US Department of Energy and Idaho National Laboratory PHEV Activity Overview

CEATI – NRECA PHEV Workshop

Arlington, VA
September 17, 2008

John Smart

INL/CON-08-14805

US Department of Energy
Vehicle Technologies Program
PHEV Research and Development Areas

System / component level activities include:

- **Energy storage**
  - **Advanced battery cells, packs and full systems**
    - **Cost, life, low temperature performance, tolerance abuse and safety**
  - **Monitoring of all technologies (capacitors, flywheels, etc)**
- **Power electronics and electric Motors**
  - **Cost, size, thermal control, integrated systems development**
- **Definition of PHEV component requirements**

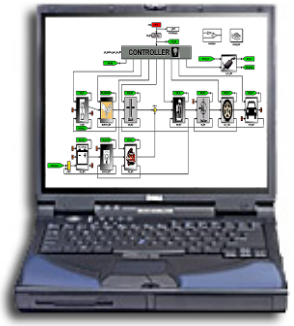
Li-ion Cells
Photo: Saft


Graphic: GM

US Department of Energy Vehicle Technologies Program
PHEV Research and Development Areas

Vehicle Technology Analysis and Evaluation activities include:

- **Modeling and Simulation**
  - **Reference Vehicle Definition**
  - **Analytical Tool Development**
  - **Technology Verification**
- **Integration and Validation**
  - **Hardware-in-the-Loop System Integration**
  - **Technology Validation**
- **Laboratory and Field Evaluation**
  - **Vehicle / Component Testing**
  - **Model Validation**



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US Department of Energy PHEV Testing Partners

Cooperative testing agreements 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**
- **State of Hawaii**
- **National Rural Electric Cooperative Association**
- **University of California-Davis**
- **PHEV conversion companies**
  - **Hymotion**
  - **EnergyCS**
  - **others**

US Department of Energy PHEV Technology Acceleration and Deployment Activity (TADA)

- Funding opportunity for vehicle manufacturers to put prototype PHEVs in field over next three years
- Proposals selected for negotiation from:
  - General Motors
  - Ford Motor Co.
  - Chrysler / General Electric

Idaho National Laboratory

- **Eastern Idaho based U.S. Department of Energy (DOE) multi-program laboratory**
- **890 square mile site with 3,600 staff**
- **Support DOE's strategic goal:**
  - **Increase U.S. energy security and reduce the nation's dependence on foreign oil**
- **The INL has managed DOE's Advanced Vehicle Test Activity since the late 1980's**

Advanced Vehicle Testing Activity (AVTA)

- **Part of the U.S. Department of Energy's Vehicle Technologies Program**
- **INL and Electric Transportation Engineering Corporation (ETEC) conduct the AVTA's light-duty vehicle testing, with Argonne National Laboratory performing dynamometer testing**

AVTA Goals

- **Determine actual petroleum displacement and overall operating cost of advanced technology vehicles**
- **Provide benchmark data to industry and government research and development programs**
- **Assist consumers in making informed vehicle purchase, usage, and operating decisions**

AVTA Testing History

- Plug-in hybrid electric vehicles
  - 9 models, ~70 vehicles in fleets
- Hybrid electric vehicles
  - 14 models, 4+ 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

PHEV Models Tested by AVTA

Nine different PHEV models are in or have completed various testing / demonstration activities

- **Hymotion Prius**
- **EnergyCS Prius**
- **Hymotion Escape**
- **HybridsPlus Escape**
- **HybridsPlus Prius**
- **Manzanita lead acid Prius**
- **Electrovaya Escape**
- **Ford E85 Escape**
- **Renault Kangoo**

- **Daimler Sprinter expected to start testing in Spring 2009**

PHEV Testing Objectives

Perform independent testing of PHEVs using:

- **Baseline performance testing**
  - **closed test tracks and dynamometers**
- **Accelerated on-road testing**
  - **dedicated drivers operating on defined routes**
- **Fleet testing**
  - **monitor everyday uncontrolled use with onboard data loggers**
- **Lab and field off-board charging / grid interaction studies**

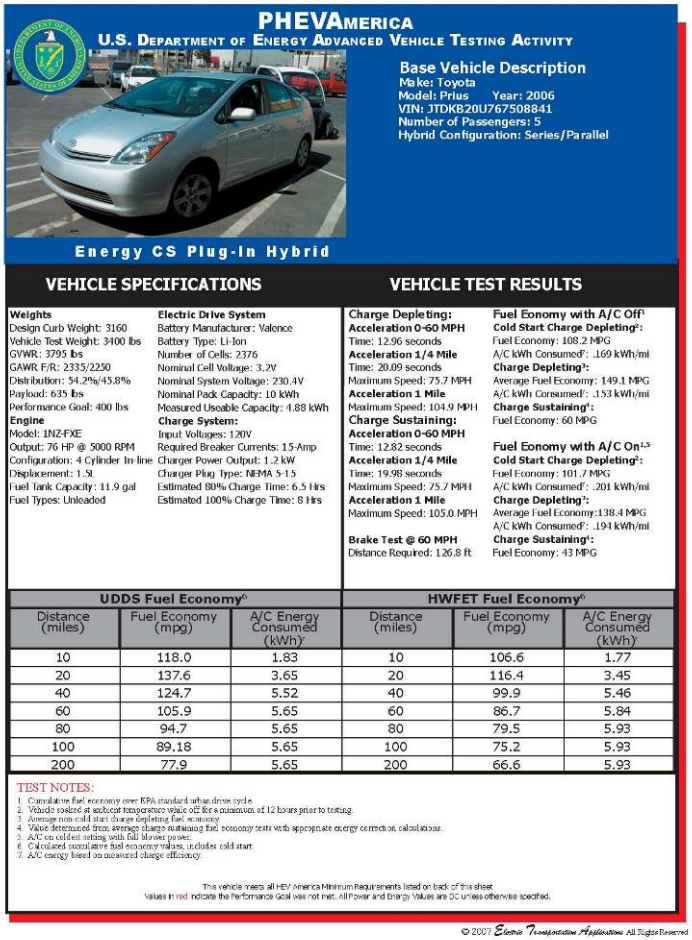
PHEV Testing Objectives

Study and document

- **How the vehicles are driven**
- **How the vehicles are charged**
- **The effect on**
  - **Gasoline and electricity fuel use**
  - **Battery life**
  - **Facility / grid demand and energy profiles**
- **Charging infrastructure requirements**
- **Cost / benefit of fast charging, vehicle-to-grid charging**
- **Overall PHEV life-cycle costs**

