INL Retired Employees Association – Electric Drive Vehicles

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Idaho Falls, Idaho
May 2011

This presentation does not contain any proprietary or sensitive information

Presentation Outline

- Advanced Vehicle Testing Activity (AVTA) background
- Comparison of Internal combustion engine (ICE), hybrid electric (HEV), plug-in hybrid electric (PHEV), and battery electric (BEV) vehicle technologies
- Grid connected vehicle charging infrastructure and charging levels
- INL / AVTA electric drive vehicle testing
- EV Project data collection
- OEM PHEV data reporting
- OEM electric drive vehicle deployment announcements
- Acknowledgement and AVTA WWW Address

AVTA Description

- Advanced Vehicle Testing Activity (AVTA) is conducted by the Idaho National Laboratory (INL) for DOE's Vehicle Technologies Program, which is part of EERE
- INL's AVTA tests light-duty vehicles, energy storage systems, and the fueling infrastructures that support:
  - 100% Electric and dual-fuel electric drive systems
  - Advanced energy storage systems
  - Advanced control systems (i.e., micro hybrid vehicles)
  - 100% Hydrogen and HCNG blended ICE vehicles
- Benchmarked testing results customers include:
  - DOE and industry R&D programs, modelers, battery manufacturers, OEMs, and target/goal setters
  - Assist early adaptor fleet managers and the public in making informed vehicle / infrastructure purchase, deployment and operating decisions
  - Presentations / webinars to industry groups and Clean Cities' groups

Comparison of Vehicle Technologies

Comparison of Vehicle Technology

- Conventional vehicle with internal combustion engine (ICE) only

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Comparison of Vehicle Technology

- Hybrid Electric Vehicle (HEV) with ICE and electric drive
- Does not plug in to electric grid

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Comparison of Vehicle Technology

- **Plug-in Hybrid Electric Vehicle (PHEV) with ICE and electric drive**

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Comparison of Vehicle Technology

- **Battery Electric Vehicle (BEV) with electric drive only**

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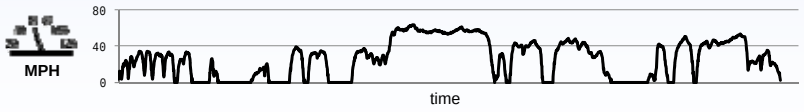
Conceptual Comparison of Vehicle Operation

- **Hypothetical 15 mile drive cycle**



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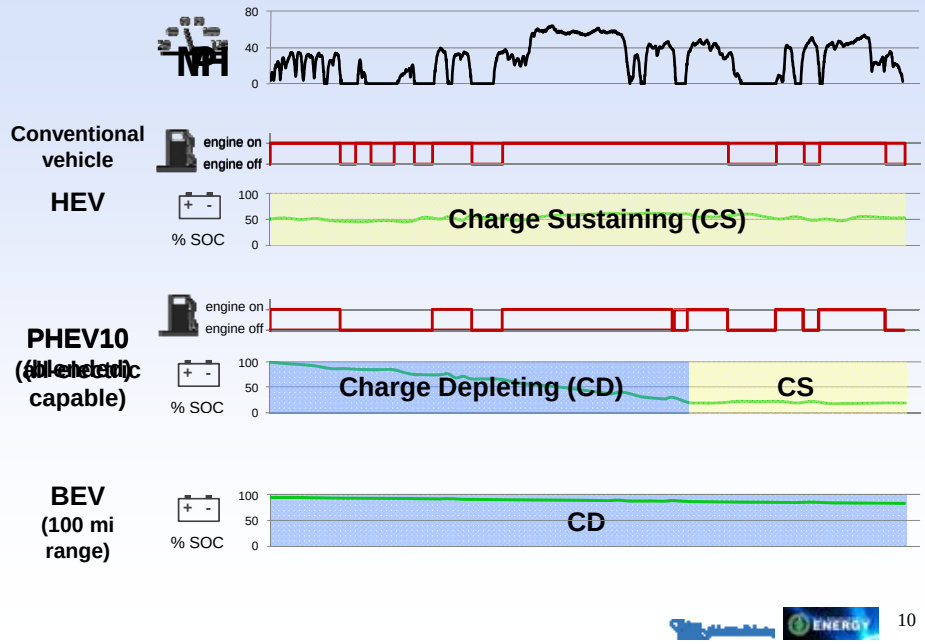
Conceptual Comparison of Vehicle Operation



