

## U.S. Department of Energy - Vehicle Technologies Program 2009 Annual Merit Review

### Advanced Vehicle Testing Activity (AVTA) - Vehicle Testing and Demonstration Activities

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### AVTA Project Description

- The AVTA is an ongoing DOE activity that conducts test track, dynamometer, battery (when appropriate), and field testing of advanced technology vehicles, including:
  - Plug-in hybrid electric vehicles (PHEV)
    - 12 models, 150 vehicles, 390,000 test miles
  - Hybrid electric vehicles (HEV)
    - 14 models, 4.3 million test miles
  - Hydrogen ICE vehicles (HICEV)
    - 7 models, 400,000 test miles
  - Neighborhood electric vehicles (NEV)
    - 21 models, 200,000 test miles
  - Full size pure electric vehicle (EV)
    - 40 EV models, 5+ million test miles
- Started late 1980's as the Site Operator Program
- Continue vehicle testing as new technologies emerge



## AVTA Participants

- The Idaho National Laboratory (INL), provides testing direction, data analysis, and results dissemination
- Electric Transportation Engineering Corporation (ETEC) (Phoenix, AZ) provides testing and technical support
- National Energy Technology Laboratory (NETL) manages the ETEC contract
- 75+ U.S. and Canadian testing partners provide mission and geographical diversity and leveraged funding:
  - 36 Electric utilities and 3 clean air agencies (CARB)
  - 10 U.S. cities, counties and state governments, and 4 Canadian provinces
  - 8 Universities and colleges
  - 8 Private companies
  - 2 PHEV conversion companies
  - Seaport, DOD base, share-ride, advocacy and other organizations



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## AVTA Technical Approach

- Provide benchmark vehicle and fueling infrastructure data to target setters, technology modelers, R&D programs and DOE management
- Assist early-adapter fleet managers in making informed vehicle purchase, deployment and operating decisions
- The AVTA accomplishes it's objectives by:
  - Documenting vehicle performance in test-track, dynamometer, accelerated, and fleet testing environments
  - Documenting fuel use (petroleum, electricity and hydrogen) and infrastructure requirements
  - Documenting operator influence on charging \ fueling times, patterns, and frequencies
  - Reducing vehicle \ battery performance uncertainties
  - Using leveraged testing relationships to maximize testing value to DOE and taxpayers



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## AVTA 2008 Milestones

- Produced 374 PHEV, 42 HEV, and 5 NEV testing fact sheets \ reports (421 total publications\reports in FY08)
- Conducted 24 presentations at electric utility, public, private, government, and industry group gatherings
- Conducted local, regional, and national press interviews with Time Magazine, MSNBC, Fox, and CBS, and various regional news groups
- Introduced 9 additional PHEV models (by battery design) into testing \ demo activities
- Initiated fleet testing of 95 additional PHEVs
- Initiated testing on 14<sup>th</sup> HEV model and accumulated 4<sup>th</sup> million HEV fleet testing mile
- Tested 5 NEV models for DOE and CARB
- Resource to other government groups such as Clean Cities Program and National Science Foundation



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## AVTA Budget and Cost Sharing

- Annual (FY08) DOE funding of \$2,700k total - (\$900k INL, \$1,800k ETEC)
- Expected future DOE funding (total \$2,700k+ per year)
- All testing \ demos have a minimum of 20% cost share
- Bank fleet saved AVTA \$5 million in HEV driver costs
- 8 HICEVs, AVTA paid for 8 data loggers, fleets paid for vehicles \ operations - 5% DOE and 95% fleet cost split
- 151 PHEVs in various testing stages, AVTA paid for 2 vehicles, 14 conversions and 60 data loggers. 15% DOE and 85% fleet cost split



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## FY08 PHEV Testing Accomplishments

