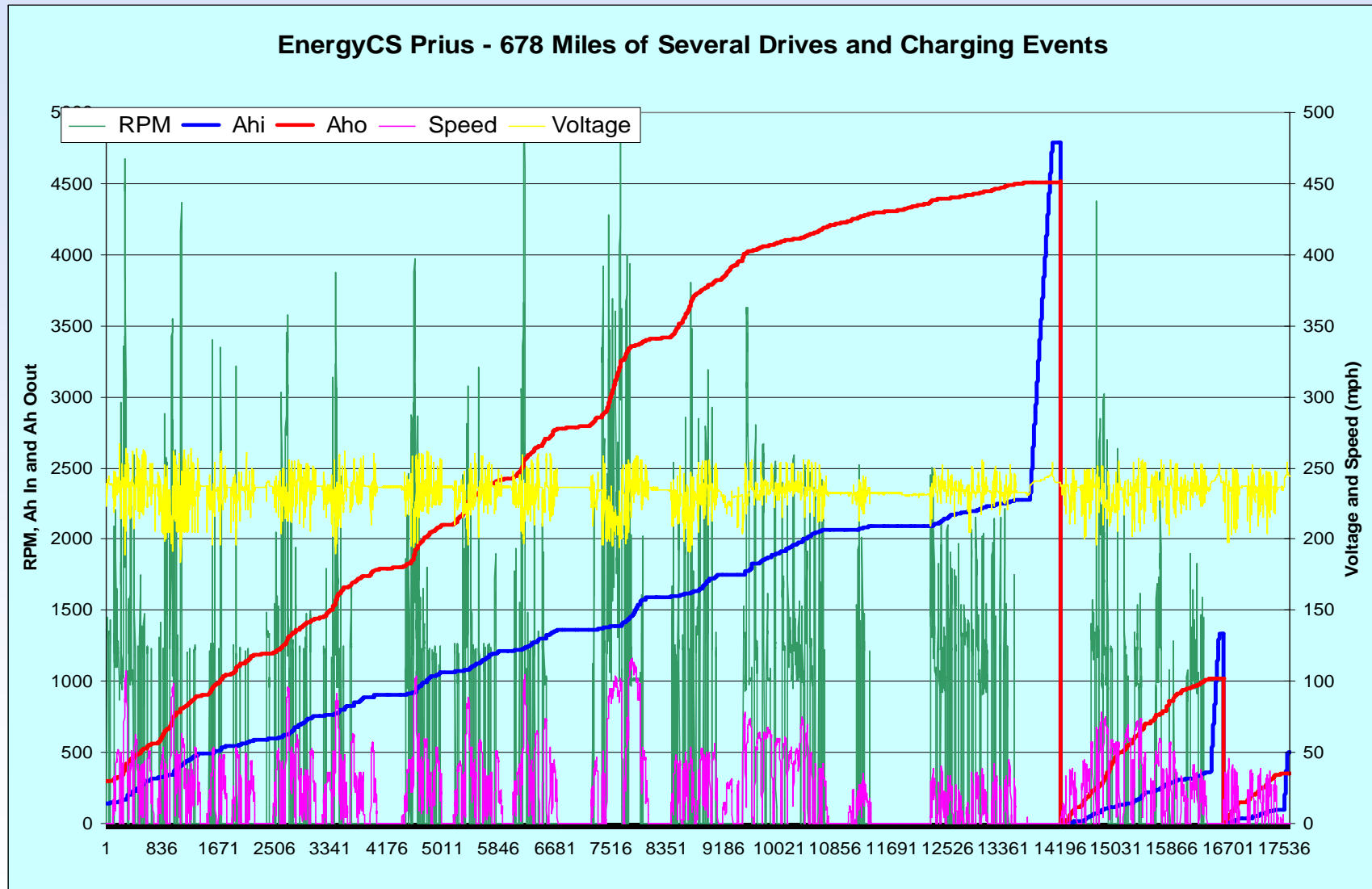
CD – charge depleting, S - sustaining

FY08 EnergyCS Joint Data Collection

- EnergyCS provided onboard data for seven vehicles operating in fleets in Canada, Arizona, and California
- Data collection methods are being modified to allow the collection of data via WiFi modems directly to INL servers
- Some reduction in battery performance due to software and pack balance problems
- AVTA / EnergyCS discussing replacement batteries



FY08 EnergyCS Onboard Data



FY07 / FY08 NYSERDA

- The AVTA is testing all six of the New York State Energy Research and Development Agency's PHEV conversions. Models and test status:

Model	Baseline Testing	Accelerated Testing	Delivery Status
EnergyCS Prius	Completed	Near completion	
Hymotion Prius	Completed	ongoing	
Hymotion Civic			Not yet delivered
Hymotion Escape	Started	After baseline	
Electovaya Escape	Problems	Starting	4 deliveries required
HybridsPlus Escape	Awaiting shipment		Delivered twice

