Plug-In 2009: PHEV Testing and Demonstration Activities Conducted by the U.S. Department of Energy's AVTA

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AVTA Background and Goals

- The Advanced Vehicle Testing Activity (AVTA) is part of DOE's Vehicle Technology Program
- The Idaho National Laboratory (INL) conducts the AVTA for DOE, with Electric Transportation Engineering Corporation (ETEC) providing testing support. Argonne National Laboratory conducts the 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, 800,000 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, 400,000 test miles
- Full-size battery electric vehicles (BEVs)
  - 40 BEV models, 5+ million test miles
- Urban electric vehicles
  - 3 models, 1 million test miles

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PHEV Questions

- What are the petroleum savings and electricity demands?
- Will fleets and the public adapt to plugging in (charging) PHEVs to maximize mpg?
- What do PHEV charging profiles look like?
- Is a two-fuel scenario a difficult transition?
- What are the charging infrastructure needs, including 110V versus 220V? Fast charging?
- V2Grid – economic and technical benefit or liability to the vehicle operator and PHEV technology?
- Are PHEVs technically and economically feasible as a transportation option?
- To answer these questions, the AVTA is testing and demonstrating 12 different PHEV models (by battery), their batteries, and the charging infrastructure

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12 PHEVs Models in Testing/Demonstrations

- Hymotion Prius (A123Systems)
- Hymotion Escape (A123Systems)
- Ford E85 Escape (Johnson Controls/Saft)
- Energy's 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

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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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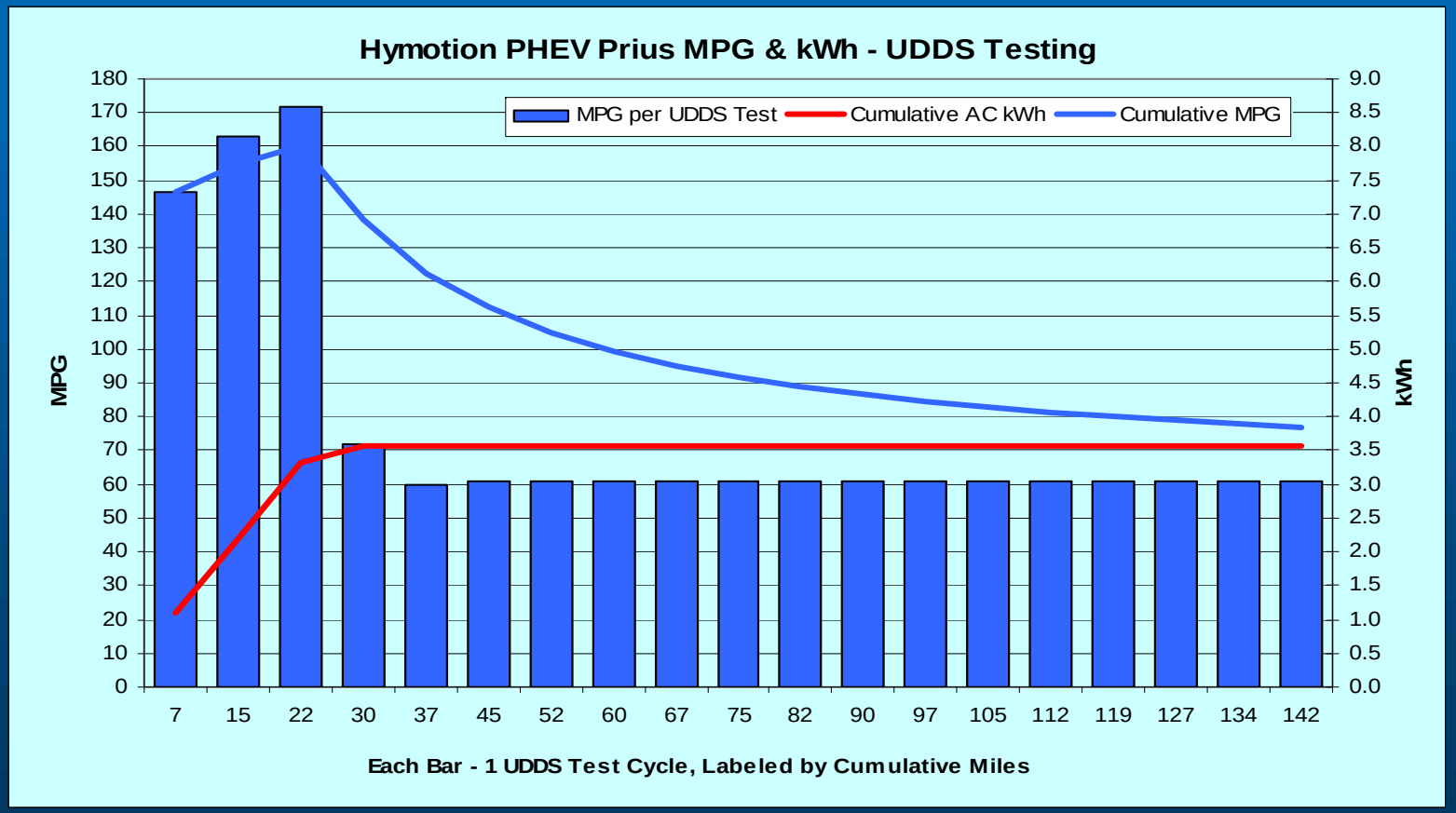
Hymotion Prius Gen I – UDDS Fuel Use

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



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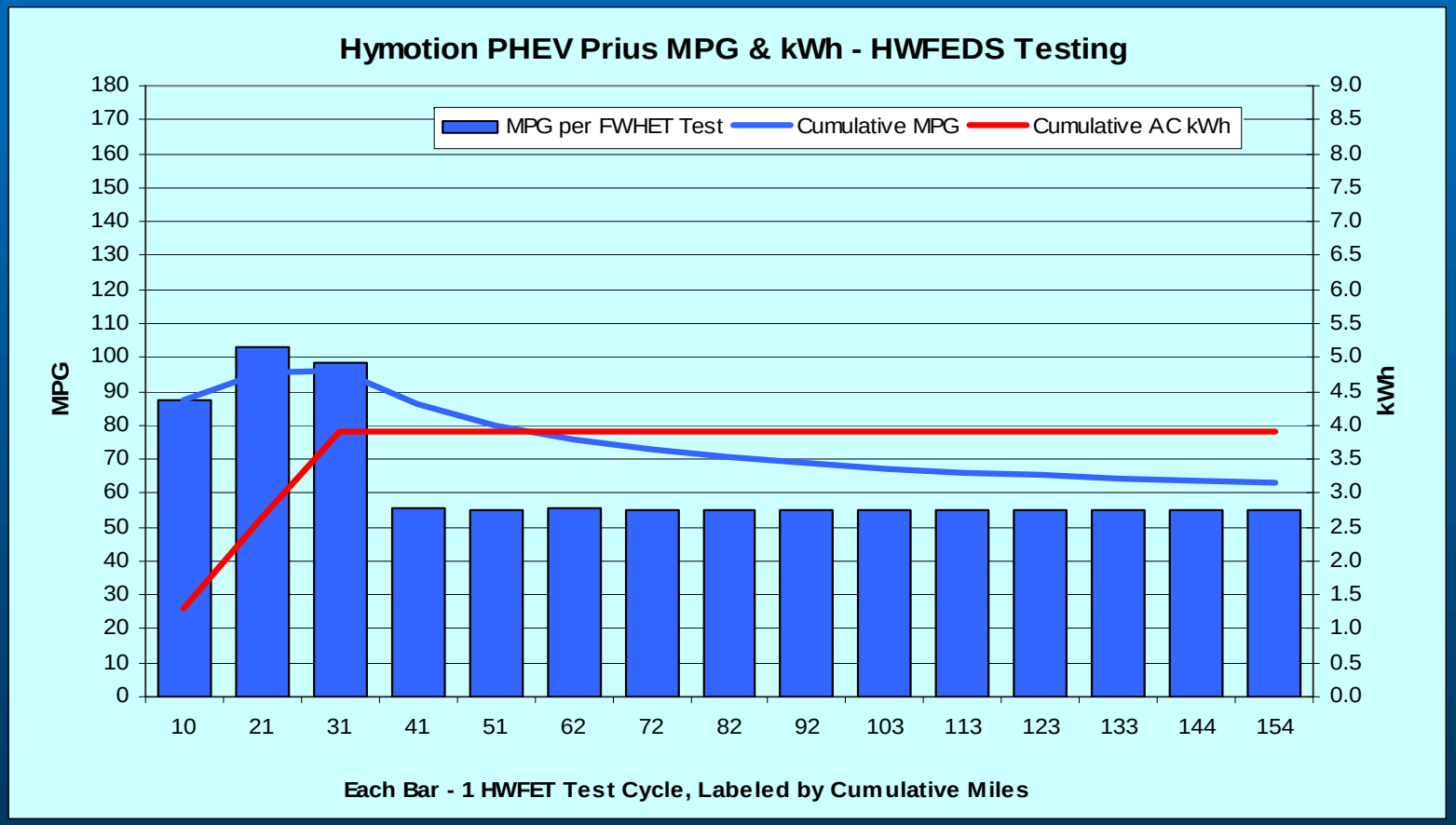
Hymotion Prius Gen I – HWFEDS Fuel Use

