U.S. Department of Energy's Vehicle Technologies Program

PHEV Operations, Performance and Charging Profiles

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Hawaiian Electric Company
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This presentation does not contain any proprietary or sensitive information

Idaho National Laboratory

- Eastern Idaho based U.S. Department of Energy (DOE) Federal 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
- Multi-program DOE laboratory
  - Nuclear Energy
  - Fossil, Biomass, Wind, Geothermal and Hydropower Energy
  - Advanced Vehicles and Battery Development
  - Energy Critical Infrastructure Protection

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AVTA Background and Goals

- The Advanced Vehicle Testing Activity (AVTA) is part of DOE's Vehicle Technologies Program
- 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 early adaptor vehicle purchase, deployment and operating decisions

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AVTA Testing by Technology

- Plug-in hybrid electric vehicles (PHEV)
  - 12 models, 187 vehicles, 850,000 fleet test miles
- Hybrid electric vehicles (HEV)
  - 17 models, 45 vehicles, 4.5 million test miles
- Neighborhood electric vehicles
  - 23 models, 200,000 test miles
- Hydrogen ICE (internal combustion engine) vehicles
  - 7 models, 500,000 test miles
- Full-size battery electric vehicles (BEVs)
  - 40 EV models, 5+ million test miles
- Urban electric vehicles
  - 3 models, 1 million test miles

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12 PHEVs Models in Testing/Demonstrations

- Hymotion Prius (A123Systems)
- Hymotion Escape (A123Systems)
- Ford E85 Escape (Johnson Controls/Saft)
- EnergyCS Prius, 2 models (Valance and Altair Nano)
- Electrovaya Escape (Electrovaya)
- Hybrids Plus Escape, 2 models (Hybrids Plus and K2 Energy Solutions)
- Hybrids Plus Prius (Hybrids Plus)
- Manzanita Prius (lead acid)
- Manzanita Prius (Thunder Sky)
- Renault Kangoo (Saft NiCad)
- (All batteries are Lithium unless noted)

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PHEV Testing Methods and 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 \ non-directed fleet and public use, with onboard data loggers
  - Laboratory testing of PHEV batteries
- Testing used to document:
  - Battery life, charging patterns and profiles
  - Vehicle operations, fuel use (electricity and gasoline) and infrastructure requirements
  - Driver influences on fuel use
  - Individual PHEV models and PHEV concepts
  - PHEV life-cycle costs

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PHEV Operating Modes

- **Charge sustaining (CS) mode: from start to finish of a single trip, there is no energy available for electric drive propulsion in the PHEV battery. Therefore, the battery state-of-charge (SOC) is sustained**
- **Charge depleting (CD) mode – from start to finish of a single trip, there is energy available for partial or full electric drive propulsion in the PHEV battery. Therefore, the battery SOC is being depleted during the trip**
- **Mixed CD/CS mode – there is energy in the battery pack at the start of a single trip, but the PHEV battery is fully depleted before the trip ends**

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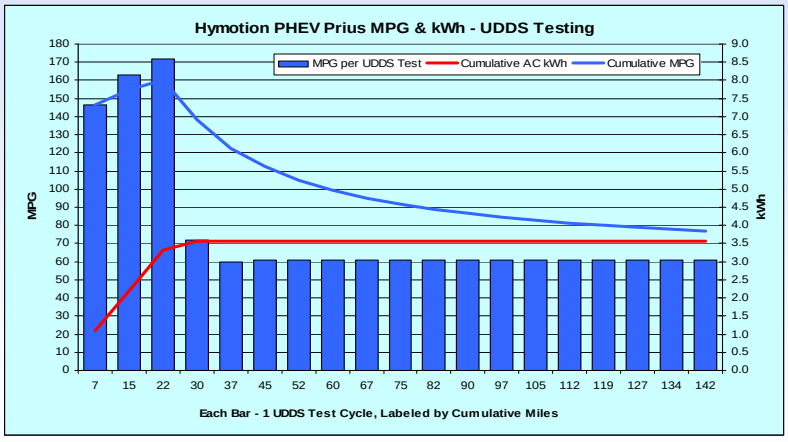
Hymotion Prius Gen I – UDDS Fuel Use

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



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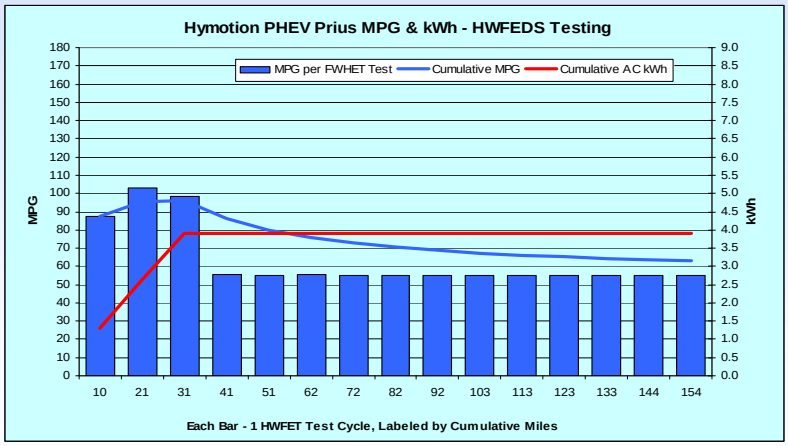
Hymotion Prius Gen I – HWFEDS Fuel Use

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



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PHEV Accelerated Testing

- **Accelerated testing in Phoenix over 5,440 onroad 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			

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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	2340	3100	1404	167	5,440	Weighted Average		79.5

Each total distance slightly greater than 600 and 640 miles. HEV version = 44 mpg

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Hymotion Prius Gen II – Accelerated Testing

Cycle	Urban	Highway	Charge	Reps	Total	Electricity	Gasoline		Recalculated without incomplete charges
(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	124.50	8.105	80.1	
40	4	0	12	15	600	71.28	9.8	62.1	64.2
40	4	0	12	15	600	44.97	7.2	84.2	135.6
40	2	2	12	15	600	64.36	9.70	64.3	65.5
40	2	2	12	15	600	75.14	6.20	99.8	101.7
40	2	2	12	15	600	70.98	6.83	90.6	98.9
40	0	4	12	15	600	75.18	6.10	103.3	100.0
40	0	4	12	15	600	63.46	8.88	70.8	92.4
60	2	4	12	10	600	33.38	10.54	58.8	
80	2	6	12	8	640	41.38	10.71	61.8	
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	2340	3100	1404	167	7,840	Weighted Average			