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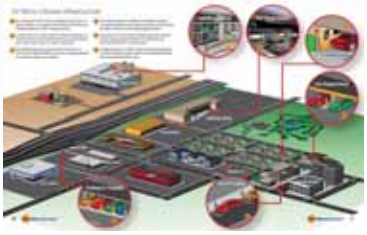
Grid Connected Vehicle Charging Infrastructure Overview

Vehicle Electrification: Grid Impacts

- In the U.S., current grid capacity could supply electricity for 70% of our vehicles without adding capacity, but assumes:
  - Vehicles would only charge off-peak
  - "Perfect" distribution of electricity
  - No local impacts such as overburdening neighborhood transformers
- EVs and PHEVs will not cause a grid "meltdown" but we clearly need to work fast to reduce vehicle rollout impacts
- Smart charging will be key to lowering costs and minimizing impacts
- Time of day pricing also important
- Administration Goal: 1 Million Plug-in Vehicles by 2015

Build-out of Charging Infrastructure

- Key today: Home Charging
  - Need to get the cost and installation process right. Currently a significant barrier
- Public Charging
  - Expansive if not well utilized
  - Expansive to fully cover full driving patterns
- Ideally need market pull to determine public infrastructure build-out
  - PHEVs may be key to help initiate market pull for public infrastructure



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Innovative Approaches

- Battery swapping
  - Requires OEM buy-in
- Fast Charging (becoming less innovative)
- Innovative Financing
- Secondary use of batteries
  - Utility ancillary services
  - Bulk energy storage
  - Present value
- Vehicle to Grid (V2G)

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Level 1 Charging Level

- This method allows broad access to change an EV or PHEV by plugging into the most common grounded electrical outlet in the U.S.
- AC energy transfer to onboard charger
- Typical hardware includes portable cord set that must utilize a vehicle connector UL approved for the purpose, a GFCI, and otherwise meet NEC 625 requirements and SAE standards, including the J1772 connector:
  - Separate circuit
  - Standard 120V/15A or 20A
  - Current 12 amps or 16 amps (80% of amp breaker)
  - Power 1.44 kW
- Charge Times (general approximation)
  - Battery EV 14 hours (20 kWh battery) to 39 hours (56 kWh battery)
  - PHEV 3 to 8 hours

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Level 2 Charging Level

- Expected to be most common method for residential and commercial charging
- EVSE (electric vehicle supply equipment) for AC energy transfer to onboard charger
- Permanently attached wall box, GFCI, some vehicle communication, UL approved, NEC 625 requirements and SAE standards, including J1772 connector:
  - 240V single phase up to 100A
  - Current up to 80A (80% of amp breaker)
  - Power up to 19.2 kW
  - 3.3 kW or 6.6 kW more typical initially
- Charge Times (general approximation)
  - 20 kWh Battery EV 3 hours (at 6.6 kW) to 56 kWh battery in 8.5 hours (at 6.6k kW)
  - PHEV 3 to 8 hours

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Level 3 Charging Level

- This charge level is NOT “FAST Charge” as currently used
- Typically would be 480VAC energy transfer to an onboard charger
- Current up to 400 amps
- Typically 60 kW to 120 kW, but can be up to 200 kW
- HOWEVER, no light-duty original equipment vehicle manufacturer plans to use onboard chargers at these energy levels

Fast Charging

- Expected to be used in an intercity grid pattern or along travel routes between cities in commercial settings
- Off-board charger (high cost, large volume and weight)
- Used for DC energy transfer to vehicle
- Requires most charger-to-vehicle communication and control
- No current U.S. SAE standard connector, however, U.S. fast chargers are using Japanese TEPCO (Tokyo Electric Power Company) connector per CHAdeMO protocol
- Up to 500VDC and 125A. 60 kW likely
- Charge Times are dependant on battery size
  - BEV intent is 50% recharge in 15 minutes and 80% recharge in 30 minutes
  - Charge times dependant on charger / battery relative sizing
  - Generally not used for PHEVs due to relatively small battery sizes