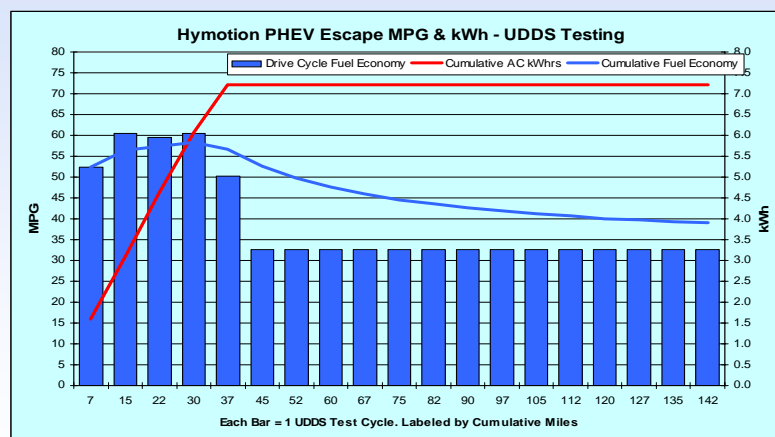
- Testing and demonstrations on 12 PHEV models
  - Hymotion Prius (A123Systems)
  - Hymotion Escape (A123Systems)
  - Ford E85 Escape (Johnson Controls/Saft)
  - EnergyCS Prius, 2 models (Valance and Altairnano)
  - ElectroVaya Escape (Electrovaya)
  - Hybrids Plus Escape, 2 models (Hybrids Plus and K2 Energy Solutions)
  - Hybrids Plus Prius (Hybrids Plus)
  - Manzanita Prius (lead acid)
  - Manzanita Prius (Thunder Sky)
  - Renault Kangoo (Saft NiCad)
  - (All batteries are Lithium ion unless noted)



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## Hymotion Escape – UDDS Fuel Use

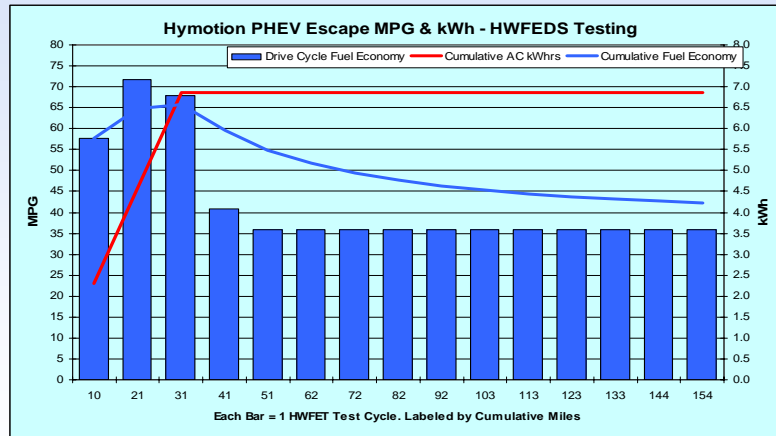
- 8.5 kWh A123Systems (Li) and Escape packs (AC kWh)



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## Hymotion Escape – HWFEDS Fuel Use

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



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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
<b>Total</b>	<b>2340</b>	<b>3100</b>	<b>1404</b>	<b>167</b>	<b>5,440</b>	<b>Weighted Average</b>		<b>79.5</b>

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



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## PHEV Fleet Testing Partners

- Hymotion – onboard data collected on 50 Hymotion PHEVs
- Baseline performance tested NYSEERDA's procurement of the first 5 PHEV models, adding 20 PHEVs into AVTA fleet
- EnergyCS provided AVTA onboard data for 12 PHEVs in fleets with (Valence and Altairnano packs)
- 17 Hymotion PHEVs in Seattle-Tacoma area and 14 in Wenatchee area
  - Initial use of V2Green data loggers, GPS and cellular communications, used in all PHEV fleets going forward



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ENERGY

## PHEV Fleet Testing Partners – cont'd

- University of California Davis, with 13 Hymotion Prius being used by 70 public drives
- Oregon State Government fleets, 3 Hymotion PHEVs
- National Rural Electric Cooperative Association, 10 PHEVs
- Hawaii, 6 Hymotion PHEVs on Maui and Oahu
- 20 Hymotion PHEVs (March 08) in fleet testing, with 28 more being added. 20 Canadian testing partners
- PHEV data to be provided to four universities
- PHEVs in fleets in 23 states and Canada



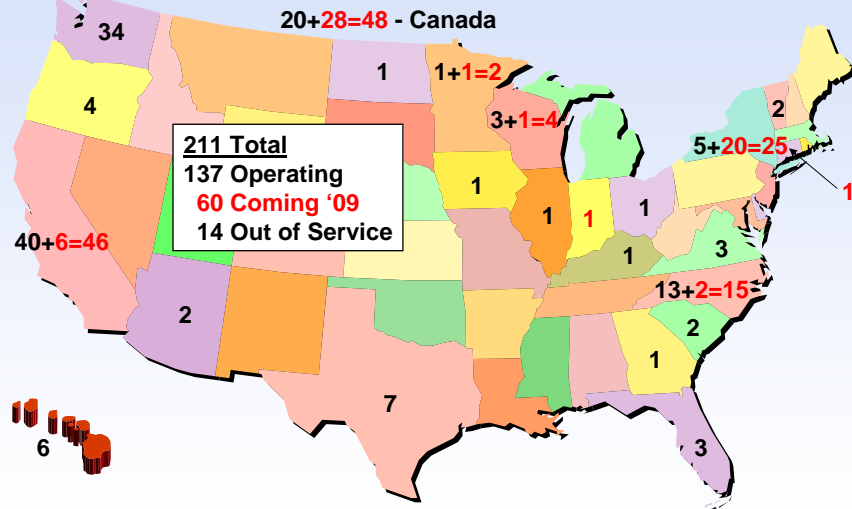
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## PHEVs and Demonstration Locations