Each total distance slightly greater than 600 and 640 miles. HEV version = 44 mpg

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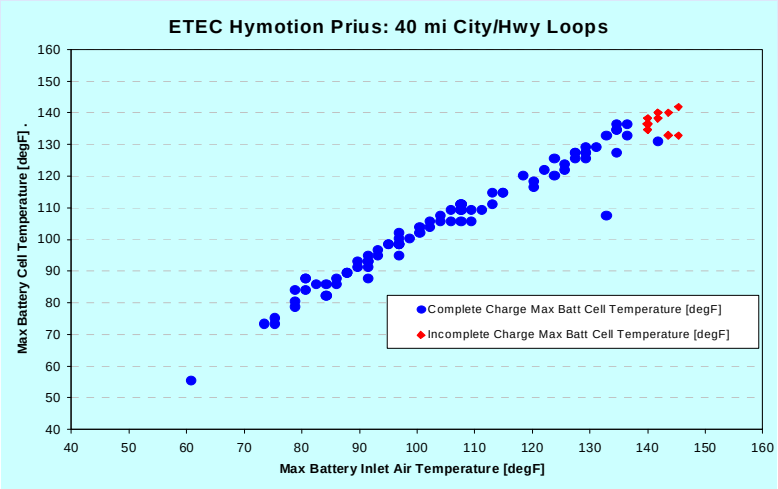
Hymotion Prius Gen II – Accelerated Testing

- 40 mile city/highway loops – high ambient temperatures results in incomplete charging



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PHEV Fleet Testing Partners

- 75+ testing partners in the U.S. and Canada:
  - 36 Electric utilities and 2 clean-air agencies
  - 10 City, county and state governments
  - 7 Private companies and advocacy organizations
  - 8 Universities and colleges and 4 Canadian provinces
  - 2 PHEV companies 1 sea port and 1 DOD facility
- Testing partners include:
  - A123Systems, EnergyCS, NYSERDA, NRECA, UC Davis, Fairfax County, Google.org, Austin Energy, Central Vt PSC, Duke Energy, Advanced Energy, Progress Energy, SDGE, Basin Electric, Buckeye Power, WI Public Power Inc., Madison GE, SCANA Corp., HCATT, BC Hydro, BC Government, various Washington State groups

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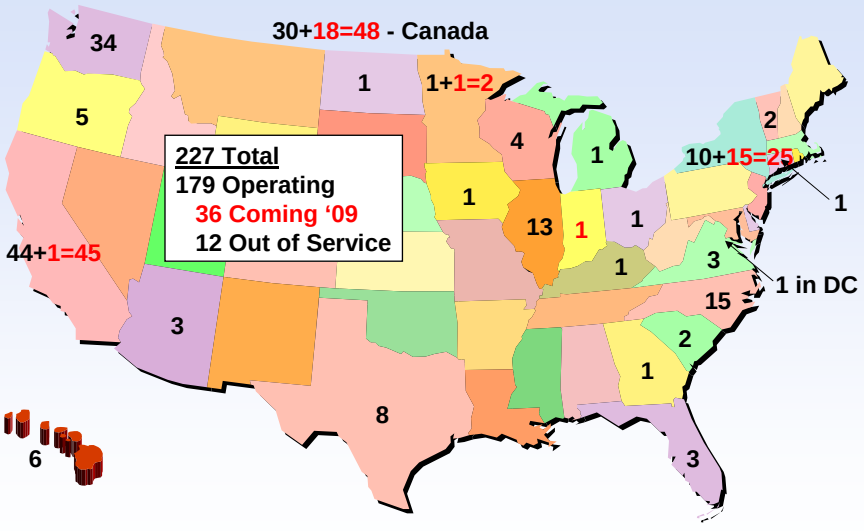
PHEVs and Demonstration Locations



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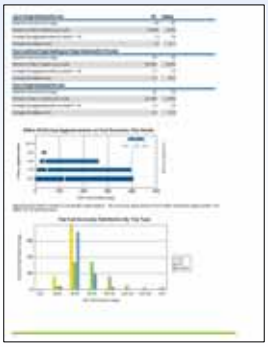
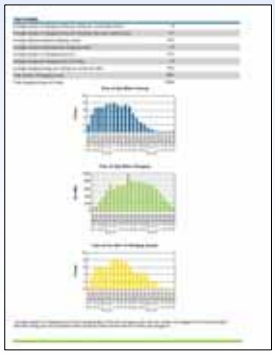
PHEV Fleet Testing Reports

- Summary reports posted monthly on web
- Individual vehicle reports only go to the respective fleets each month, 1,060+ reports to date (August 1, 2009)
- 153 Hymotion Prius PHEVs, 780,000 miles, 86,000 trips, 20,500 charging events, 47,000 kWh used. V2Green and Kvaser data logger reports





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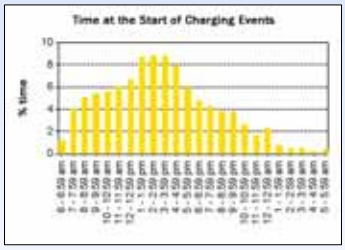
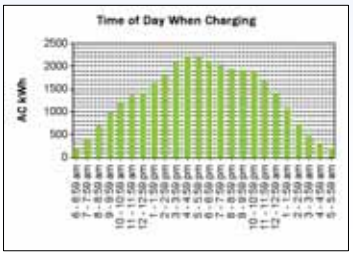
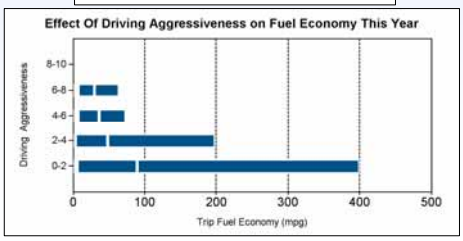
Hymotion Prius (V2Green Logger) Fleet Tests