INL / AVTA Electric Drive Vehicle Testing

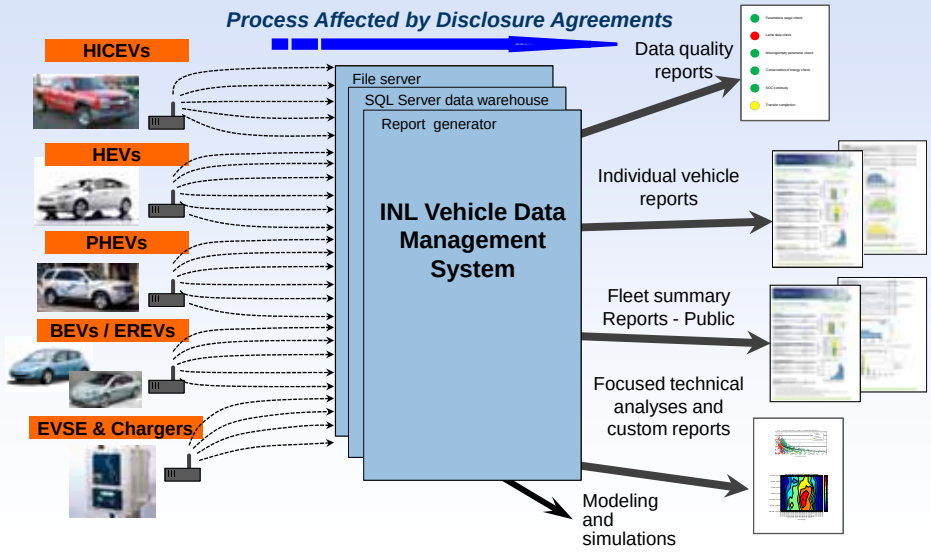
AVTA Vehicle Testing Approach

- Depending on vehicle technology and capabilities, vehicles are tested via:
  - Closed test tracks
  - Dynamometer testing
  - Laboratory testing (batteries)
  - Accelerated testing, using dedicated drivers and other methods to accumulate miles and cycles
  - Fleet testing, uses unstructured vehicle utilization
  - Different testing methods are used to balance testing control/repeatability, sample size, and costs
- Current INL staff has used onboard data loggers to document vehicle and charging operations since 1993
- Publish testing results in relevant ways to accurately
  - Document real-world petroleum reduction potentials
  - Document fuel and infrastructure use
  - Document life-cycle risks and costs

Vehicle Testing Experience

- Plug-in hybrid electric vehicles: 14 models, 430 PHEVs, 5+ million (ml) miles
- Extended Range Electric Vehicles: 1 model, 150 EREVs, 400+ thousand (k) miles
- Hybrid electric vehicles: 19 models, 50 HEVs, 6+ ml miles
- Micro hybrid vehicles: 3 models, 7 MHVs, 200+ k miles
- Neighborhood electric vehicles: 24 models, 372 NEVs, 200k miles
- Hydrogen internal combustion engine vehicles, 7 models, 18 HICEVs, 500k miles
- Battery electric vehicles 47 models, 2,300 BEVs, 5+ million miles (includes 500+ USPS BEVs)
- Urban electric vehicles: 3 models, 460 UEVs, 1 million miles
- 18+ million test miles accumulated on 2,300 electric drive vehicles representing 110 models