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## 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



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## 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
<b>Total</b>	<b>912</b>	<b>6,417</b>	<b>7.0</b>		
<b>CD, CS, CD/CS results (excludes EV results)</b>	<b>775</b>	<b>6,291</b>	<b>8.1</b>	<b>55.9</b>	

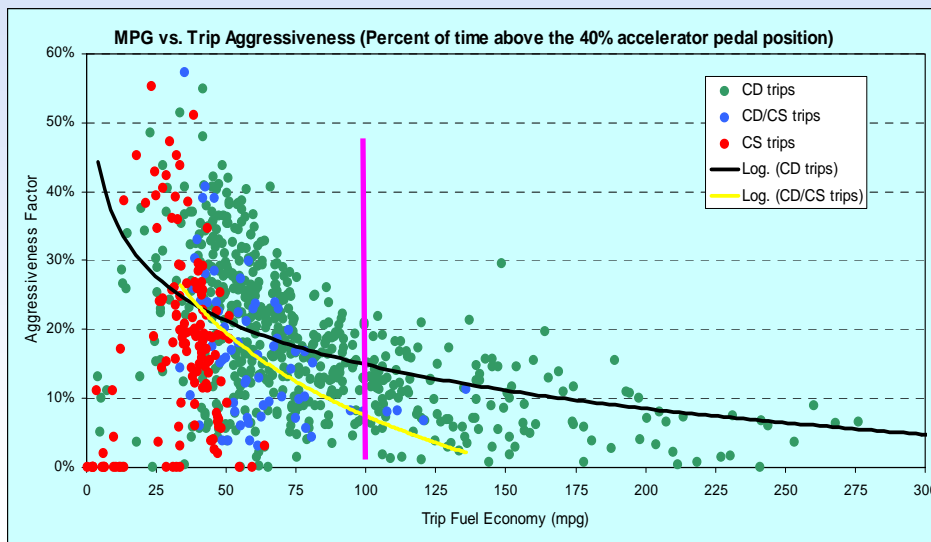


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## 13 Hymotion Prius and Aggressive Driving



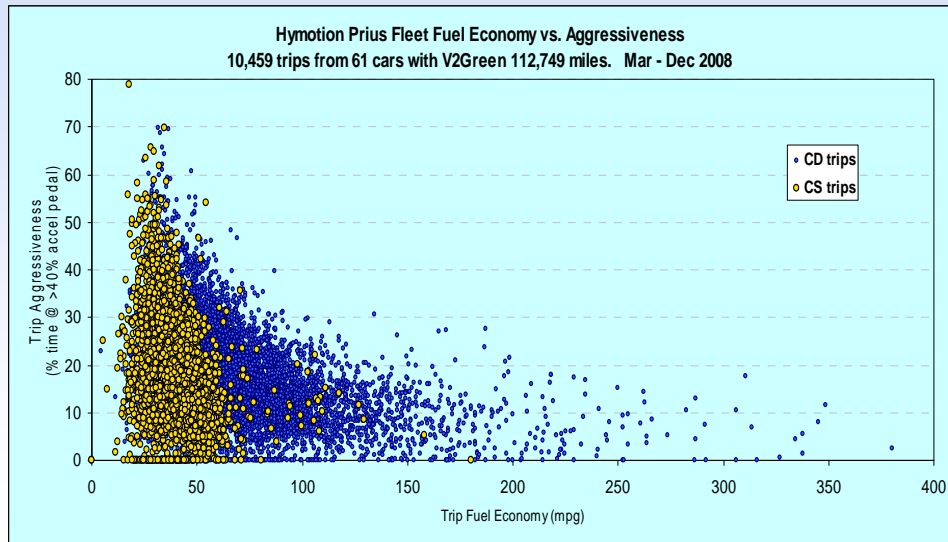
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## 61 Hymotion Prius and Aggressive Driving