- **March 01/08 to July 01/09. 110 PHEVs, 498,000 miles, 54,000 trips, 12,400 charging events and 31,000 kWh used**







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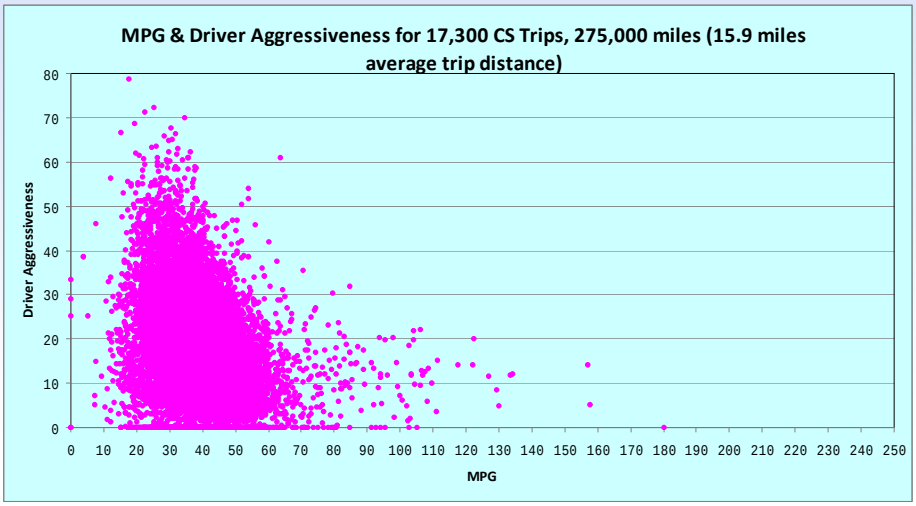
Hymotion Prius PHEVs – CS Trips

- **MPG and aggressive driving impacts March '08 – May '09**



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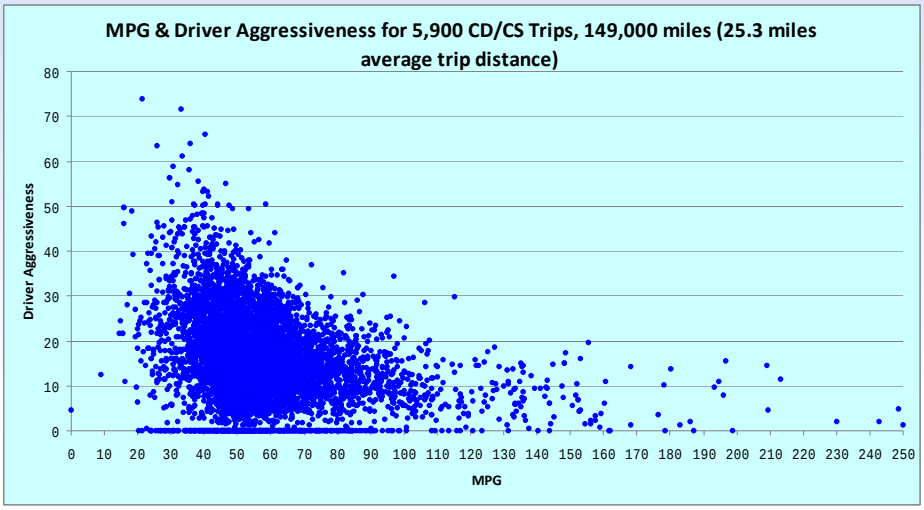
Data from 150 Hymotion Prius with V2Green and Kvaser loggers

Hymotion Prius PHEVs – CS/CD Mixed Trips

- MPG and aggressive driving impacts March '08 – May '09



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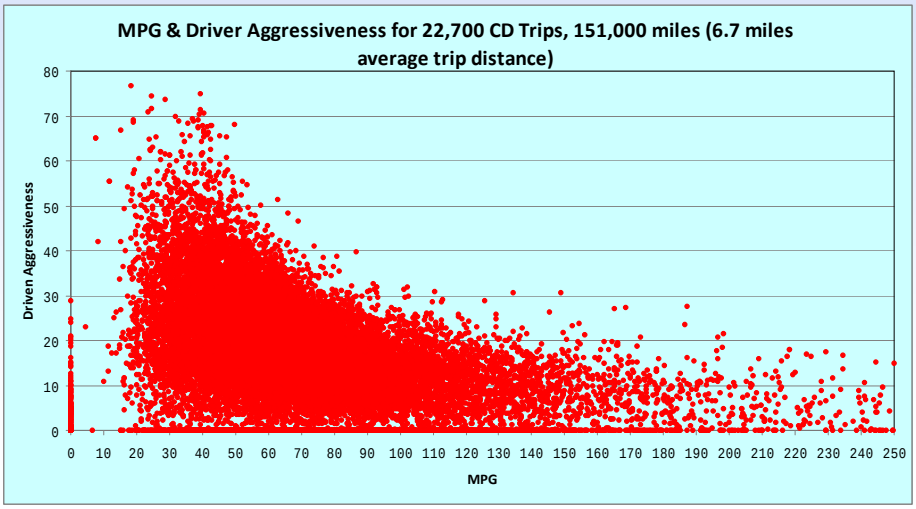
Data from 150 Hymotion Prius with V2Green and Kvaser loggers

Hymotion Prius PHEVs – CD Trips

- MPG and aggressive driving impacts March '08 – May '09



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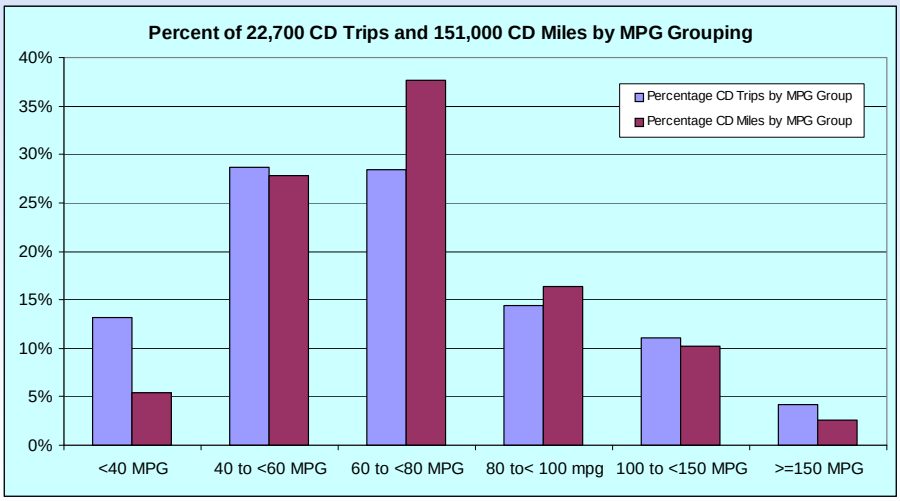
Data from 150 Hymotion Prius with V2Green and Kvaser loggers