PHEV Baseline Performance Testing

- These and other test results at http://avt.inl.gov



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

Energy CS Plug-In Hybrid

Base Vehicle Description
Make: Toyota
Model: Prius Year: 2006
VIN: JTDKB20U767508841
Number of Passengers: 5
Hybrid Configuration: Series/Parallel

VEHICLE SPECIFICATIONS

Weights
Design Curb Weight: 3160
Vehicle Test Weight: 3400 lbs
GVWR: 3795 lbs
GAWR F/R: 2335/2250
Distribution: 54.2%/45.8%
Payload: 635 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: Valence
Battery Type: Li-Ion
Number of Cells: 2376
Nominal Cell Voltage: 3.2V
Nominal System Voltage: 230.4V
Nominal Pack Capacity: 10 kWh
Measured Useable Capacity: 4.88 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: 6.5 Hrs
Estimated 100% Charge Time: 8 Hrs

VEHICLE TEST RESULTS

Charge Depleting:
Acceleration 0-60 MPH
Time: 12.96 seconds
Acceleration 1/4 Mile
Time: 20.09 seconds
Maximum Speed: 75.7 MPH
Acceleration 1 Mile
Maximum Speed: 104.9 MPH
Charge Sustaining:
Acceleration 0-60 MPH
Time: 12.82 seconds
Acceleration 1/4 Mile
Time: 19.98 seconds
Maximum Speed: 75.7 MPH
Acceleration 1 Mile
Maximum Speed: 105.0 MPH
Brake Test @ 60 MPH
Distance Required: 126.8 ft

Fuel Economy with A/C Off[1]
Cold Start Charge Depleting[2]:
Fuel Economy: 108.2 MPG
A/C kWh Consumed[3]: .169 kWh/mi
Charge Depleting[3]:
Average Fuel Economy: 149.1 MPG
A/C kWh Consumed[3]: .153 kWh/mi
Charge Sustaining[4]:
Fuel Economy: 60 MPG

Fuel Economy with A/C On[1,5]
Cold Start Charge Depleting[2]:
Fuel Economy: 101.7 MPG
A/C kWh Consumed[3]: .201 kWh/mi
Charge Depleting[3]:
Average Fuel Economy:138.4 MPG
A/C kWh Consumed[3]: .194 kWh/mi
Charge Sustaining[4]:
Fuel Economy: 43 MPG

UDDS Fuel Economy[6]

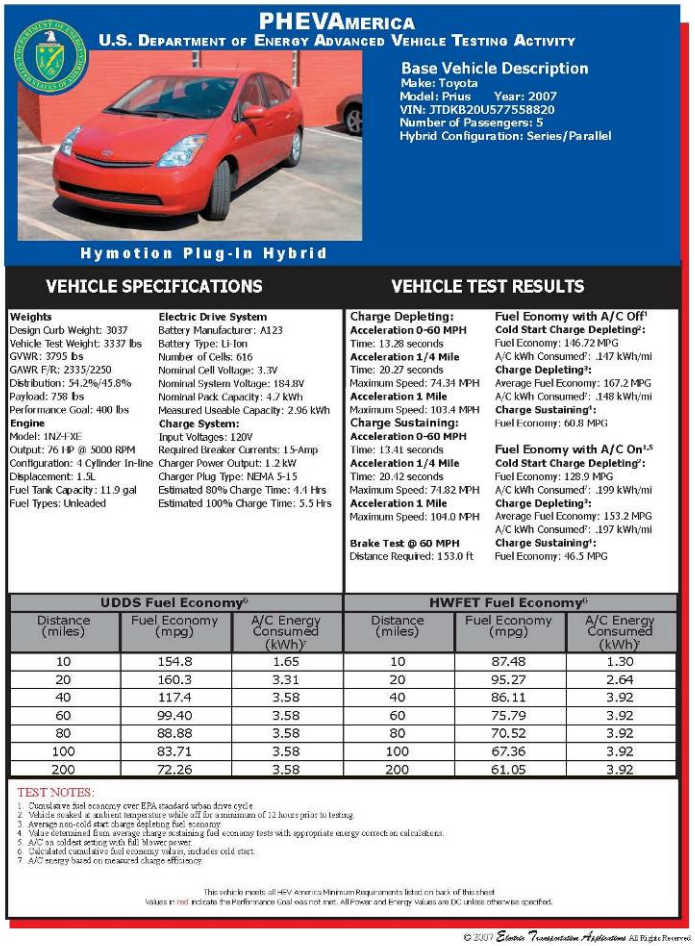
Distance (miles)	Fuel Economy (mpg)	A/C Energy Consumed (kWh)[7]
10	118.0	1.83
20	137.6	3.65
40	124.7	5.52
60	105.9	5.65
80	94.7	5.65
100	89.18	5.65
200	77.9	5.65

HWFET Fuel Economy[6]

Distance (miles)	Fuel Economy (mpg)	A/C Energy Consumed (kWh)[7]
10	106.6	1.77
20	116.4	3.45
40	99.9	5.46
60	86.7	5.84
80	79.5	5.93
100	75.2	5.93
200	66.6	5.93

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.



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

Hymotion Plug-In Hybrid

Base Vehicle Description
Make: Toyota
Model: Prius Year: 2007
VIN: JTDKB20U577558820
Number of Passengers: 5
Hybrid Configuration: Series/Parallel