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## Fleet Data Collection \ Reporting Processes

- Along with testing partners, implemented onboard data logging for 150+ PHEVs, 16 HEVs, 8 HICE vehicles
- Created automated data warehousing, analysis, and reporting process for fleet data
- Accommodates 4 different data transfer methods from a multitude of vehicle / data logger combinations:
  - 8 PHEV, 8 HEV and 1 HICE models
  - 4 data logger manufacturers \ designs
- Reporting formats include 69 metrics describing energy use, driving and charging patterns, and status monitors
- Developed quality assurance \ exploratory analysis tools
- Created flexible automated report generation processes for individual and multiple vehicle reports
- The fleet onboard data collection system is growing at approximately 40 million records per month

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## Database Generated PHEV Reports

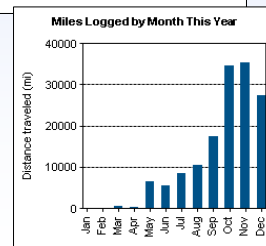
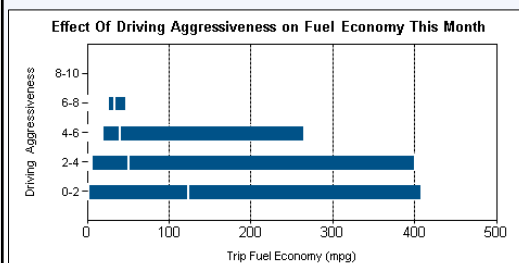
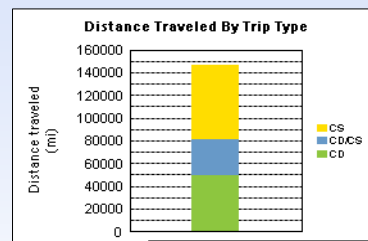
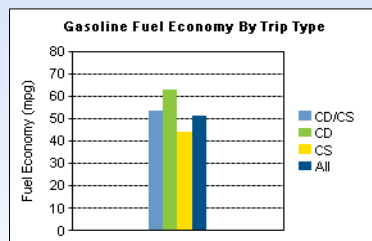
- Summary reports posted monthly on web
- 364 summary and individual reports generated in FY08
- Individual vehicle reports only go to vehicle owners each month



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## Database Generated PHEV Reports

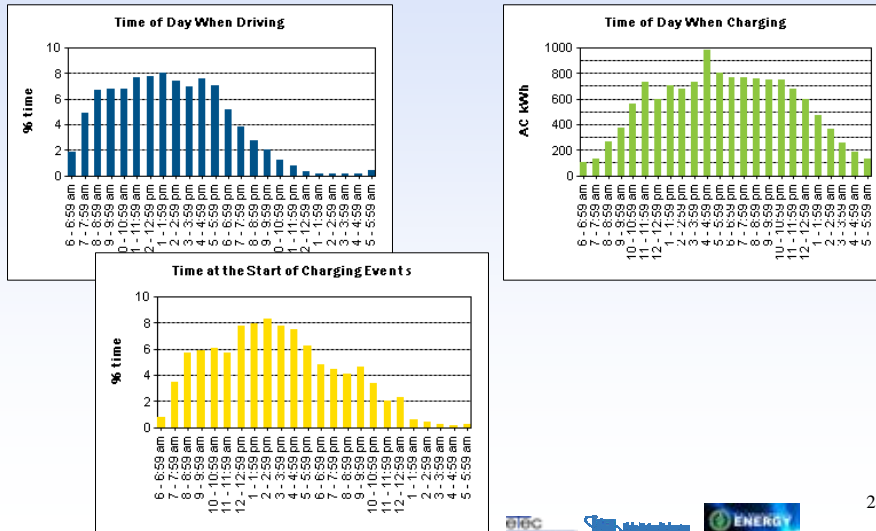
- 61 Hymotion Prius PHEVs, 147,000 miles, 15,900 trips, 4,047 charging events – Mar/Dec 2008, V2Green collected



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## Database Generated PHEV Reports – cont'd

- 61 Hymotion Prius PHEVs, 147,000 miles, 15,900 trips, 4,047 charging events – Mar/Dec 2008, V2Green collected



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## FY08 HEV Testing Accomplishments