MPG Results - Charge Depleting (CD) Mode



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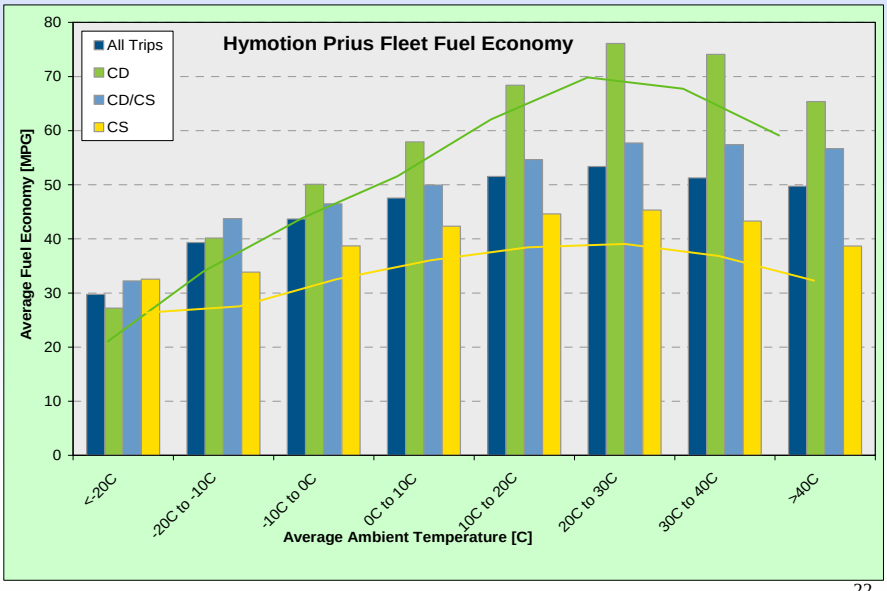
Data from 150 Hymotion Prius with V2Green and Kvaser loggers

Ambient Temperature MPG Impacts



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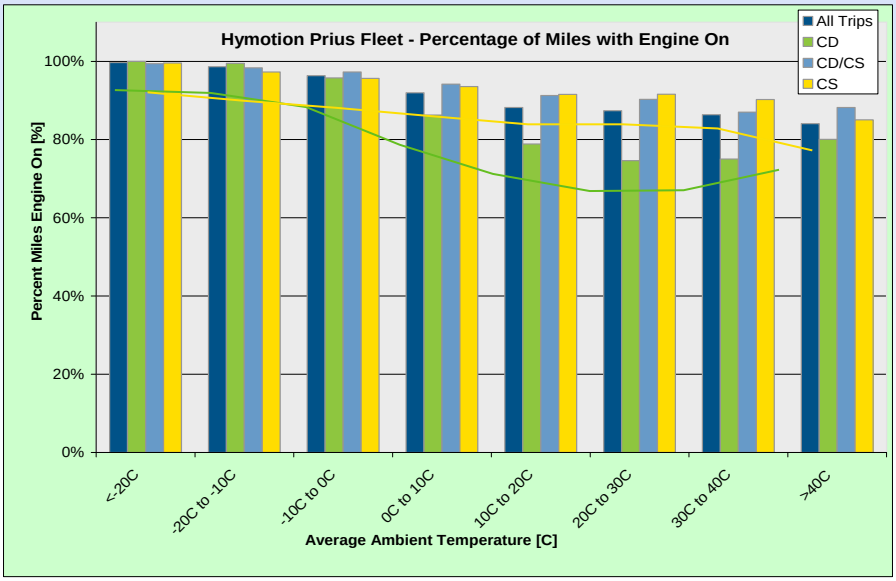
Engine Operations by Ambient Temperatures



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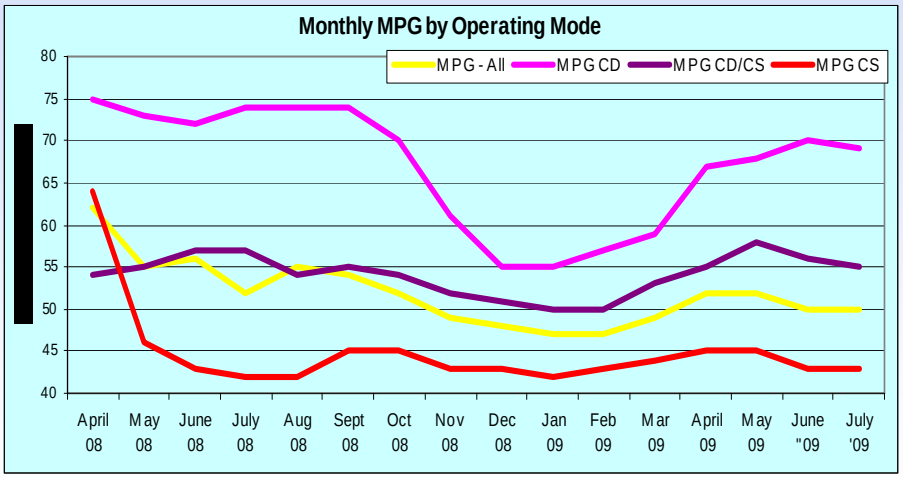
Monthly Fleet Testing MPG Results