- Probable fleet testing of 30 PHEVs later CY08



FY08 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
- Fleets will operate PHEVs in various missions
- Using V2Green cellular data loggers and GPS units to collect onboard data (45 parameters)
- Obtain offboard fuel use, maintenance requirements, and mission descriptions from fleets
- Start April 2008
- Likely partner in charge demand study with Seattle City Light



FY08 Tacoma Power

- **Tacoma Power obtained two lead acid battery Prius PHEVs from the Green Car Company**
- **One Hymotion Prius on order (April 2008)**
- **Conduct cooperative testing of vehicles and charging infrastructure**
- **Lead acid PHEVs are supposed to be the first PHEVs deployed with an all-electric range of 10 to 15 miles**
- **Testing will include charging and driving profiles as well as charging infrastructure analysis**
- **Using V2Green cellular data loggers and GPS units**
- **Started 1st quarter CY08**
- **AVTA considering baseline and accelerated testing of lead acid PHEV conversions**

FY08 National Rural Electric Cooperative Association (NRECA)

- Total of seven Prius and Escape PHEVs from Hymotion, EnergyCS, and HybridsPlus will be / are operated by rural electric coop utilities
- Collect and process onboard data from the fleets, and provide individual vehicle and fleet operations data to NRECA and fleets
- Testing will include charging and driving profiles as well as charging infrastructure analysis



FY08 University of California Davis

- **UCDavis will use 13 Hymotion Prius for public fleet demonstration**
- **Demonstration will include up to 100 drivers that are identified by AAA of California**
- **Each public driver will operate a vehicle for ~2 months**
- **V2Green cellular data loggers and GPS units will be used to track vehicle operations and performance, and charging practices and locations of the public**
- **AVTA will provide data collection, handling, analysis and dissemination support**
- **AVTA, UCDavis and AAA partnering to capture first study of public use of PHEVs**
- **Start ~April 2008**

FY08 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**
 - **Three colleges**
 - **Port agencies, cities and counties**
- **Includes daily solar (photovoltaic array) charging of at least one PHEV**
- **Electricity costs as low as 2.5 cents/kWh (hydropower)**
- **Start early summer of 2008**
- **Use V2Green cellular data loggers and GPS units**

FY08 Hawaii PHEV Demonstration

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



FY08 International Truck PHEV Bus Testing

- Conduct baseline performance testing of 40-foot PHEV school bus from International Truck with lithium pack
- Perform coastdown and dynamometer testing, likely use either or both the Manhattan driving cycle or the Orange County cycle
- With PHEV option on, 1st day of testing will include:
 - Cold start in charge depleting mode
 - Followed by hot starts in charge depleting modes
 - Followed by at least 2 charge-sustaining hot starts
 - In diesel engine only mode, 2nd day of testing will include 1 cold start, followed by several hot starts
- International completing internal testing



FY08 PHEV Technology Acceleration and Deployment Activity Financial Assistance

- **DOE's Vehicle Technologies Program seeks to accelerate development of PHEVs that:**
 - **Substantially reduce petroleum consumption**
 - **Are fully compliant with FMVSS**
 - **Meet all relevant emissions regulations**
 - **Can be economically massed produced**
 - **Have (minimum) 10-mile cumulative UDDS electric range**
- **Round I proposals were due 2/13/08, Round II 4/30/06**
- **Each awardee required to demonstrate 80 PHEVs over 3 years**
 - **10 PHEVs 1st year, 20 in 2nd year, 50 in 3rd year**
- **\$7 million first year, total of \$30 million over 3 years**

Summary PHEV Testing Activities

- Continue testing current and upcoming PHEVs and PHEV batteries
- Continue to perform due diligence to identify suitable PHEV candidates for testing
- Identify and determine the value of partnering in additional PHEV demonstrations
- Perform controlled accessory load testing for PHEV modelers
- Coordinate PHEV and charging infrastructure testing with industry and other DOE entities
- Explore possible vehicle to grid testing opportunities
- Supply charging behavior patterns and demands to PHEV infrastructure modelers at Oak Ridge and Pacific Northwest National Laboratories

Summary PHEV Testing Activities – cont'd

- **Provide PHEV cost data to other DOE labs and OEMs**
- **Continue AVTA's role as DOE's sole independent tester of whole-vehicle technologies in field applications. By late summer, PHEVs will be demonstrated in:**
 - **37 fleets**
 - **18 states and 2 provinces**
- **The AVTA will provide testing and data collection support for DOE's PHEV Technology Acceleration and Deployment Demonstration**
- **Provide PHEV testing results feedback to:**
 - **Domestic OEM industry, vehicle modelers and target setters, battery and other subsystem developers, DOE/Industry Technical Teams, and early fleet adaptors**

Acknowledgement

This work is supported by DOE's

Vehicle Technologies Program

Hybrid Electric Systems Leader, Tien Duong

**Vehicles and Systems Simulation and Testing Leader,
Lee Slezak**

Additional Information

<http://avt.inl.gov>

or

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

INL/CON-08-13848