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[3]: .147 kWh/mi
Charge Depleting[3]:
Average Fuel Economy: 167.2 MPG
A/C kWh Consumed[3]: .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[3]: .199 kWh/mi
Charge Depleting[3]:
Average Fuel Economy: 153.2 MPG
A/C kWh Consumed[3]: .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.
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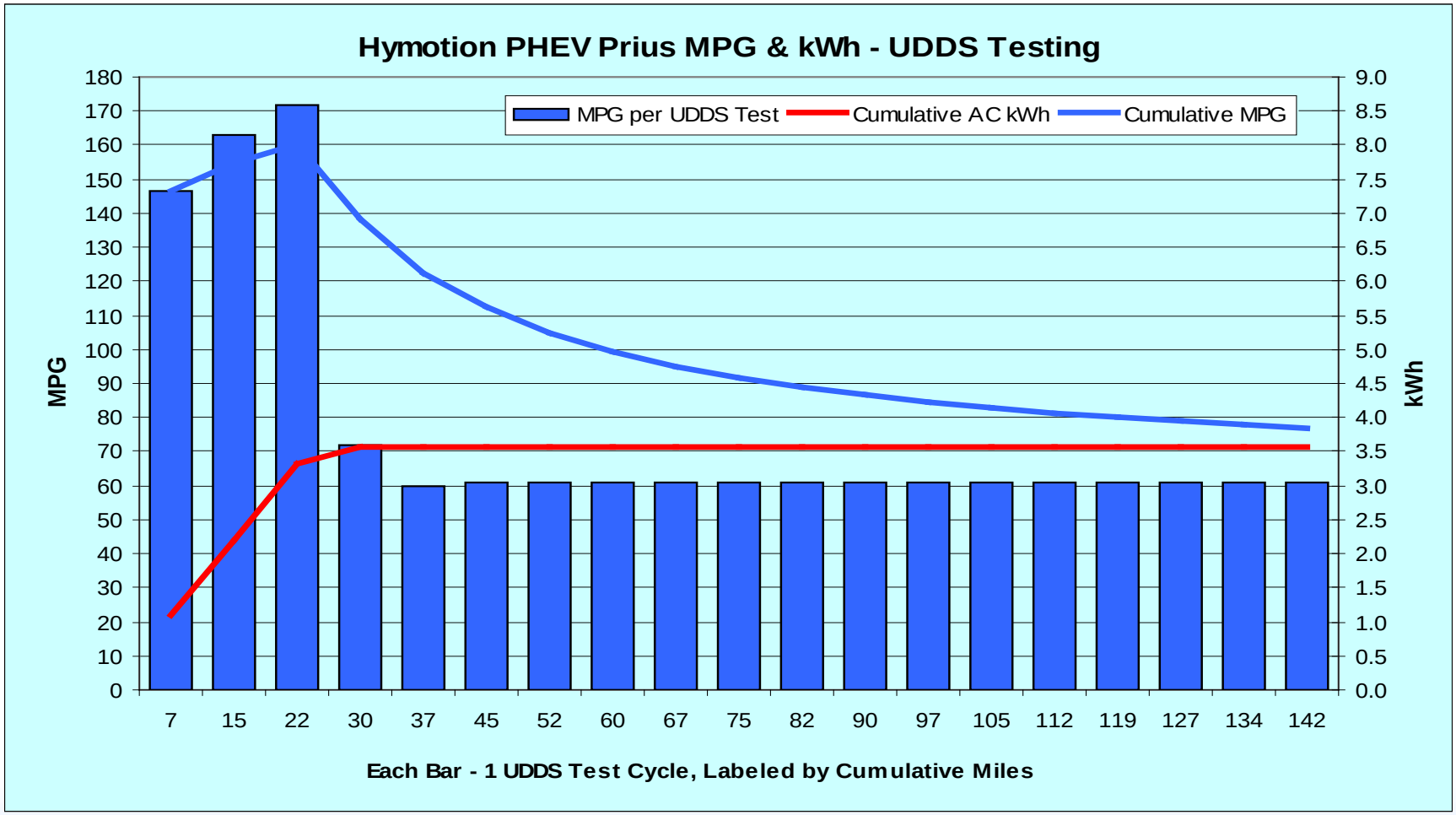
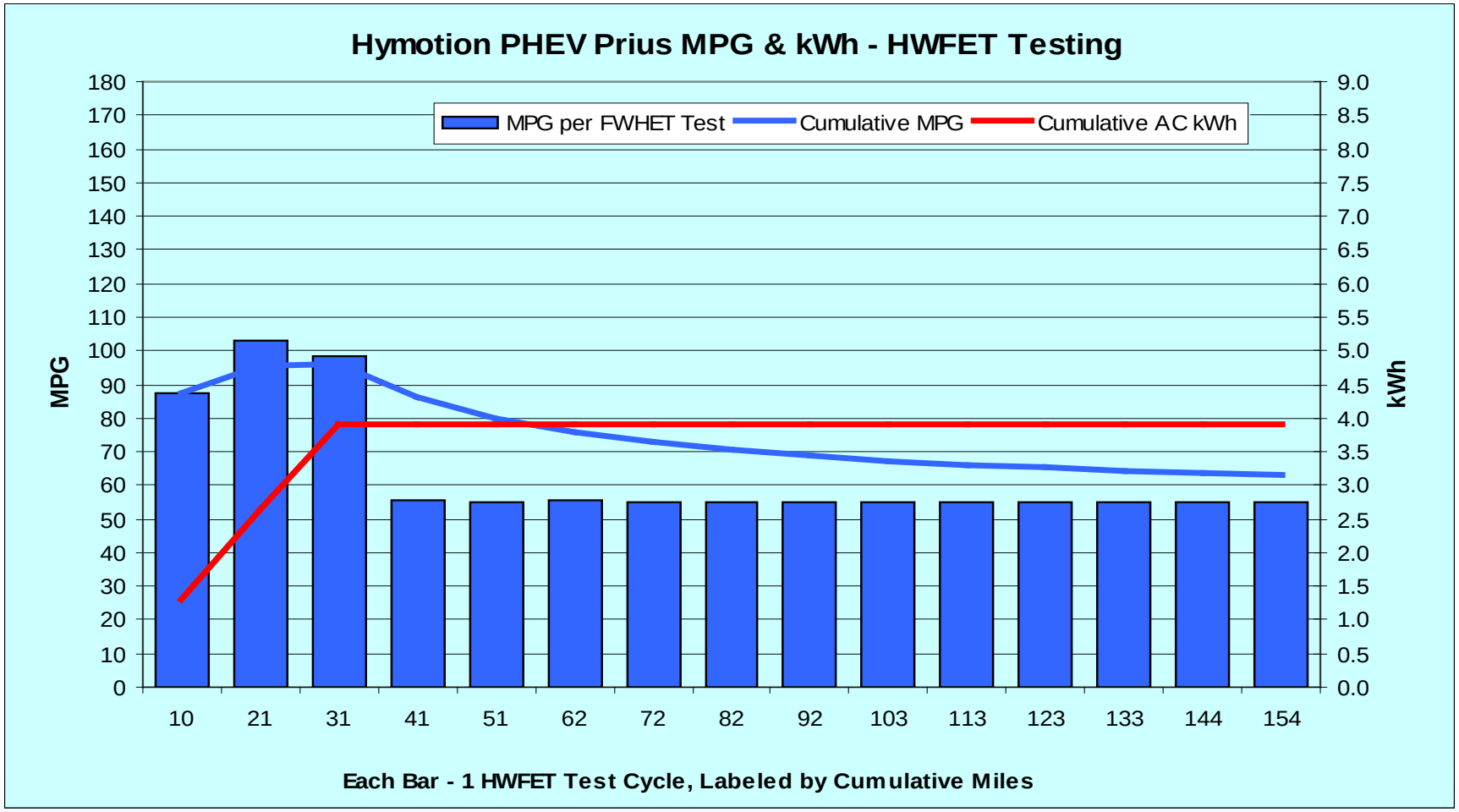
Toyota Prius with Hymotion PHEV conversion – EPA City Test