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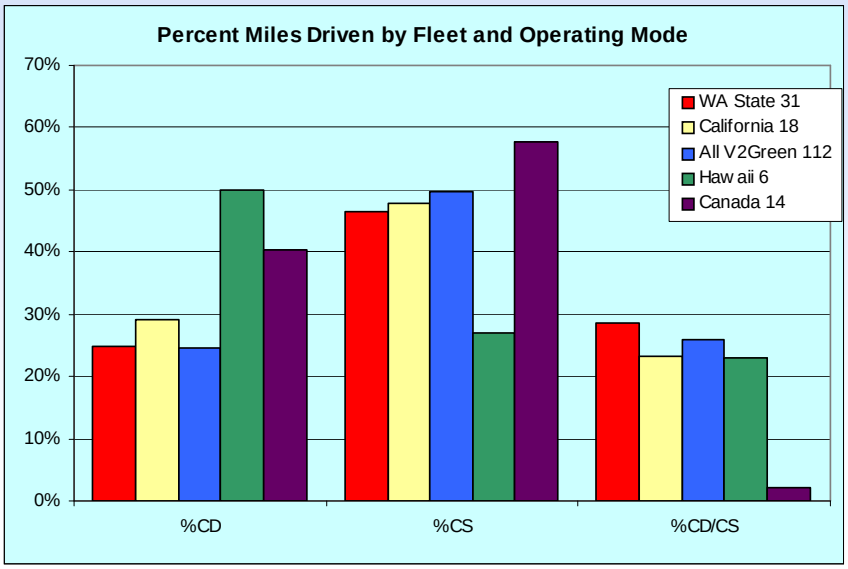
Testing Results by Fleet



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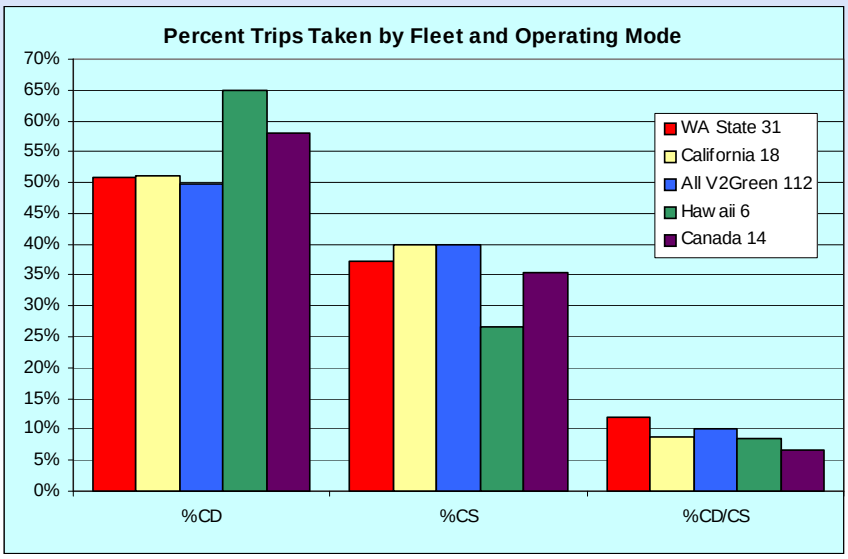
Testing Results by Fleet – cont'd



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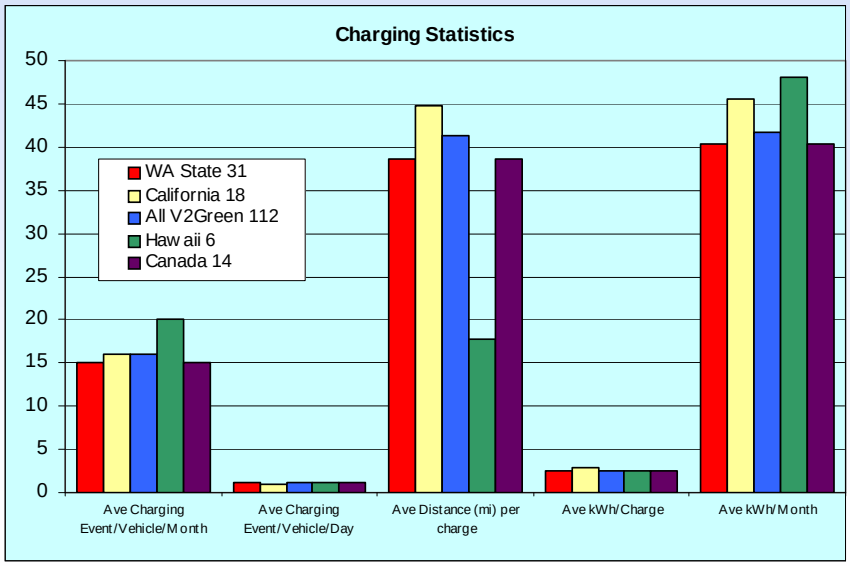
Testing Results by Fleet – cont'd



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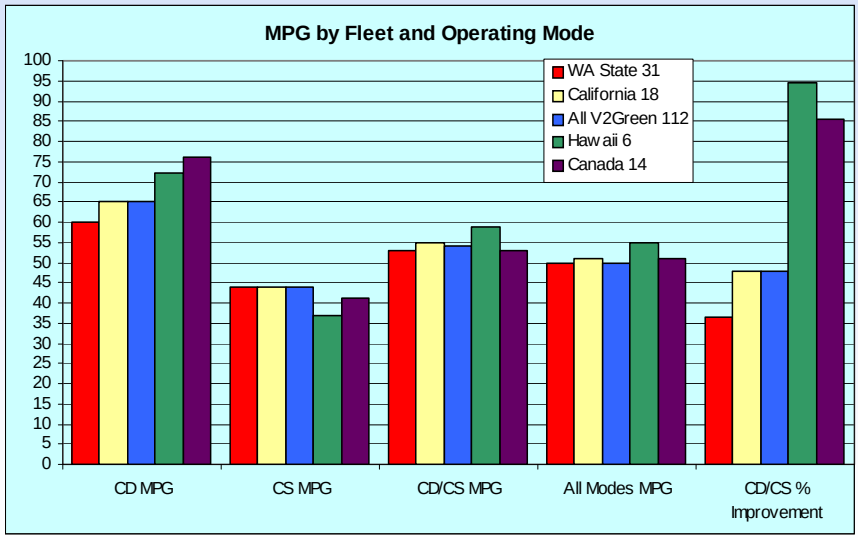
Testing Results by Fleet – cont'd