- 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 (mi)	Urban (10 mi)	Highway (10 mi)	Charge (hr)	Reps (N)	Total (mi)	Electricity AC kWh	Gasoline Gals	Gasoline MPG	Recalculated without Incomplete charges
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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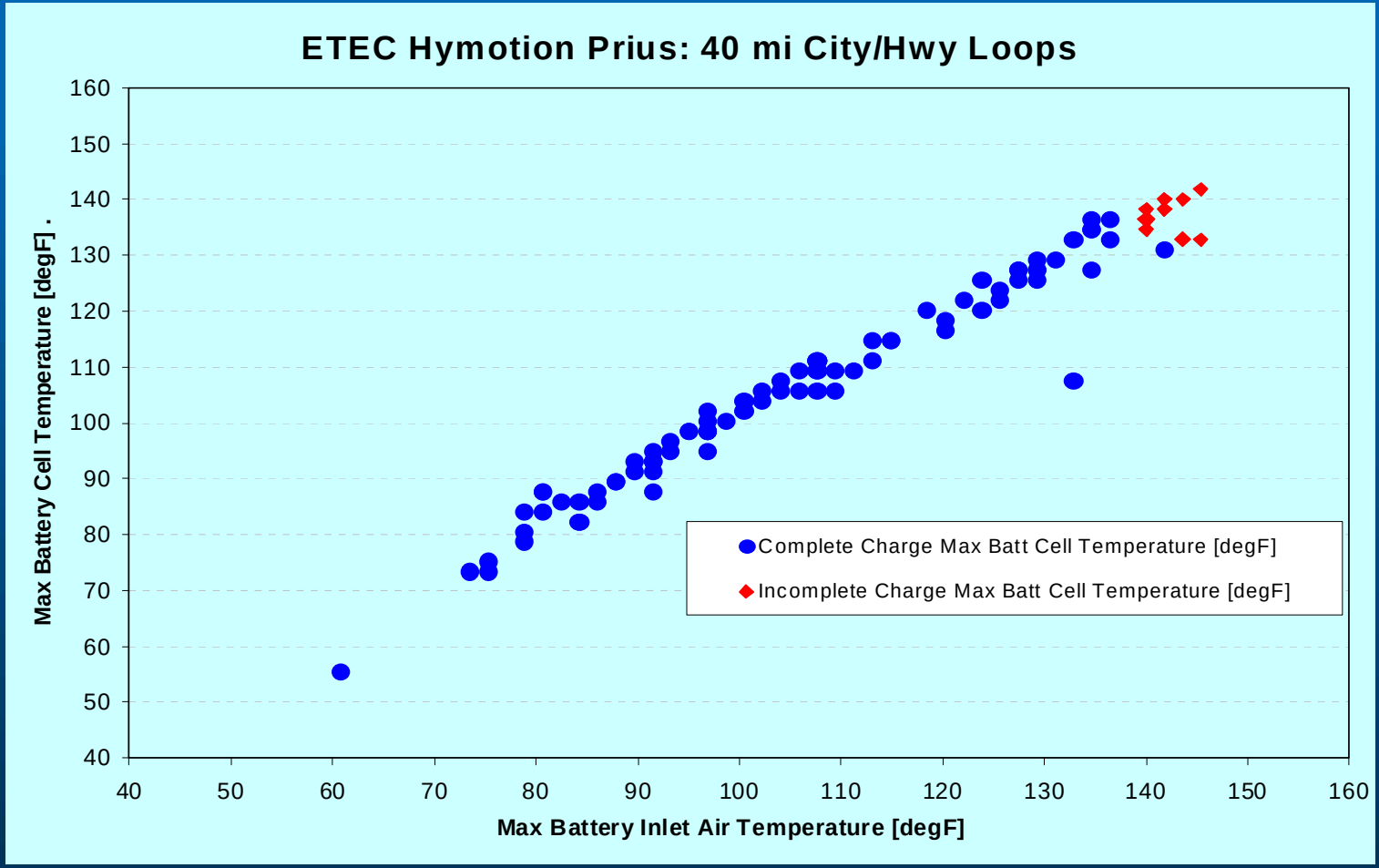
Hymotion Prius Gen II – Accelerated Testing

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



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Energy's Prius (Valance) – 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	5440	Weighted Average		66.1

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

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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.

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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	198.93	11.52	53.1
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		42.5

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

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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	135.24	9.55	65.1
20	1	1	8	30	600	101.13	17.54	34.7
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		36.7

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

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Fleet Demonstration Partners

- 75+ Testing partners in the U.S. and Canada, including:
  - 40 Electric utilities and 2 clean air agencies
  - 10 City, county, state, and province governments
  - 7 Private companies and advocacy organizations
  - 8 Universities and colleges
  - 2 PHEV conversion companies
  - 1 sea port and 1 DOD facility
  - Operating in
    - 22 U.S. states
    - 4 Canadian provinces