Toyota Prius with Hymotion PHEV conversion – EPA Highway Test

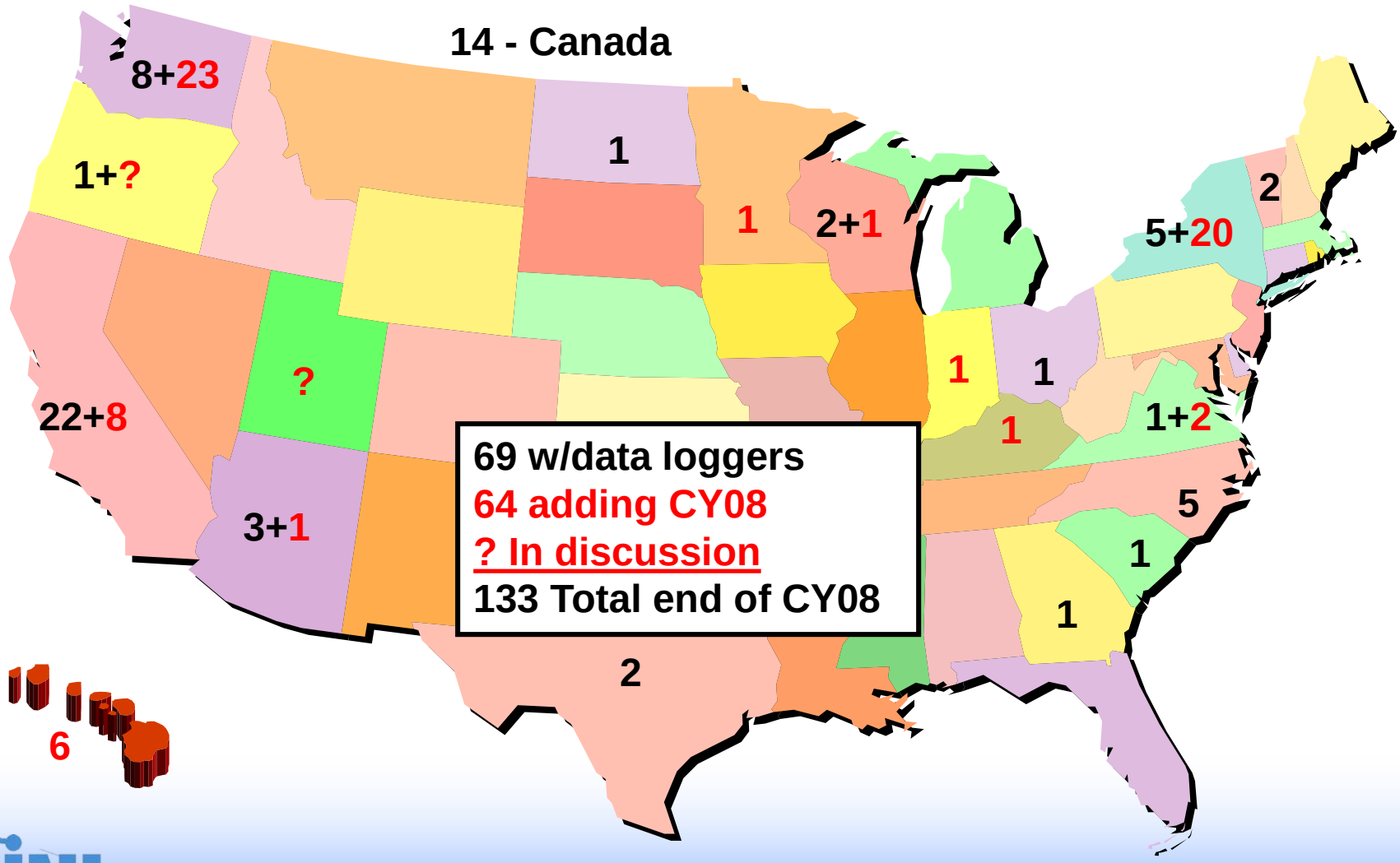


Hymotion Prius – On-road Accelerated Testing

Cycle	Urban	Highway	Charge	Reps	Total	Electricity	Gasoline	
(mi)	(10 mi)	(10 mi)	(hr)	(N)	(mi)	AC kWh	Gal	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

PHEV Demonstration Fleets



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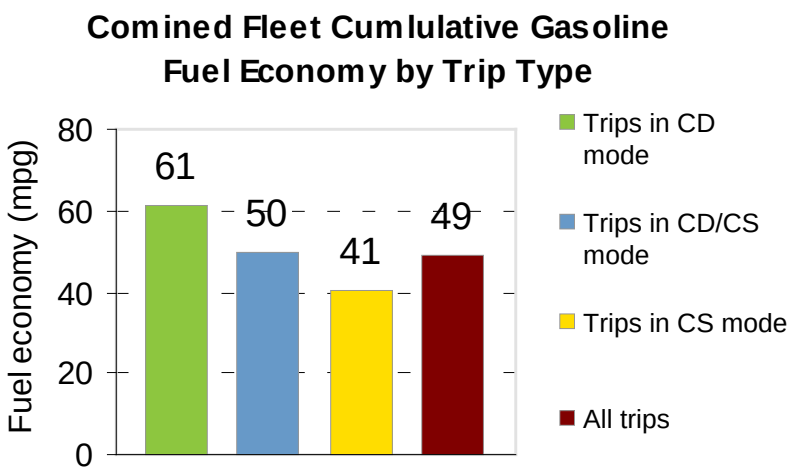
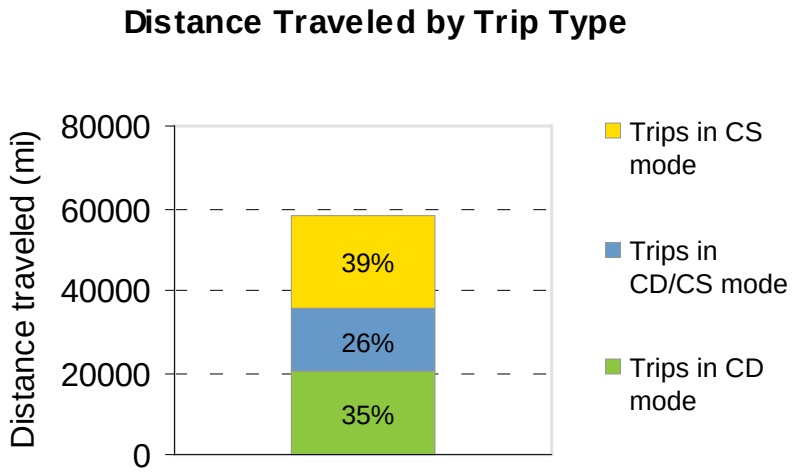
PHEV Fleet Performance