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Puget Sound PHEV Smart Charging Trials

- 13 Seattle PHEV's participated in trials conducted by Seattle City Light using GridPoint's Electric Vehicle Management Solution
- Types of Trials:
  - Time of Day Charging – Vehicles charging allowed only during certain hours of the day.
  - Goal Based Charging – Normalize power demand for vehicle charging around a goal load.
  - Economic Charging – Allow vehicle charging only when the price of electricity is below a threshold

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Trial Analysis

- INL analyzed data collected from the participating vehicles during four trials:

Trial and Description	Date Range Analyzed
Pre-Trials – No Charging Control	1/9/09-1/23/09
Trial 1 – Time of Day Charging	4/3/09-4/16/09
Trial 2 – Goal Based Charging – 7kW* Trial not included, 7kW load not reached	4/17/09-4/30/09
Trial 3 – Economic Charging	5/1/09-5/14/09
Trial 4 – Goal Based Charging – 3kW	5/15/09-5/28/09

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Equivalent Battery Cycles

- The charging data can be used to estimate the equivalent battery cycles (e.g., a simple battery "odometer")
- Equivalent cycles are based on a nominal capacity of 25.4 Ah (4700 Wh / 184.8 V)
- SCL1 appears to have experienced the most aging so far

Estimated Equivalent Cycles

	Pre-Trial	Trial 1	Trial 2	Trial 3	Total
King County 1	6	2	5	6	**19**
King County 2	2	2	2	3	**9**
King County 3	1	7	3	2	**13**
Port of Seattle 1	1	2	2	1	**6**
Port of Seattle 2	1	3	0	0	**4**
PSCA 1	3	3	5	4	**14**
PSCA 2	3	1	5	3	**12**
SCL 1	7	4	7	6	**24**
SCL 2	4	3	4	4	**14**
SCL 3	4	3	4	6	**17**
Seattle 1	6	4	3	4	**18**

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Gridpoint VCM with Hymotion L5 Plug-In Conversion Modules in Prius

- GridPoint Vehicle Connectivity Module (VCM):
  - Controlled charging, as directed by GridPoint's server
  - Logged vehicle charging and driving data
- VCM controls charging by requesting the Hymotion pack wait to charge or charge at a specified power level (% of full) - no physical interruption of the circuit
- Uncontrolled Hymotion pack will begin to charge immediately when plugged in (as temperature, state-of-charge, etc allow)

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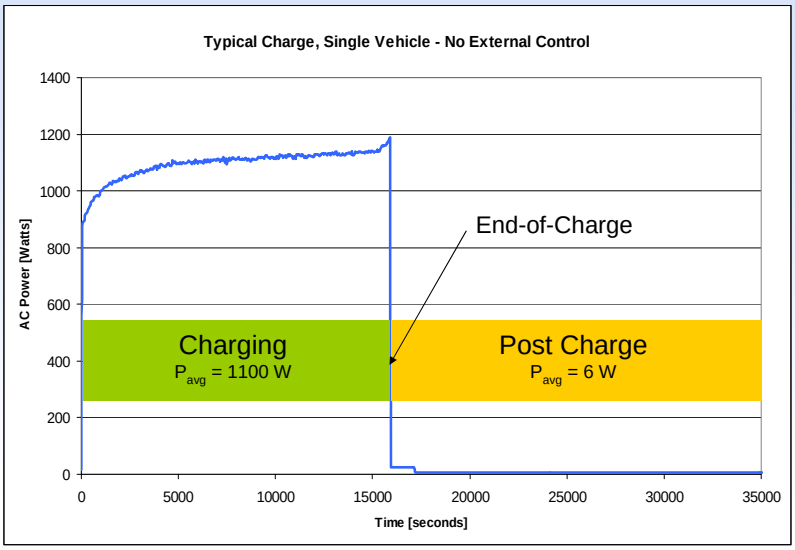
Charging – No Control



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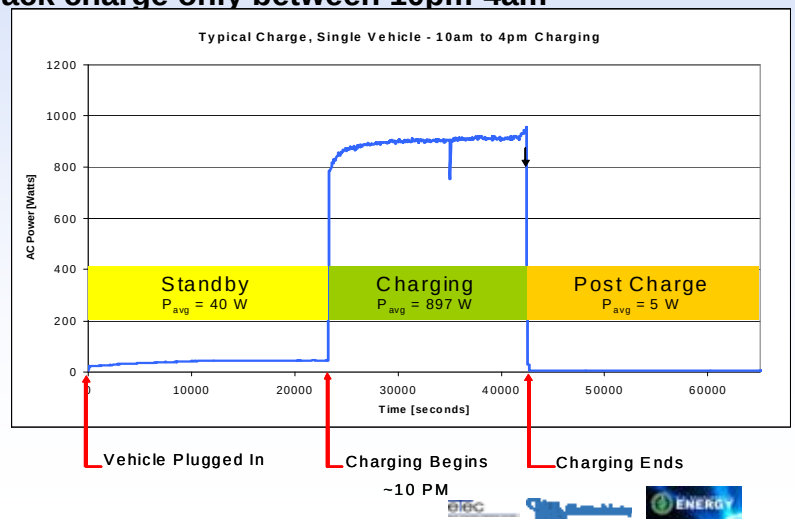
Results of Charging Trials – Trial #1

- **When a vehicle is plugged in, the VCM establishes communication with control server, requests Hymotion pack charge only between 10pm-4am**



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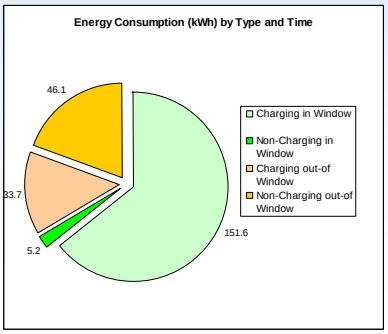
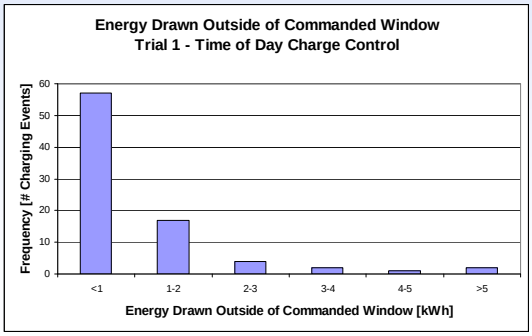
Results of Charging Trials – Trial #1 (cont.)