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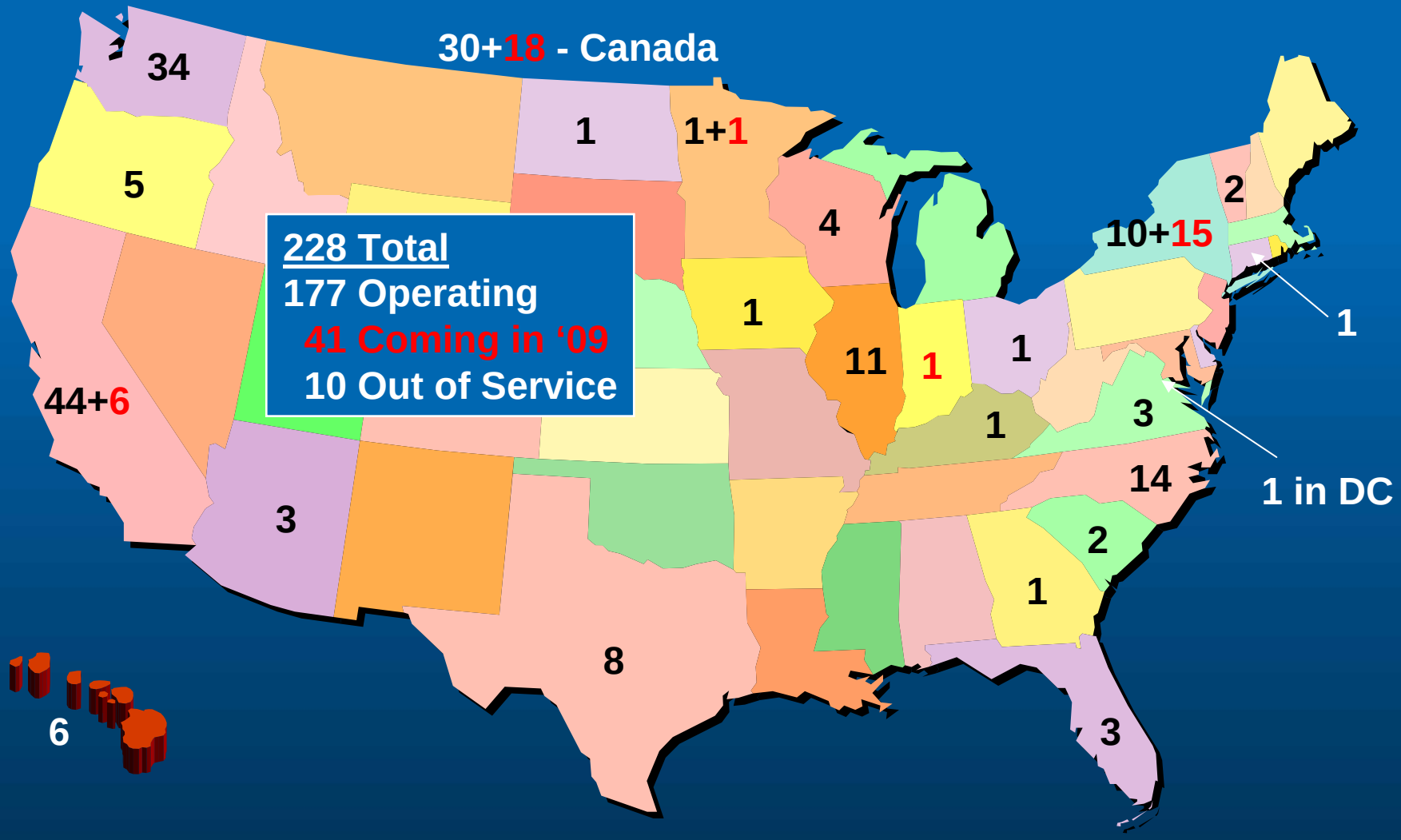
PHEVs and Demonstration Locations



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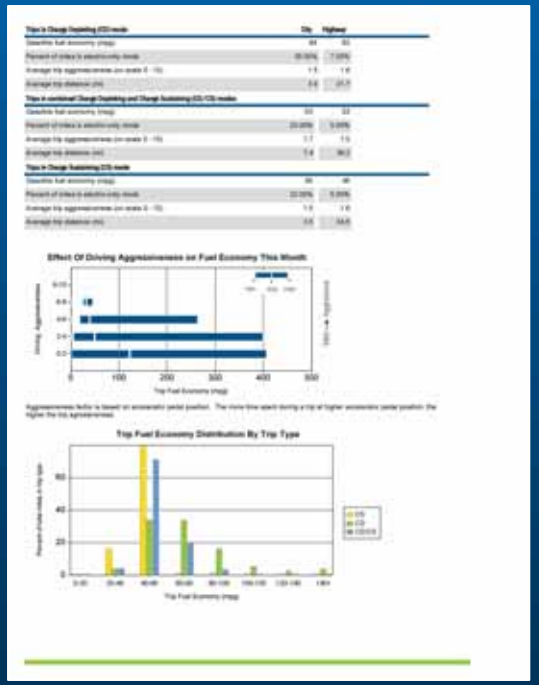
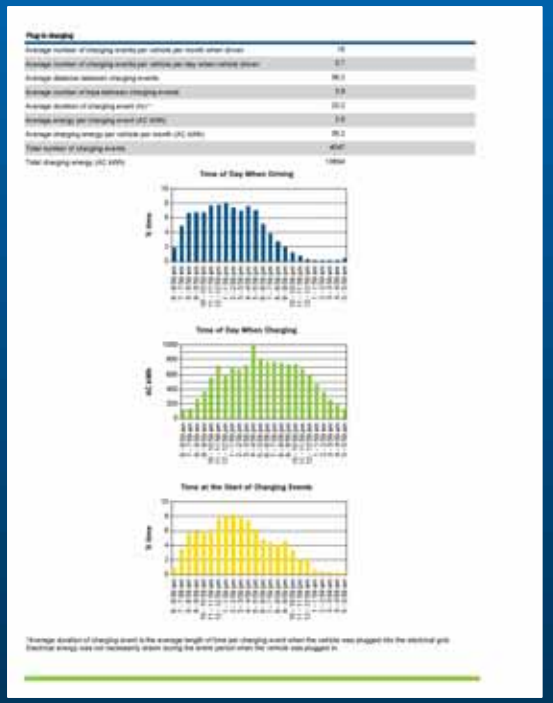
PHEV Fleet Testing Reports

- Summary reports posted monthly on web
- Individual vehicle reports only go to the respective fleets each month, 950+ reports to date (July 1, 2009)
- 150 Hymotion Prius PHEVs, 710,000 miles, 76,000 trips, 18,000 charging events, 43,000 kWh used. V2Green and Kvaser data logger reports