- **Data sampled from 28 Hymotion Prius vehicles**
- **Jan – Jun 2008**
- **58,005 miles**

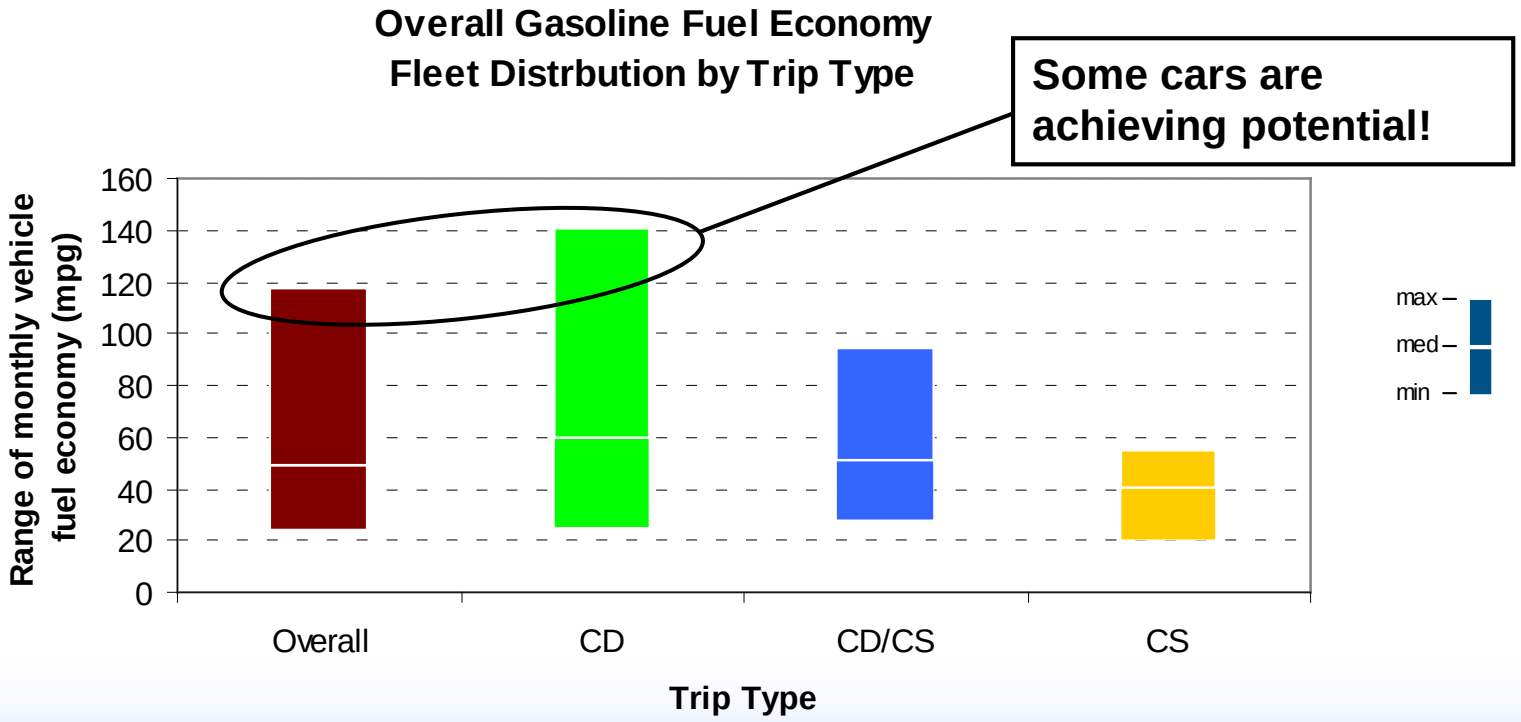




CD = Charge depleting
CS = Charge sustaining

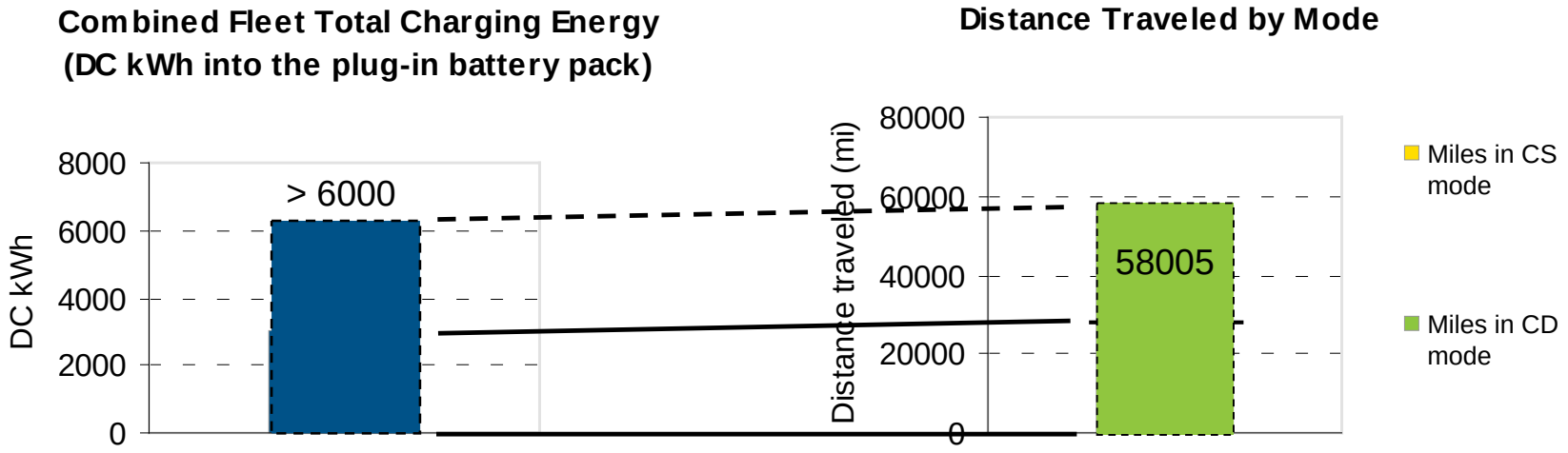
PHEV Fleet Performance

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



PHEV Fleet Performance

- **Same 28 Hymotion Priuses, Jan – Jun 2008**
- **Charging energy:**



3073 kWh / 28185 mi = 108 Wh/mi

58005 mi * 108 Wh/mi = 6265 kWh

Need > twice the electricity for 100% charge depleting miles (all other things equal)