- **Rogue AC kWh – Energy drawn outside of allowable charging window:**
  - **Communication not established or lost - charging occurs**
  - **Cumulative standby energy draw when not charging**





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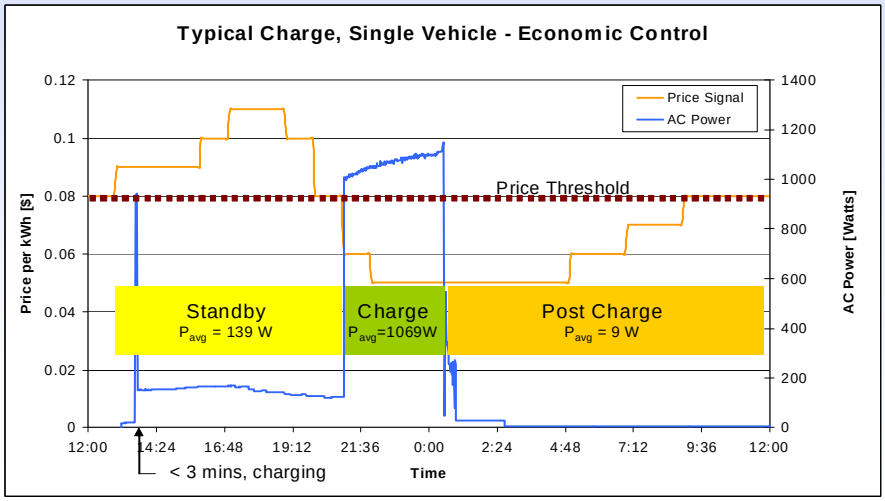
Results of Charging Trials – Trial #3

- **Artificial price signal supplied, vehicles are to charge when energy price < $.08/kWh**



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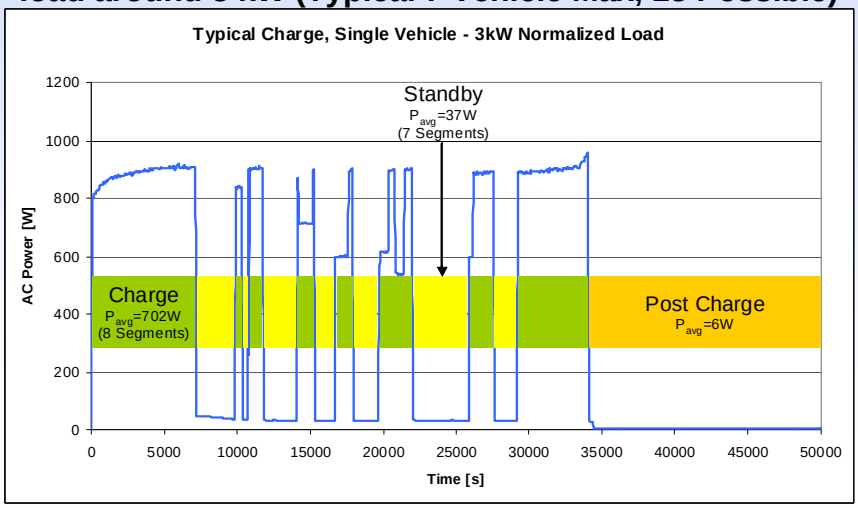
Results of Charging Trials – Trial #4

- **Vehicles' charging controlled to normalize the resource load around 3 kW (Typical 7 Vehicle Max, 13 Possible)**



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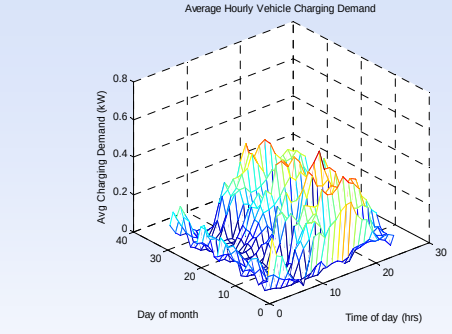
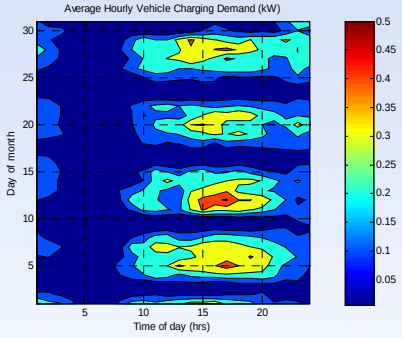
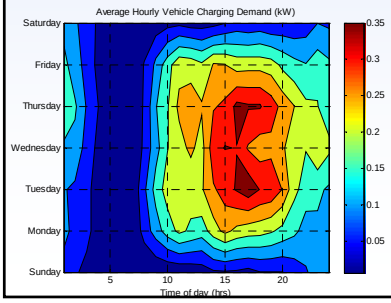
Commercial Fleet, Uncontrolled Charging May 2009

66 vehicles, 1218 charging events







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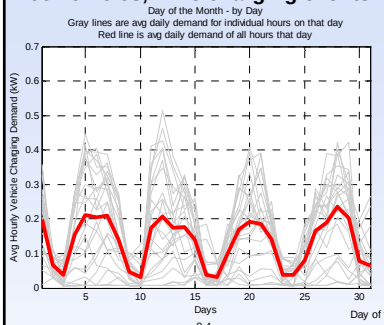
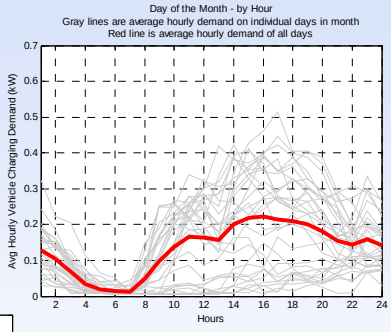
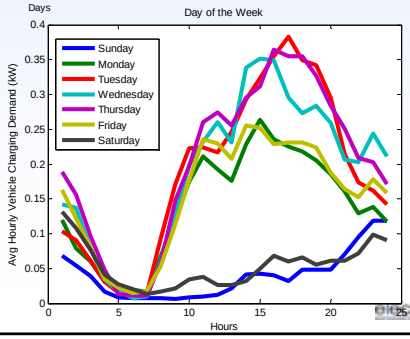
Commercial Fleet, Uncontrolled Charging May 2009