- Completed baseline performance testing on 14 HEV models to date (2 during FY08)
- HEV accelerated testing places 160,000 test miles on a minimum of 2 HEVs per model in 3 years
  - At end of FY08, 4.1 million accelerated test miles have been accumulated on 14 models and 39 HEVs
  - During FY08, 936,000 accelerated test miles were accumulated on 10 models and 21 HEVs
  - Fleet testing included documenting miles driven, gasoline use, maintenance, and repairs
  - Above plus registration, insurance, and depreciation costs captured to determine life-cycle costs
- Conducted and conducting battery testing at Beginning (BoT) and End (EoT) of accelerated testing on 21 HEVs

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## HEVs in Fleet and Accelerated Testing

2001 Honda Insight	6	Completed
2002 Gen I Toyota Prius	6	Completed
2003 Gen I Honda Civic	4	Completed
2004 Chevrolet Silverado (2- & 4-WD)	2	Ongoing
2004 Gen II Toyota Prius	2	Completing
2005 Ford Escape (front & 4-WD)	2	Completing
2005 Honda Accord	2	Ongoing
2006 Lexus RX 400h (front & 2 AWD)	3	Ongoing
2006 Toyota Highlander (AWD)	2	Ongoing
2006 Gen II Honda Civic	2	Ongoing
2007 Saturn Vue	2	Ongoing
2007 Toyota Camry	2	Ongoing
2008 Nissan Altima	2	Ongoing
2008 GM 2-mode Tahoes	2	Starting
Total tested or in testing	39 to date	



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## HEV Battery Testing Status

Vehicle			Test Status		
VIN No.	Year	Make	BOT	EOT	Report Type
8725	2006	Civic	N/A	Test	Battery only
9329	2006	Civic	N/A	Test	Battery only
657	2005	Accord	N/A	Review	Battery only
1096	2005	Accord	N/A	Review	Battery only
1052	2004	Prius	N/A	Review	Battery only
2721	2004	Prius	N/A	Review	Battery only
6395	2006	Highlander	Surrogate	Pending	Fuel Econ., Accel. and Battery
5681	2006	Highlander	Surrogate	Fleet	Fuel Econ., Accel. and Battery
9664	2005	Silverado	Test	Pending	Fuel Econ., Accel. and Battery
8122	2007	VUE	Pending	Fleet	Fuel Econ., Accel. and Battery
3344	2007	VUE	Pending	Fleet	Fuel Econ., Accel. and Battery
8237	2005	Escape	N/A	Review	Battery only
5881	2005	Escape	N/A	Review	Battery only
2351	2007	Altima	Pending	Fleet	Fuel Econ., Accel. and Battery
7982	2007	Altima	Pending	Fleet	Fuel Econ., Accel. and Battery
2527	2006	Lexus	Surrogate	Pending	Fuel Econ., Accel. and Battery
4807	2006	Lexus	Surrogate	Pending	Fuel Econ., Accel. and Battery
6330	2007	Camry	Surrogate	Pending	Fuel Econ., Accel. and Battery
7129	2007	Camry	Surrogate	Pending	Fuel Econ., Accel. and Battery
7400	2008	Tahoe	Pending	Fleet	Fuel Econ., Accel. and Battery
5170	2008	Tahoe	Pending	Fleet	Fuel Econ., Accel. and Battery

Note: Surrogate data from identical vehicles and/or batteries will be used when needed.



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## AVTA HEV Battery Reports

- **Characterize test vehicle battery performance by using**
  - On-road testing by ETEC
  - Vehicle dynamometer testing at ANL
  - Lab testing by ETEC at Beginning (BOT) and End of accelerated Testing (EOT)
- **Benchmark the battery's energy and power capabilities during**
  - Normal driving conditions
  - Wide-open throttle conditions
  - Controlled-environment capacity and hybrid pulse power testing
- **Side-by-side analyses of vehicle and battery performance enables**
  - Determination of battery capabilities vs. vehicle demands
  - Confirmation of laboratory data vs. field data and vehicle performance
  - Confirmation of manufacturer's specs
  - Confirmation of U.S. DOE Electrochemical Energy Storage (ECES) technical targets, procedures and results
  - Value added vehicle systems analysis and ECES technical support
- **New capabilities address important real-world issues**
  - Prototype battery testing in mule vehicles in high-miles on-road testing environments
  - First on-road mule vehicle testing starting with the Ultra lead-acid battery
  - Evaluate various charging scenarios, e.g., full discharge, opportunity charge, etc
  - Evaluate infrastructure needs

All testing was done in accordance with FreedomCAR Battery Test Manual for Power-Assist Hybrid Electric Vehicles and AVTA procedures.