CD = Charge depleting
CS = Charge sustaining

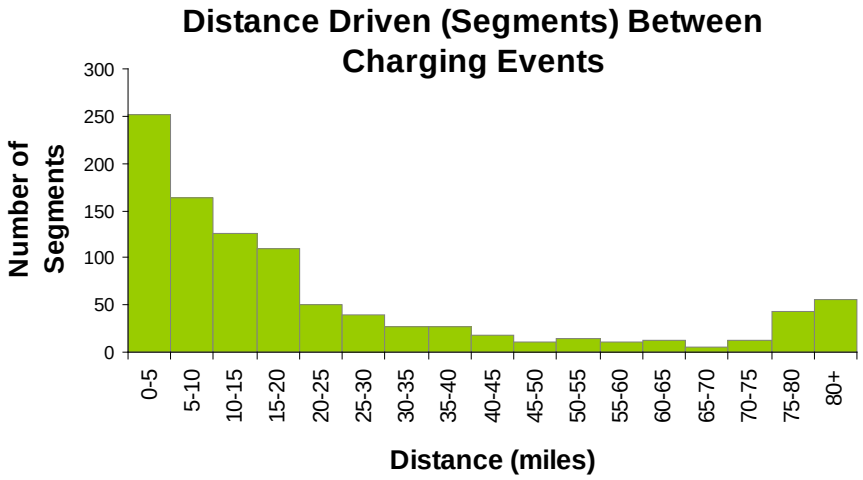
PHEV Fleet Performance

- **For better gasoline fuel efficiency, use more electricity!**
- **Battery capacity limited, so plug in more often**

- **Or put another way:**

  For charge depleting operation, distance driven between charging events must be less than charge depleting range

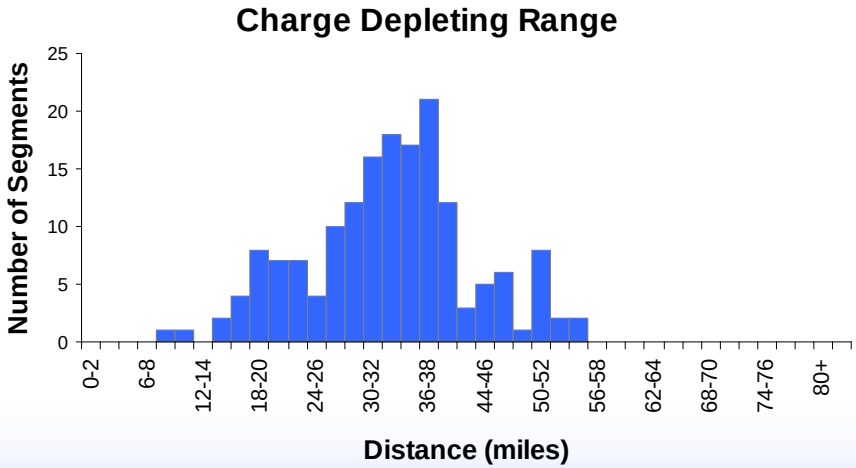
Fleet Distance vs. Range



Hymotion Prius

23 cars

Jan – Jul 2008

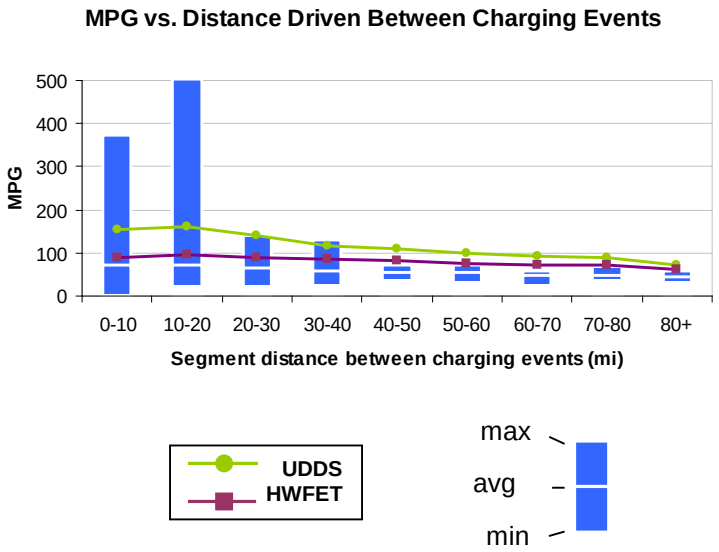


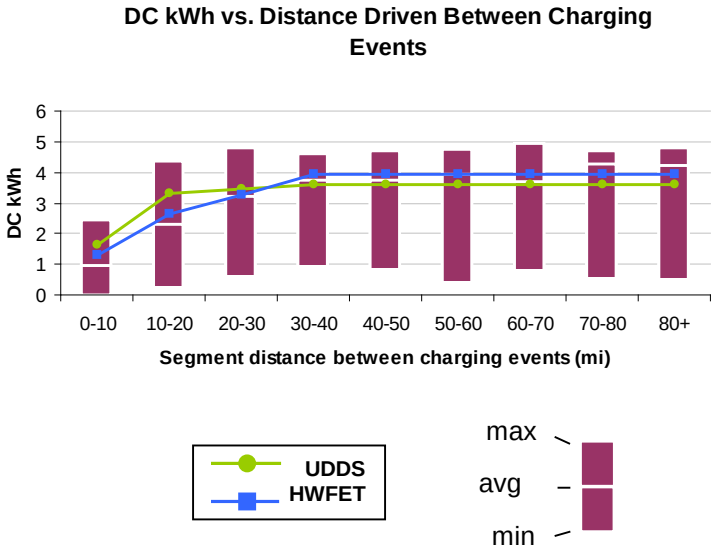
Same cars, date range

Includes all segments that started with SOC > 95%, ended in CS mode.

CD range is CD distance for each segment.