66 vehicles, 1218 charging events







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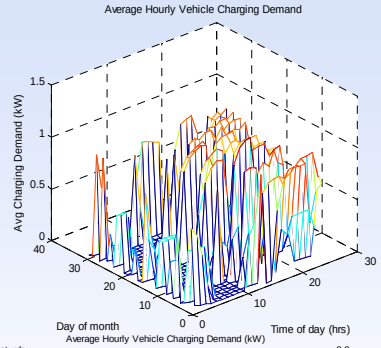
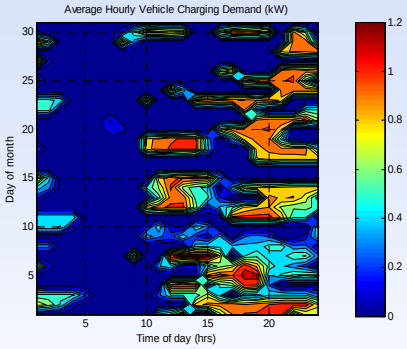
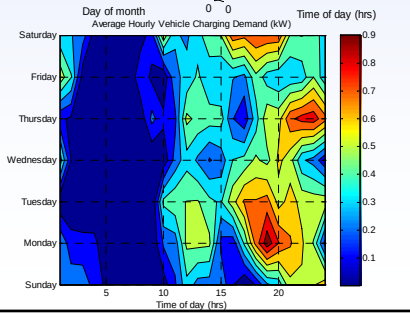
Private Fleet, Uncontrolled Charging May 2009

7 vehicles, 98 charging events







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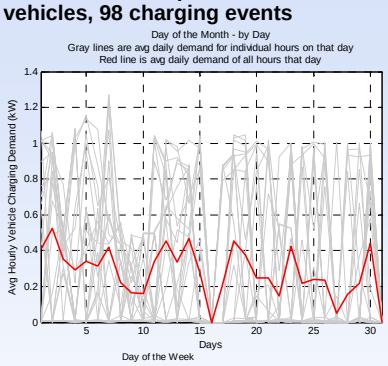
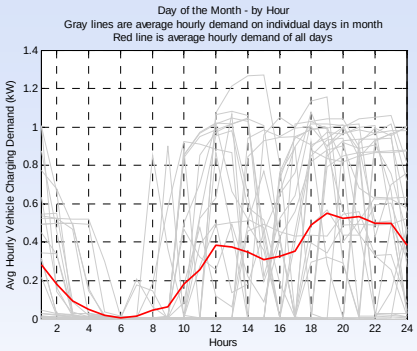
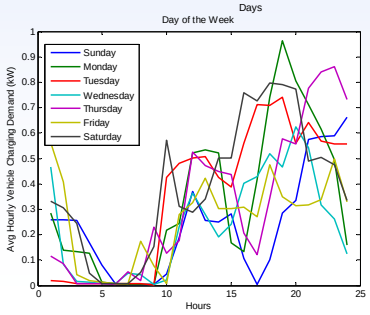
Private Fleet, Uncontrolled Charging May 2009

7 vehicles, 98 charging events







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PHEV Charging Infrastructure Cost Report

- **Analyzes PHEV infrastructure requirements in single and multi-family residential, and commercial facilities as well as driving trends. No site specific costs**
- **Charging infrastructure equipment/administrative costs:**
  - **Levels 1 (120V, 15 or 20 amp) and 2 residential**
  - **Levels 1 and 2 (208/240V ~40 amp) apartment complex**
  - **Level 2 commercial facility**
- **Battery sizes & charge times for various PHEV platforms**
- **Power electronics & battery costs for PHEV platforms**

Level 1 Residential	Labor	Material	Permits	Total
EVSE (charge cord)	- -	$250	- -	$250
Residential circuit installation (20A branch circuit, 120 VAC/1-Phase)	$300	$131	$85	$516
Administration costs	$60	$43	$9	$112
Total Level 1 Cost	$360	$424	$94	$878

Report @ http://avt.inl.gov/pdf/phev/phevInfrastructureReport08.pdf

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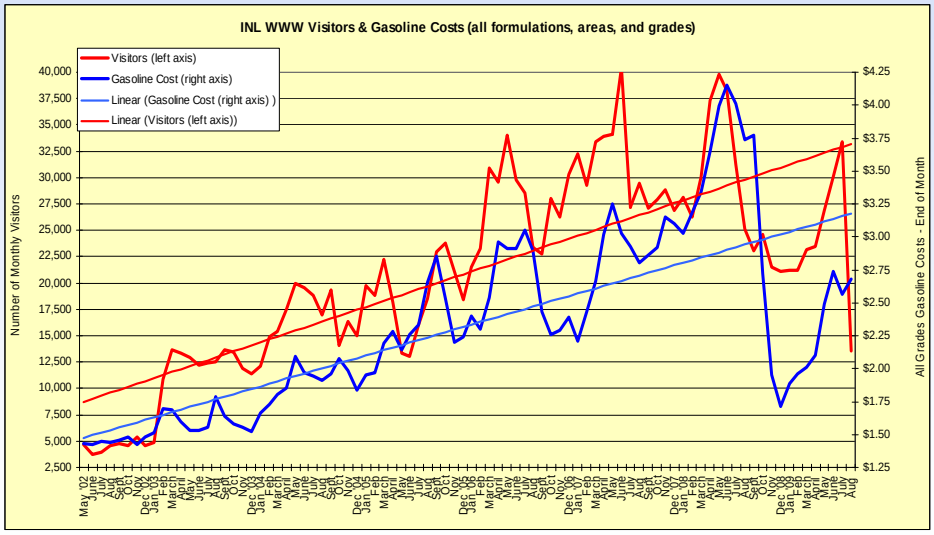
AVTA Webpage Use and Gasoline Costs



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Acknowledgement

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Additional Information

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

INL/CON-09-17005

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