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## Camry Hybrid System Specifications

Vehicle Specifications		Battery Specifications	
Manufacturer:	Toyota	Manufacturer:	Panasonic EV
Model:	Camry	Battery Type:	NiMH
Year:	2007	Rated Capacity:	6.5 Ahr (C/3 rate)
Number of Motors <sup>1</sup> :	1	Rated Power:	44 kW (216 W/cell)
Motor Power Rating:	105 kW	Number of Cells:	204
VIN #:	JTNBB46K673006330	Nominal Pack Voltage:	244.8 VDC
Date of First Service:	July 2006	Nominal Cell Voltage:	1.2V



1. Drive Motor in Toyota Synergy drive



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## Camry Battery Laboratory Test

	<u>BOT<sup>2</sup></u>	<u>EOT</u>	<u>Δ (%)</u>
<b>Static Capacity Test<sup>1</sup></b>			
Capacity (Ahr)	5.74	5.41	0.32 (5.6)
Energy Capacity (Whr)	1,480	1,390	90 (6.1)
<b>HPPC Test @ 50% SOC<sup>1</sup></b>			
Disch. Power @ 10s (kW)	25.7	22.1	3.6 (14)
Charge Power @ 10s: (kW)	23.4	20.2	3.2 (14)
<b>Test Conditions</b>			
Odometer (mi)	413	160,431	
Date of Test	9/20/07	9/09/08	
Max. Cell Charge Voltage (V)	1.5	1.5	
Min. Cell Charge Voltage (V)	1.0	1.0	

1. Static Capacity and HPPC tests were performed in accordance with the FreedomCAR Battery Test Manual for Power-Assist Hybrid Electric Vehicles, DOE/ID-11069, October 2003.  
 2. BOT lab results are derived from Nissan Altima VIN: IN4CL21E87C172351, battery manufacturer and model are the same as the Toyota Camry.



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## Camry Baseline Performance Testing

Acceleration Test (0 to 60 mph)		Fuel Economy Test (SAE J1634)	
Peak Disch. Power:	27.8 kW	Peak Disch. Power:	29.4 kW
10-sec-Avg. Disch. Power:	23.6 kW	Peak Charge Power:	24.5 kW
Capacity Disch. @ 1mi:	1.10 Ahrs	Capacity Discharged:	7.28 Ahr
Energy Disch. @ 1mi:	230 Whrs	Capacity Regenerated:	9.00 Ahr
		Battery Charge/Disch. Effic'y:	80.9%
		Max. Charge Pack Voltage:	308.0 VDC
Min. Disch. Pack Voltage:	200.1 VDC	Min. Disch. Pack Voltage:	227.7 VDC
Date:	Fall 2006	Date:	Fall 2006

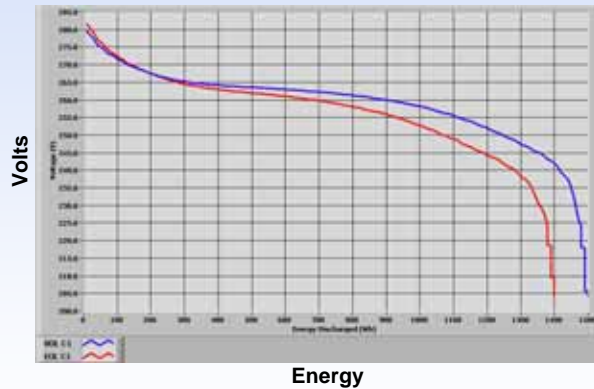
1. Vehicle test results are derived from baseline testing of a 2007 Toyota Camry VIN: JTNBB46K773007129.  
 2. Acceleration Testing by eTec and Fuel Economy Testing by ANL were performed in accordance with the AVTA HEV test Procedures ETA-HTP02 and ETA-HTP03, respectively.



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## Camry Static Capacity (and Energy) Test

The Static Capacity Test measures the battery's capacity (and energy) at the one-hour discharge rate. The energy decreased by 90 Whr (6.1%) and the capacity by 0.32 Ahr (5.6%) during the 160,000 vehicle miles from **BOT** to **EOT**.