Vehicle Data Management Process



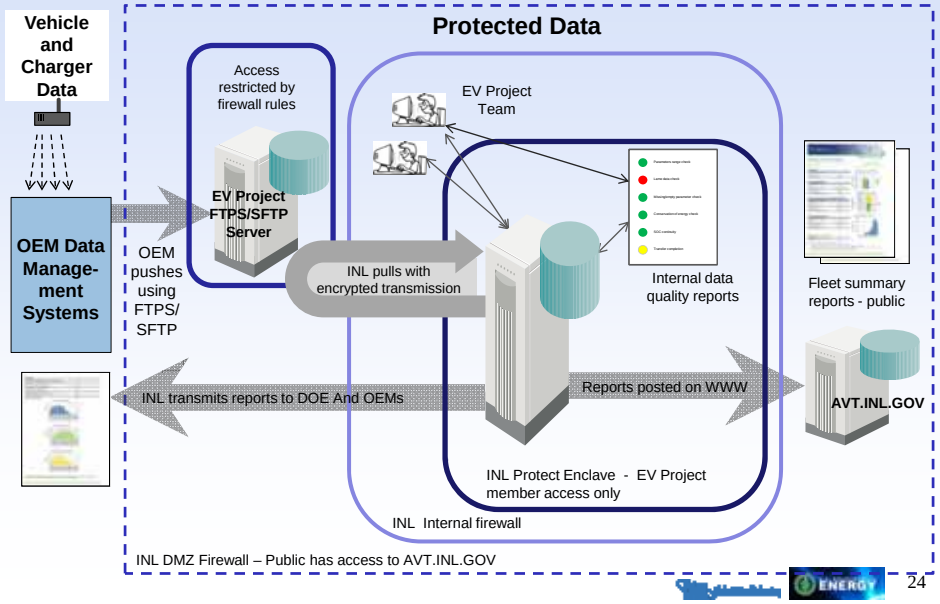
Vehicle and Infrastructure Data Sources

Vehicle time-history data (second-by-second)	HEV: 12 vehicle models, 1 data logger
	HICE: 1 vehicle model, 1 data logger
	Conversion PHEVs: 8 vehicle models, 3 data loggers
	Ford Escape PHEV, Ford wireless logger
	Chrysler Ram PHEV, Chrysler wireless logger
Vehicle event data (key-on, key-off)	**Nissan** Leaf, Nissan telematics
	Chevrolet Volt, OnStar telematics
Charger event and 15 min time-history data	**ECOtality** Blink networked level 2 EVSE, DC/fast chargers
	Coulomb ChargePoint networked level 2 EVSE

Managing 26 different data models

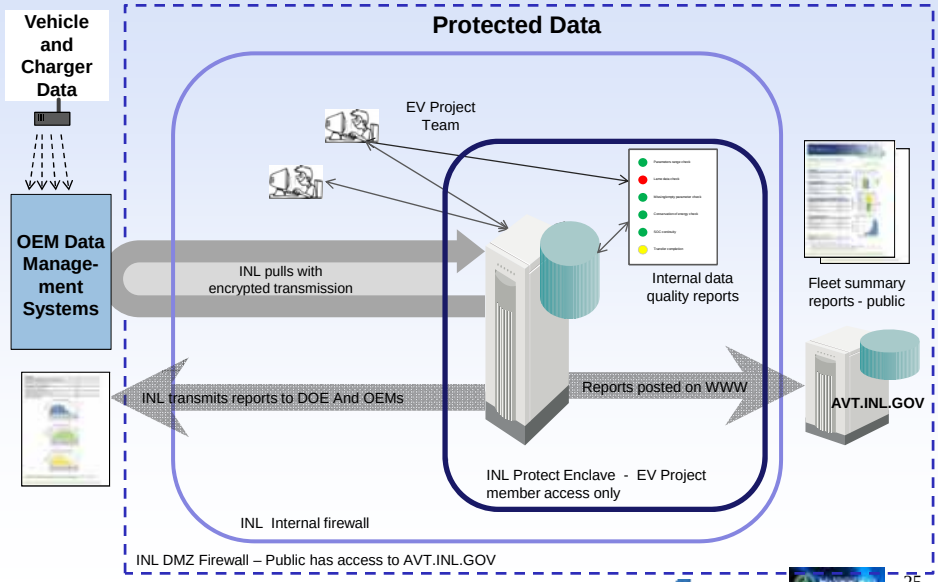
INL Data Management System - Push

(Nissan, GM, Chrysler, Coulomb)



INL Data Management System - Pull

(ECOtality, Ford, conversion PHEVs, HEVs, HICEs)



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PHEV Conversion Testing Partners