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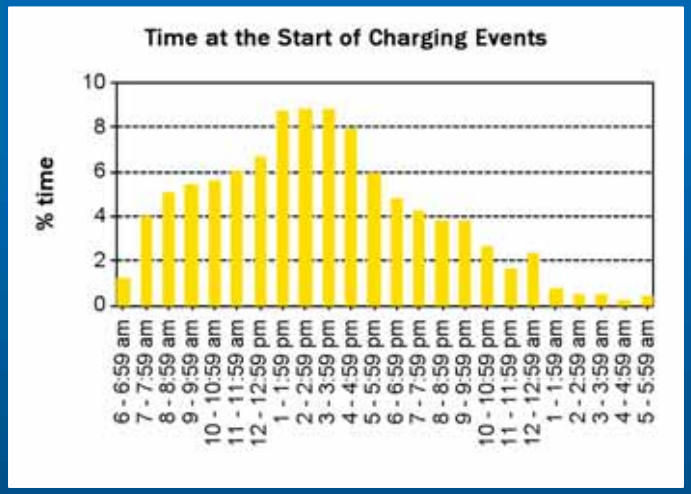
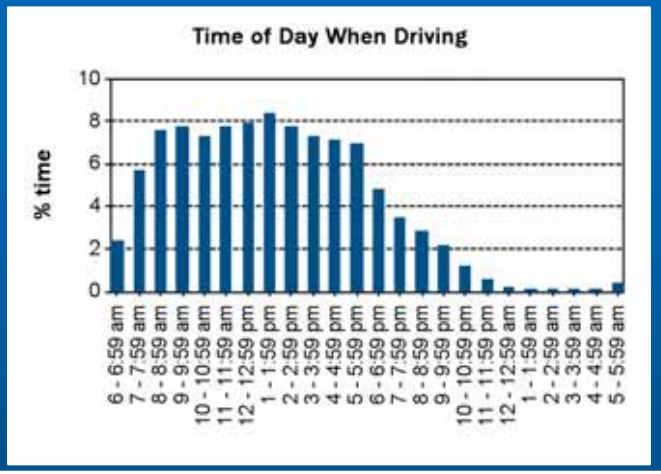
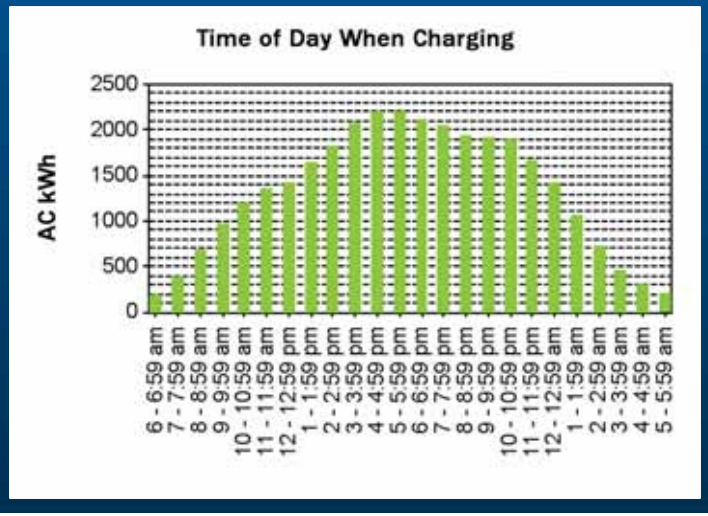
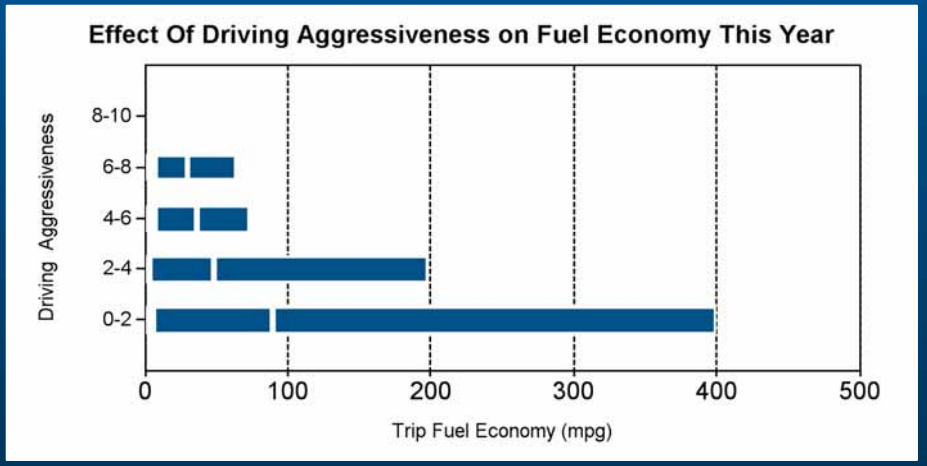
Hymotion Prius (V2Green Logger) Fleet Tests

- **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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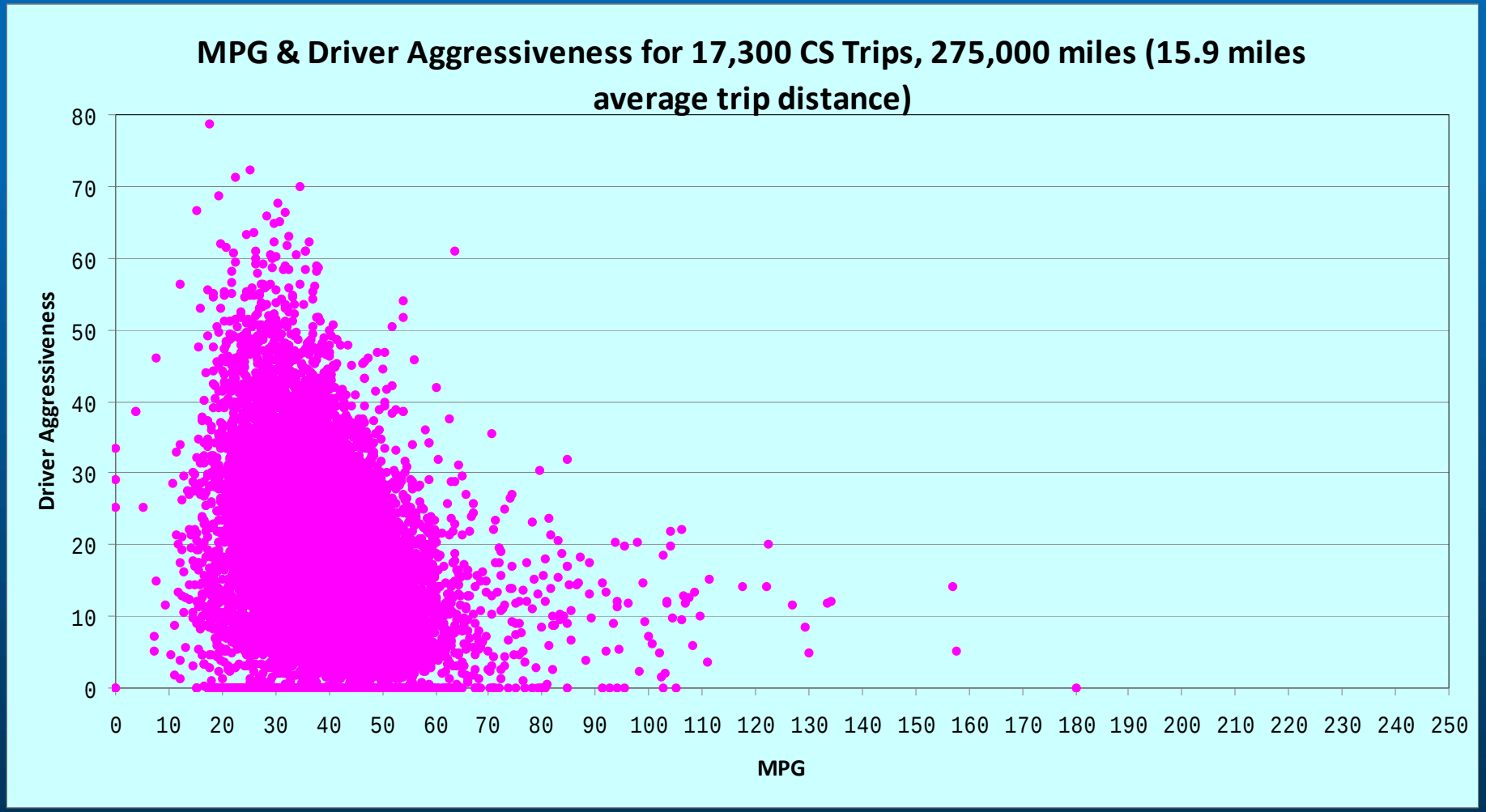
Hymotion Prius PHEVs – CS Trips