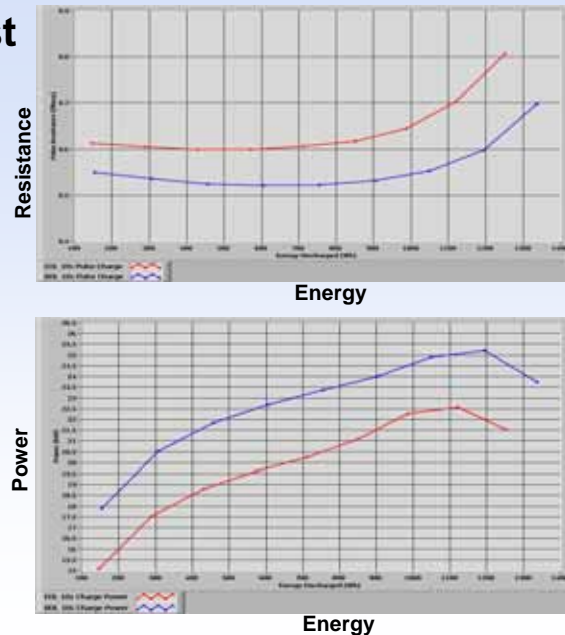
ETEC



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## Camry HPPC Test

The battery's resistance and power are calculated as a function of SOC from the HPPC results. At 50% SOC, the discharge and regen powers decreased by 14% and 9.4% respectively, from **BOT** to **EOT**.



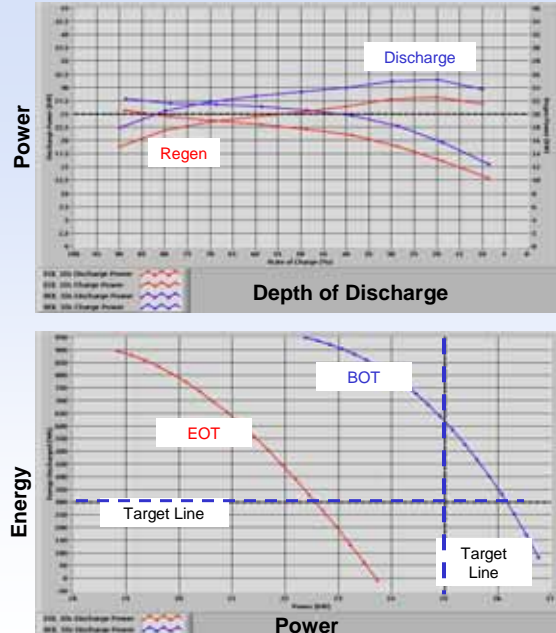
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## Camry Power Vs. Energy

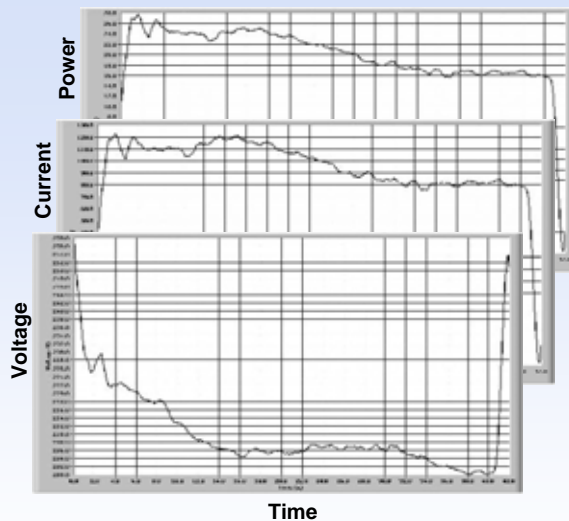
The battery's power and energy are calculated from the Static Capacity and HPPC tests and compared to the DOE/USABC Power-Assist HEV targets of 25 kW and 300 Whr. At **BOT**, the battery had a power margin of 1.2 kW but then fell below the DOE / USABC targets.



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## Camry Acceleration Test

The Acceleration Test provides on-road, real-world battery power, current and voltage data which may be compared to the manufacturer's specs, DOE/USABC targets and to battery test results and used to update vehicle systems analyses.



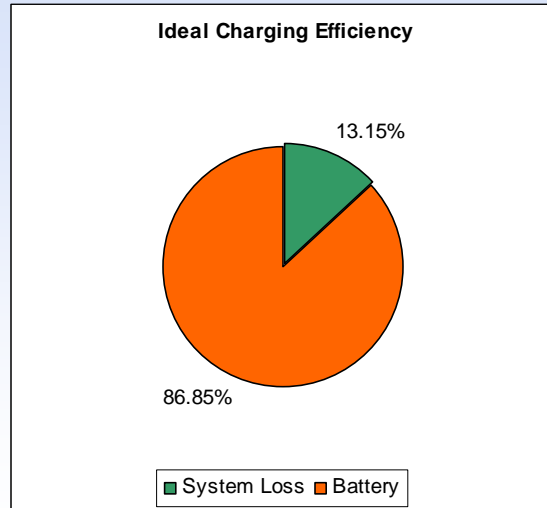
The Acceleration Test 10-second average discharge power of **23.6 kW** is within 10% of the HPPC BOT value of **25.7 kW**.