- **267 PHEV conversions in 26 states, Canada and Finland, 3 million miles - AVTA only purchased 2 PHEVs and conducted 12 conversions. Highly leveraged testing activity**
- **93 PHEV testing partners include:**
  - **38 Electric utilities**
  - **10 County governments**
  - **4 State governments**
  - **9 City governments**
  - **10 Universities**
  - **2 Clean Air Agencies**
  - **10 Canadian government groups**
  - **3 Sea ports and military bases**
  - **2 PHEV conversion companies**
  - **5 Private companies and advocacy organizations**
- **3,000+ automated monthly 3-page summary reports have been generated and disseminated to testing partners**

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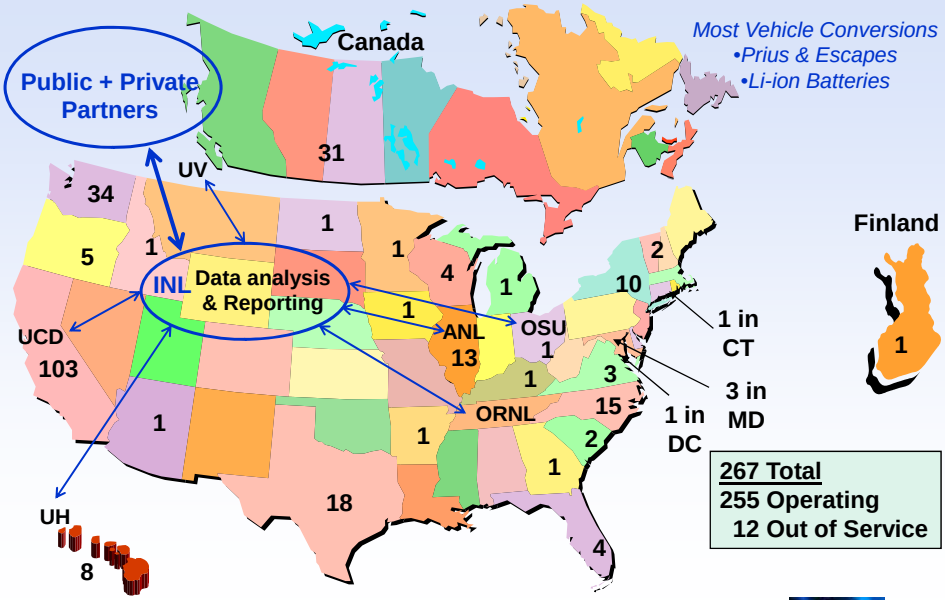
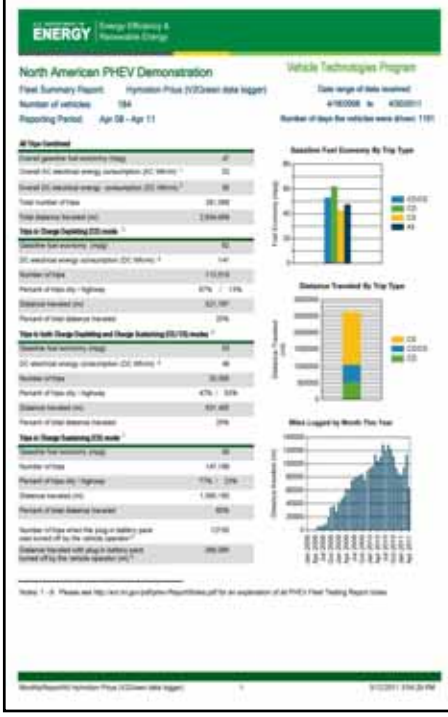
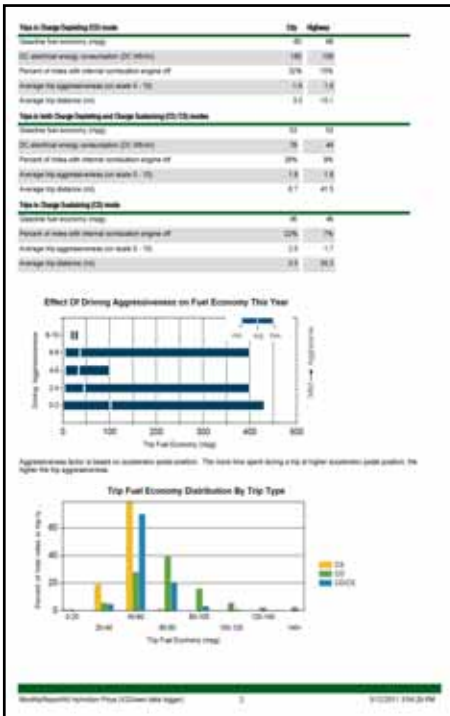
FY-10 PHEV Conversion Demonstrations