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



Data from 150 Hymotion Prius with V2Green and Kvaser loggers

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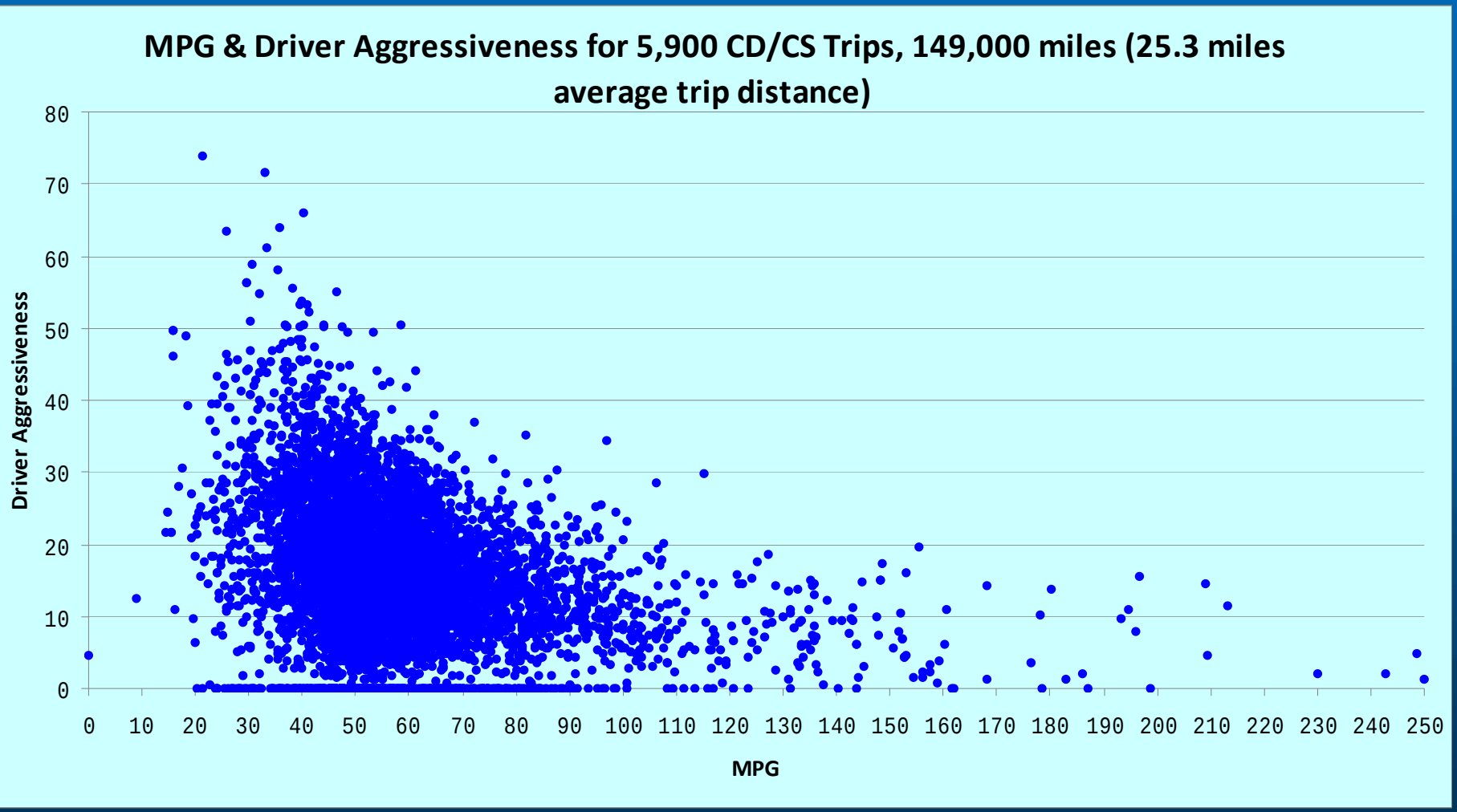
Hymotion Prius PHEVs – CS/CD Mixed Trips

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



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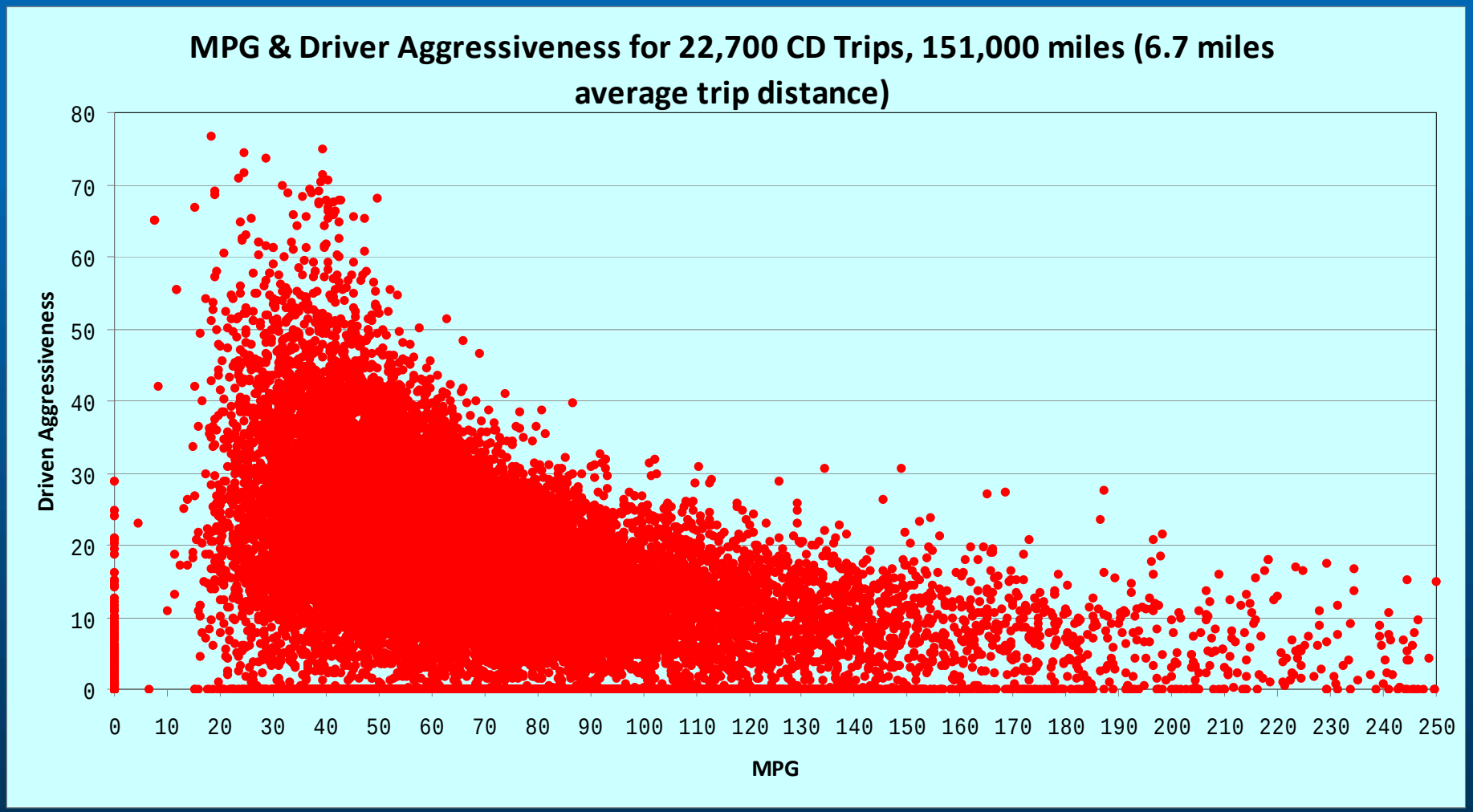
- MPG and aggressive driving impacts March ‘08 – May ‘09