Fleet Fuel and Electricity vs. Segment Distance



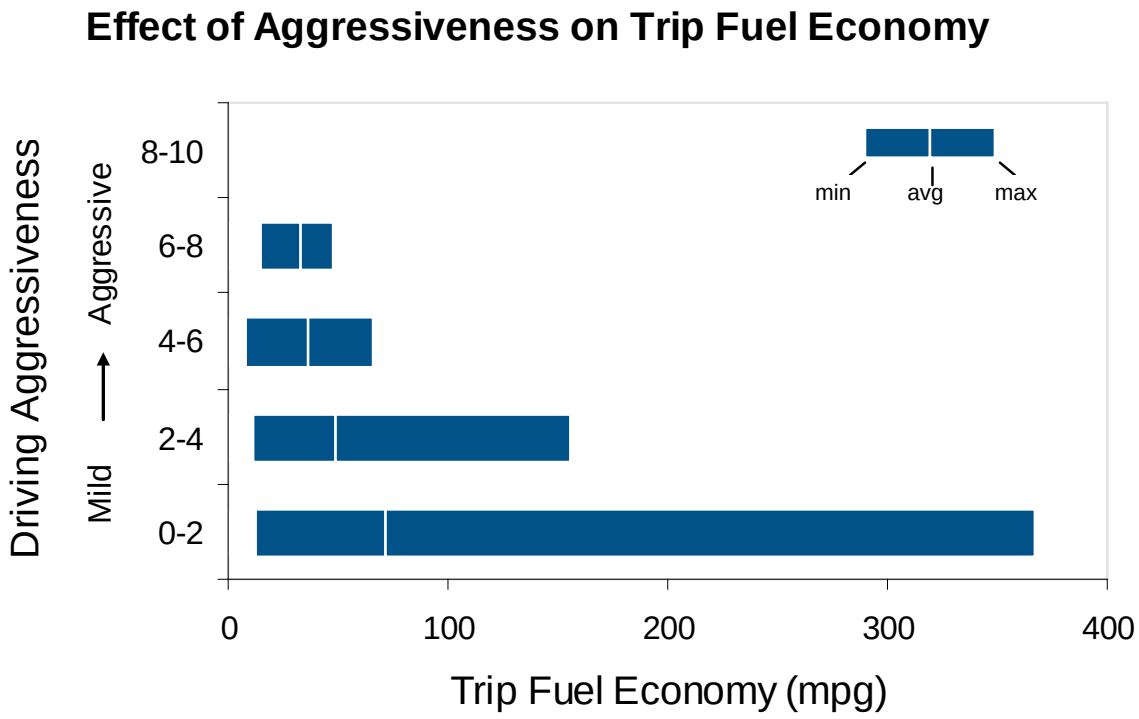


(42 EV-only segments not included)

“Actual Mileage May Vary”

- Even when in charge depleting mode, gasoline fuel efficiency, electrical energy efficiency, and charge depleting range vary widely depending on usage
- Causes of variation
  - Driver aggressiveness
  - Location (city, rural, highway)
  - Temperature
  - Payload
  - Etc.

Driver Aggressiveness



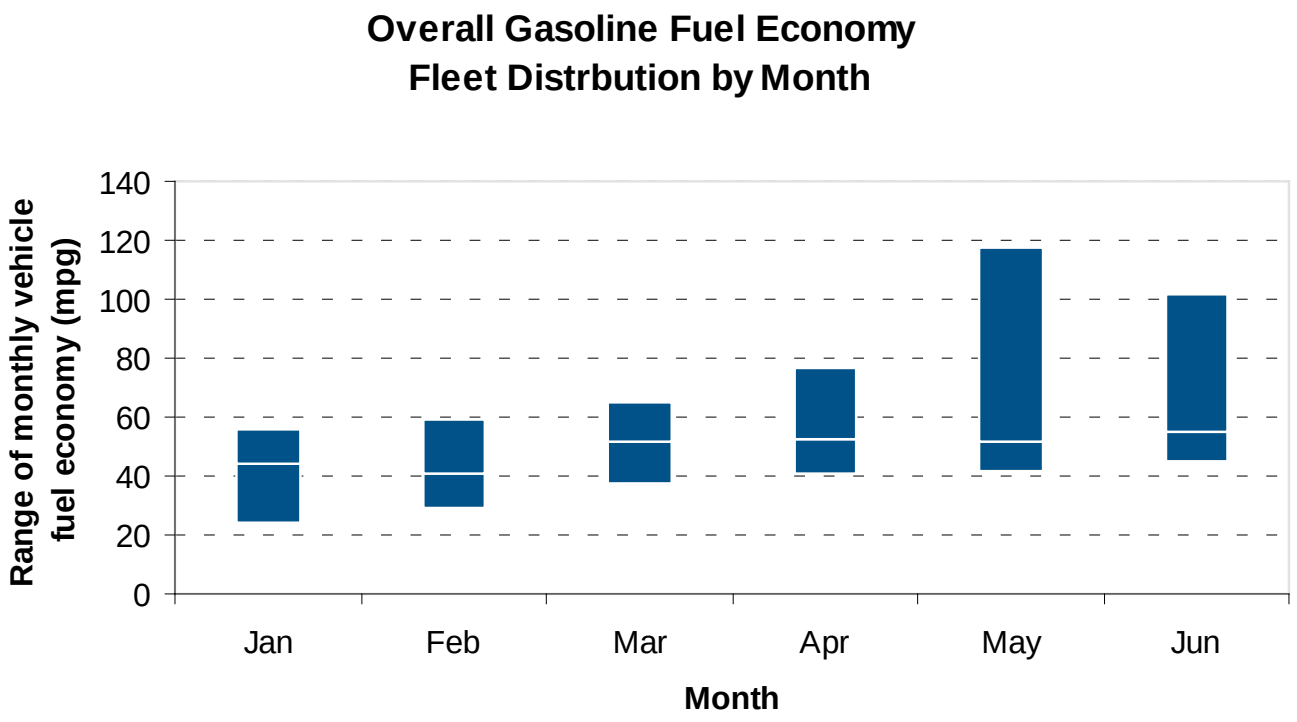
28 Hymotion Priuses

Jan – Jun 2008

All trips with distance > 1 mi

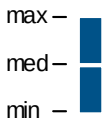
- **Aggressiveness measured by time at accelerator pedal position**
- **The deeper the pedal, the higher the aggressiveness**