PHEV 3-Page Report

- Reports 2.6 million Hymotion Prius test miles and 281,000 trips
- Report by charge mode:
  - Charge depleting (CD)
  - Charge sustaining (CS)
  - Mixed (CD/CS)
- All trips, 47 mpg, 52 AC Wh/mi & 38 DC Wh/mi
- CD, 62 mpg & 141 DC Wh/mi
- CD/CS, 53 mpg & 49 DC Wh/mi
- CS, 43 mpg



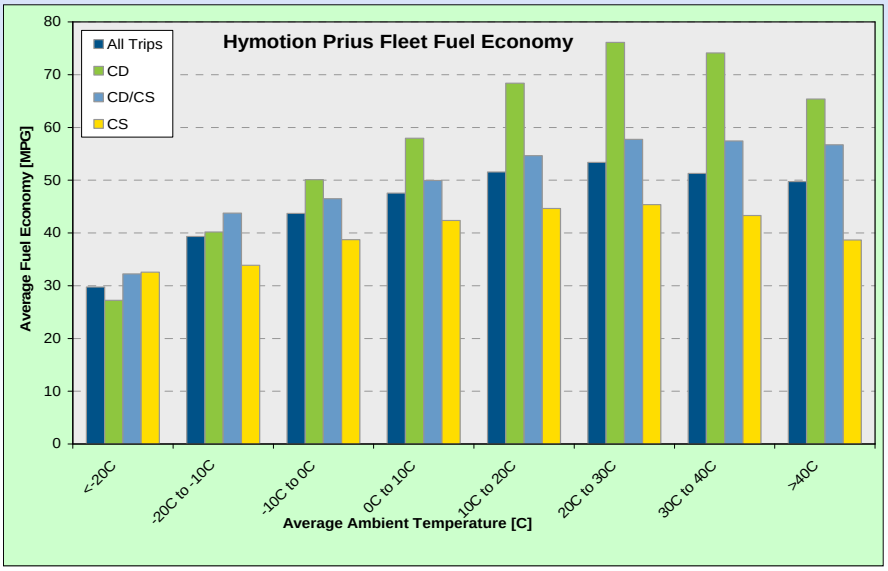
PHEV 3-Page Report

- Report fuel use by highway/city cycles and driver style
- CD city, 60 mpg, 165 DC Wh/mi
- CD highway, 66 mpg, 109 DC Wh/mi
- CS city, 36 mpg
- CS highway, 46 mpg
- Less aggressive driving (0 to 20%) averages ~100 mpg
  - (Aggressiveness = accelerator pedal position)

PHEV 3-Page Report

- Report charging stats, time of day driving, and charging profiles
- Average 0.9 charging event per day when PHEV driven
- 52 miles between charge events
- 5.5 trips between charge events
- 2.8 hours per charge
- 34.3 hours time plugged in per charge
- 2.7 AC kWh per charge event