Data from 150 Hymotion Prius with V2Green and Kvaser loggers

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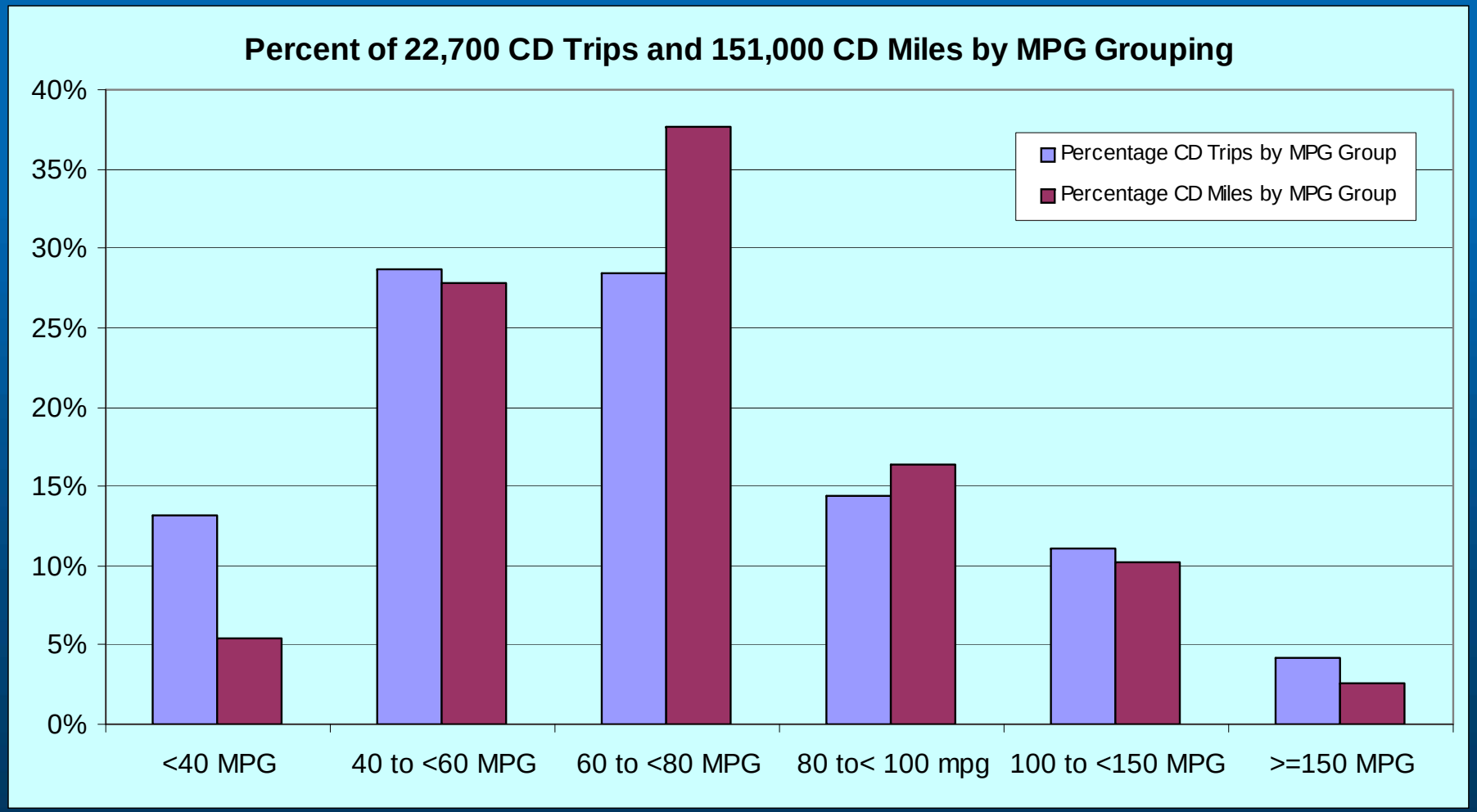
Hymotion Prius PHEVs MPG Results - Charge Depleting (CD) Mode



Data from 150 Hymotion Prius with V2Green and Kvaser loggers

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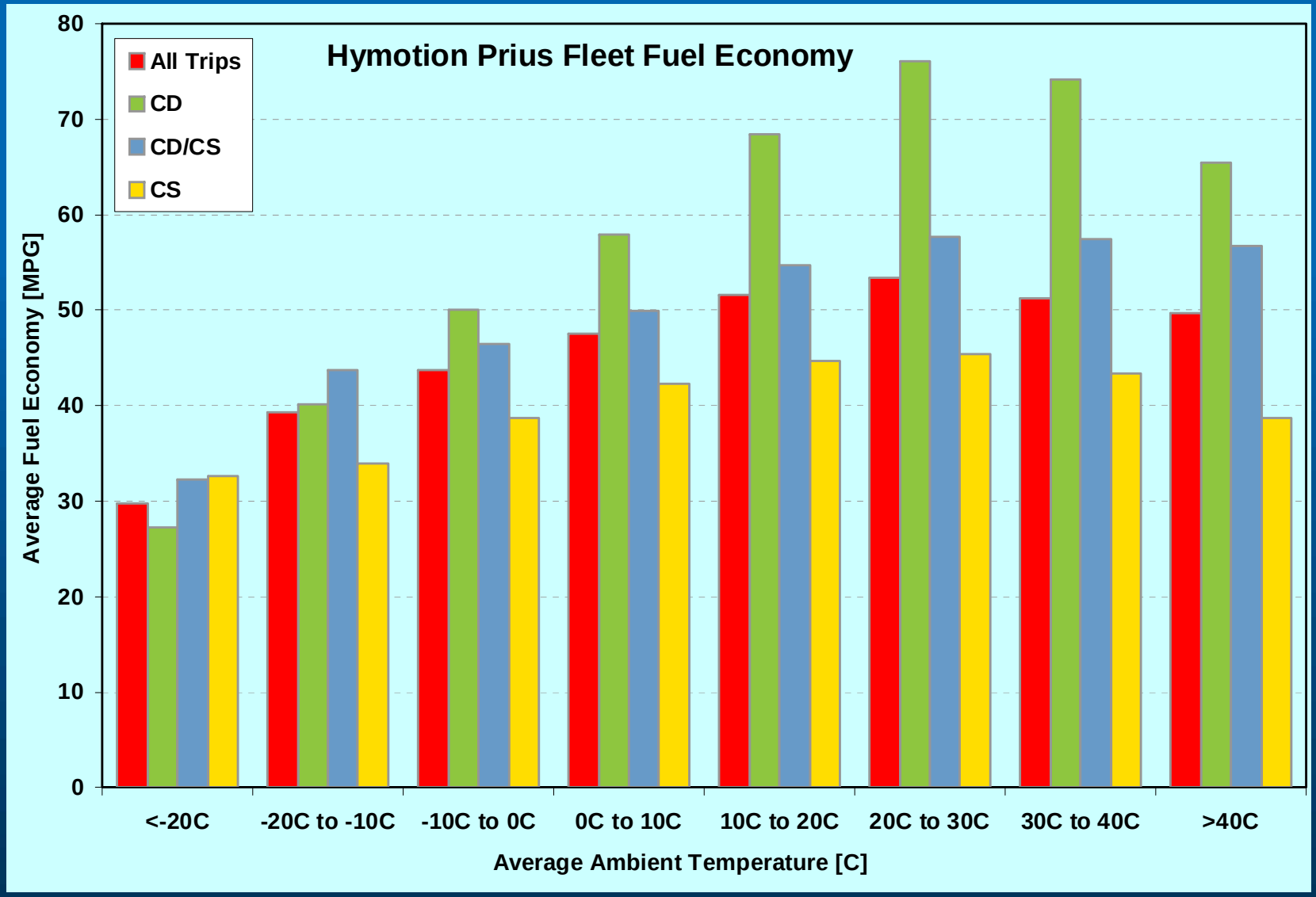
Hymotion Prius PHEVs MPG Results by Temperature