Fuel Economy Seasonal Variation



28 Hymotion Priuses

Jan – Jun 2008

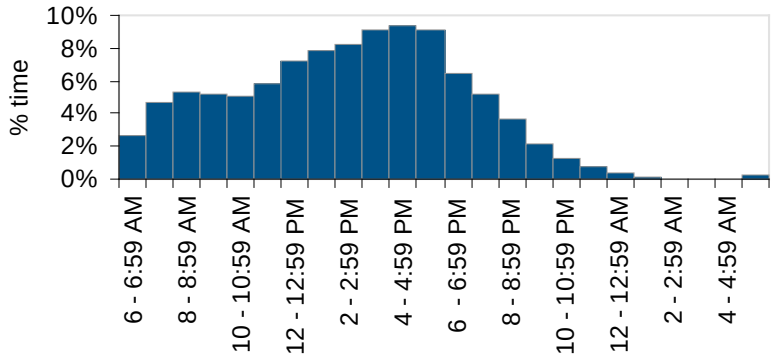


Plug-in Charging Patterns

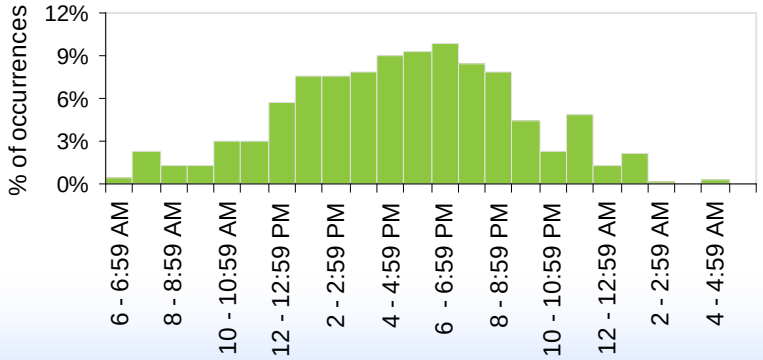
Average number of charging events per vehicle per month	20
Average number of charging events per vehicle per day when vehicle driven	0.7
Average number of trips between charging events	3.9
Average distance driven between charging events (mi)	34.0
Average duration of charging event (hr)	2.4
Average energy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

Plug-in Charging Patterns

Time of Day When Driving



Time at the Start of Charging Events



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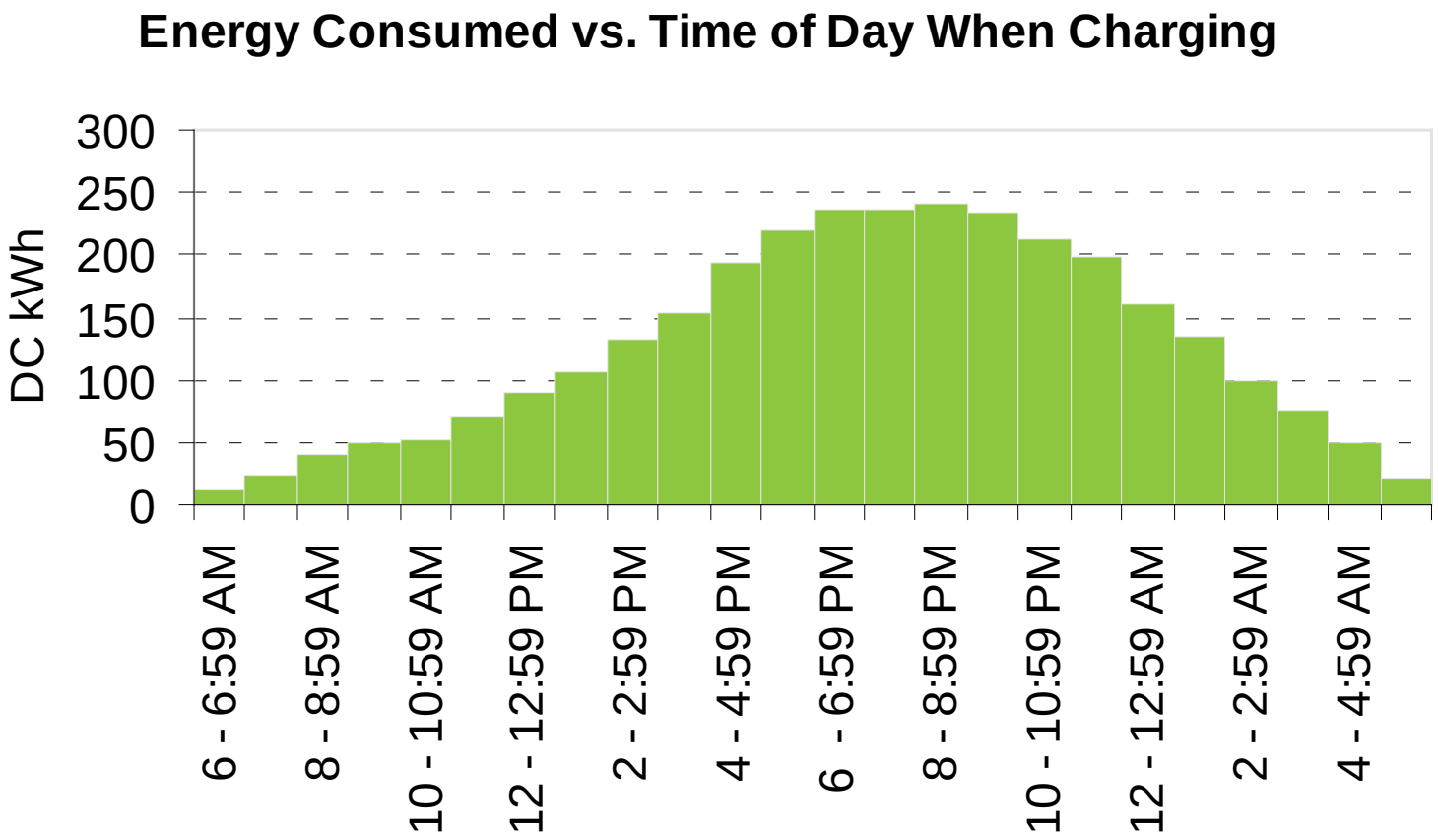
Plug-in Charging Patterns



PHEV – Grid Interaction Testing

- **Time-of-day charging study (Fall 2008)**
  - **Conducting charging demonstration with City of Seattle using 13 Seattle area PHEVs**
  - **Includes INL battery impact analysis**
  - **Uses V2Green wireless charging control**
- **Charging infrastructure and facility demand study (started May 2008)**
  - **Conducting charging demonstration with Tacoma Power to:**
    - **document charging infrastructure needs**
    - **determine demand and energy profiles of PHEV charging as portion of facility profiles**
  - **Using WiFi local energy meter (LEM) data collection system**
- **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**

Acknowledgement

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

Pat Davis, Tien Duong, Lee Slezak and Ro Sullivan

Additional Information

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

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