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## Camry Fuel Economy Test - Regen

The **battery** captures 87% of the available regen energy with the remaining 13% going to **system losses**.



## AVTA Future Testing Activities

- Continue to focus on testing EV, HEV, and PHEV technologies and sub-systems that:
  - Incorporate advanced electric drive systems
  - Incorporate advanced electric storage (battery) technologies
  - Support DOE's goal of ensuring the continued supply of secure energy sources
  - Have realistic near-term potential for commercialization
  - Can be tested in a lower-cost manner that accurately portrays real world performance
  - Can be tested in a manner that leverages non-DOE cost share
- Within budgetary constraints, continue to support CARB's requirement that all NEVs be tested by the AVTA

## **AVTA Future Testing Activities – cont'd**

- Complete bidirectional vehicle-to-grid (V2G) charging study with electric utility participation
  - 6 kW and 20 kW levels, using two lithium PHEV batteries, V2Green cellular charging control, documenting infrastructure requirements and costs
- Conduct vehicle \ battery testing on PHEVs when received via DOE's OEM PHEV Technology Assistance and Demonstration Activity and stimulus activities
- Support British Columbia's and BC Hydro's testing of 32 PHEVs. Access to these PHEVs cost the AVTA \$0 to BC's costs of \$1.2 million + operating costs
- Develop a battery \ mule vehicle testing activity for advanced electric storage devices



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## **AVTA Future Testing Activities – cont'd**

- Supply vehicle and subsystem performance, costs and charging behavior patterns to vehicle and infrastructure modelers at ANL, ORNL, NREL, and PNNL
- Continue the ALABC and DOE \ AVTA development, manufacturing and testing of the lead acid Ultra Battery in a 100,000-mile HEV testing regime
- Complete NDAs with Hymotion \ A123Systems and universities in order to further share PHEV data
- Continue to build PHEV, HEV and EV data analysis and dissemination tools
- Continue AVTA's role as DOE's sole independent tester of light-duty whole-vehicle technologies in field applications



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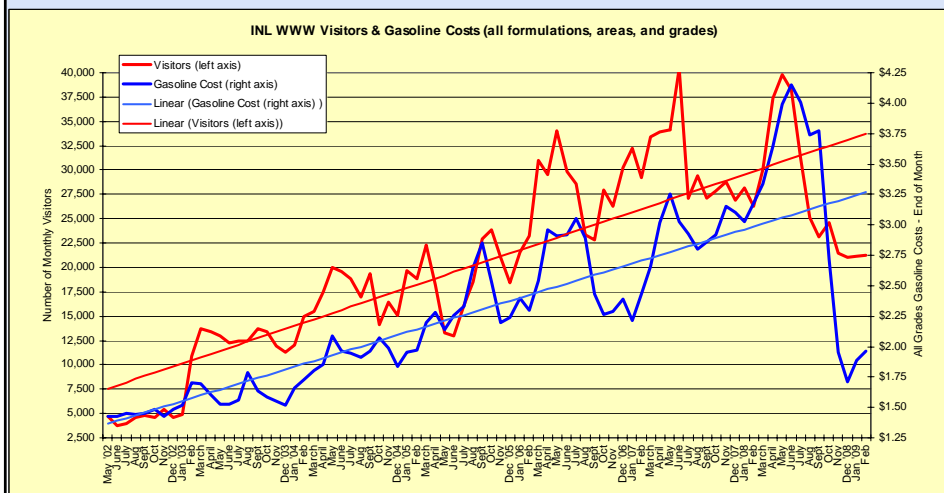
## AVTA Summary

- Before a vehicle testing regime or demonstration is initiated, the AVTA identifies and determines the technical and economic values of testing partnerships to ensure that the maximum value to DOE and taxpayers are achieved
- AVTA is a very low-cost project for the number of test miles and data accumulated, and the number of reports published (445 reports and presentations), as all funding is highly leveraged via testing partnerships to provide maximum benefits to DOE and taxpayers
- Taxpayers receive independent information on emerging technologies and the associated amounts of petroleum used or avoided
- Every testing regime has at least 20% cost share, and most PHEV testing is cost-shared at greater than 50% with non-DOE sectors



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## AVTA Summary – WWW Visitors



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## **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/CON-09-15561



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