Data from 150 Hymotion Prius with V2Green and Kvaser loggers

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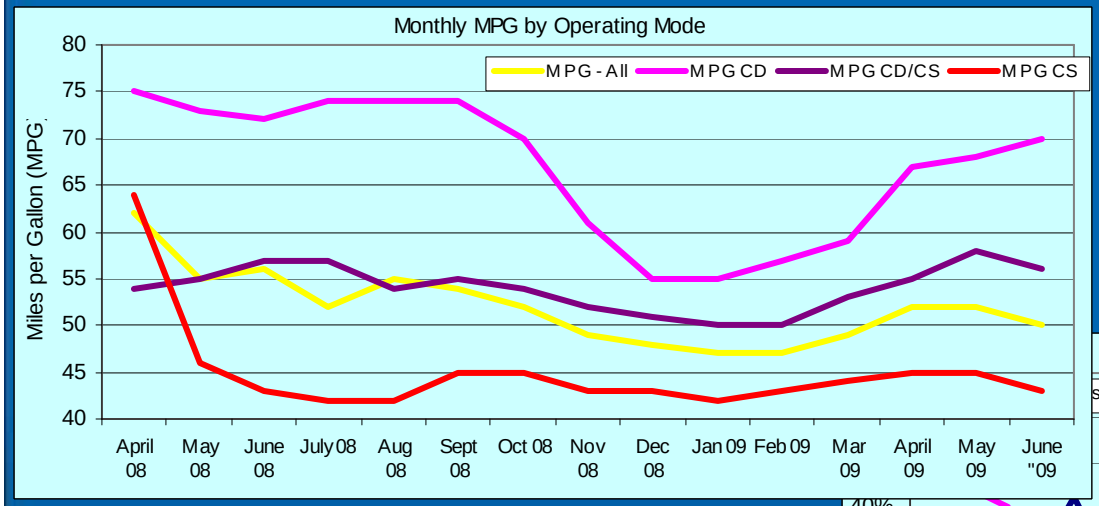
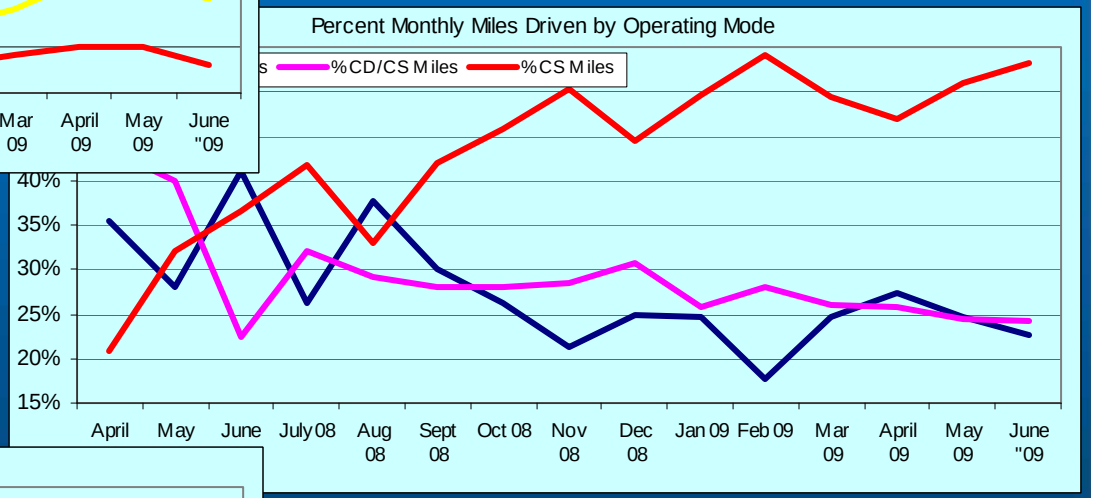
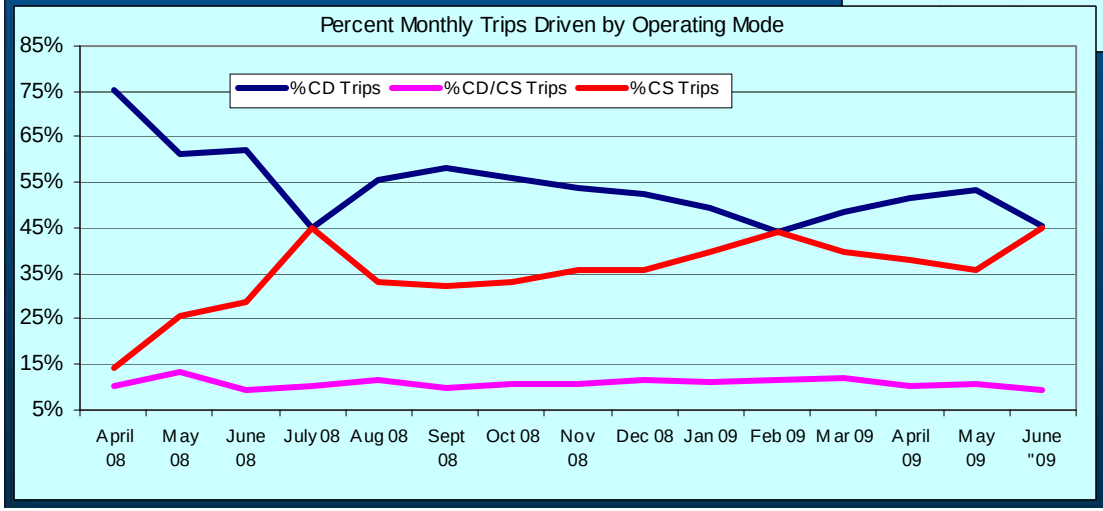
Hymotion Prius Fleet Testing Results (Trends)







Data from 110 Hymotion Prius with V2Green loggers

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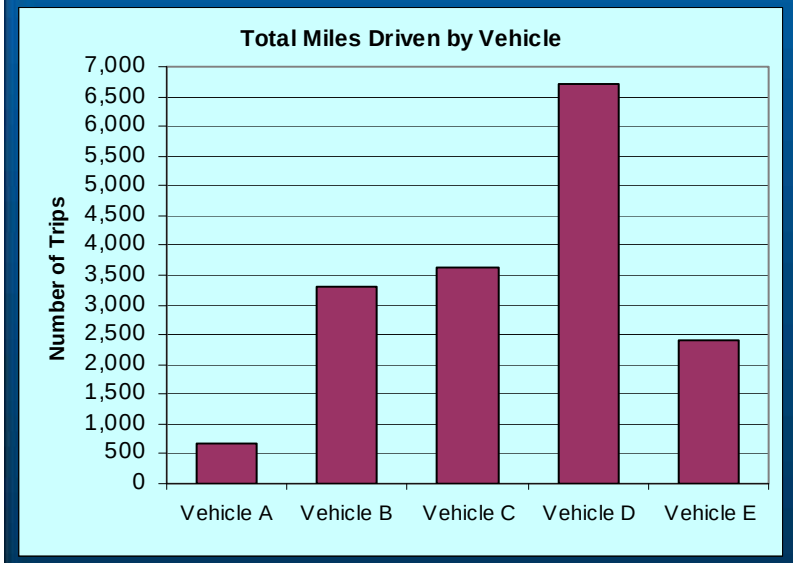
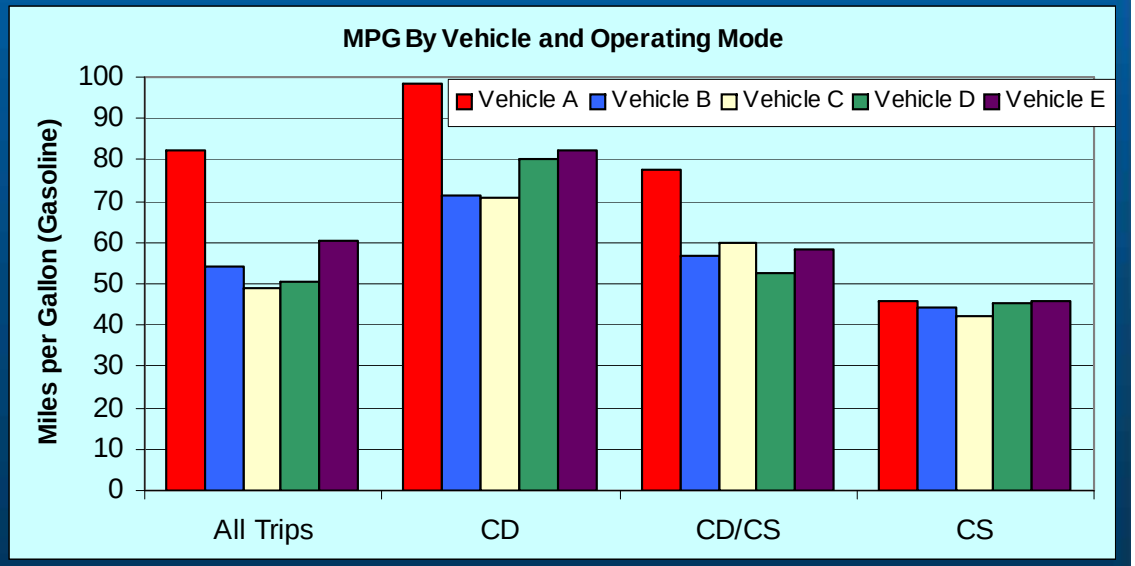
Energy CS Prius (Valance Battery) Fleet Tests

Trip Type	Fuel Economy (mpg)	Number of Trips	Percent of Trips	Miles Driven	Percent Total Distance
All	53.0	1,966		16,470	
CD	78.1	953	48%	3,911	24%
CD/CS	56.1	184	9%	4,896	30%
CS	44.4	829	42%	7,933	48%





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Energy CS Prius (Altairnano Battery) Fleet Tests

Trip Type	Fuel Economy (mpg)	Number of Trips	Percent of Trips	Miles Driven	Percent Total Distance
All	60	915		7,312	
CD	73	475	52%	1,724	24%
CD/CS	68	101	11%	3,156	43%
CS	47	339	37%	2,431	33%

Average number of charging events per vehicle per month when driven	17.7
Average number of charging events per vehicle per day when driven	1.2
Average distance between charging event (miles)	33.7
Average number of trips between charging event	4.2
Average energy per charging event (DC kWh)	2.0
Average charging event duration (hours)	21.9
Total number of charging events	217
Total charging energy (AC kWh)	590

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Other PHEV Testing

- Bidirectional vehicle-to-grid (V2G) charging study
  - 6 kW and 20 kW levels, using lithium PHEV batteries, V2Green cellular charging control. Documents infrastructure requirements and costs
- City of Seattle \ V2Green lead time-of-day charging demonstration on 13 Seattle-area PHEVs. Includes INL battery impact analysis. Uses wireless charging control
- Developing vehicle-based battery test bed research project for testing PHEV and BEV batteries in various vehicle and charging operating scenarios
- Conduct vehicle \ battery testing on PHEVs when received via DOE's Technology Assistance and Demonstration Activity

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Other PHEV Testing – cont'd

- Tacoma Power charging infrastructure study
  - AVTA and Tacoma Power are collecting 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

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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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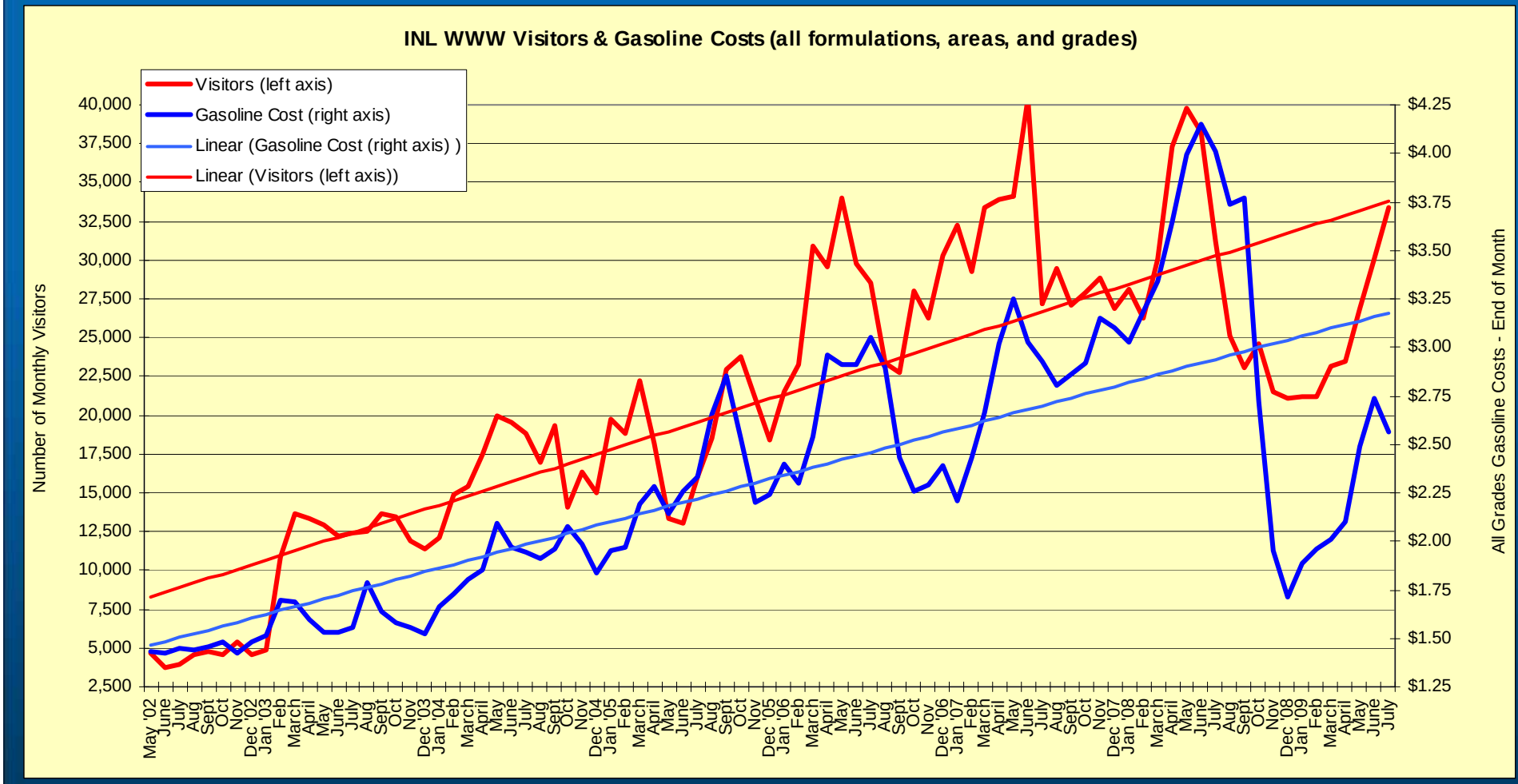
AVTA Webpage Use and Gasoline Costs



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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-09-16431