PHEV Ambient Temperature MPG Impacts



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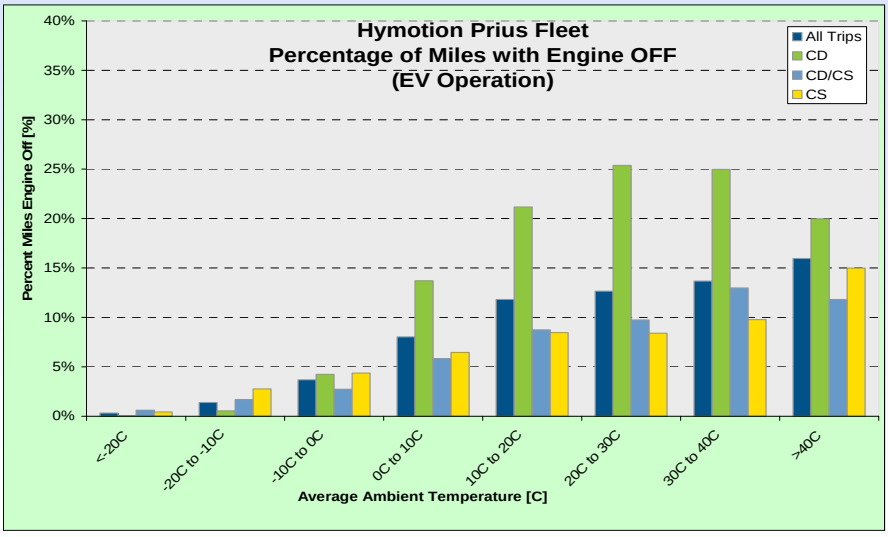
Engine Operation is a Main Factor for PHEV Fuel Economy Changes



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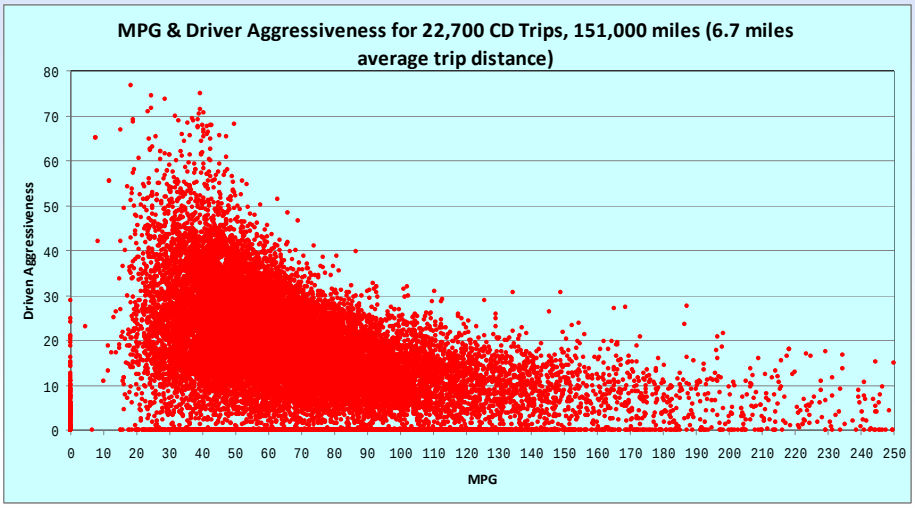
Hymotion Prius PHEVs – CD Trips

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



Data from 150 Hymotion Prius with V2Green and Kvaser loggers

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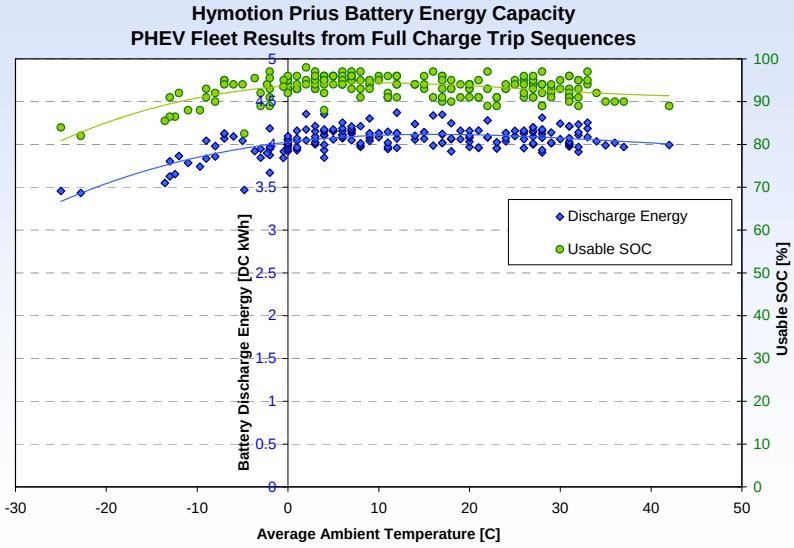
Usable Battery Capacity is Slightly Effected by Temperature



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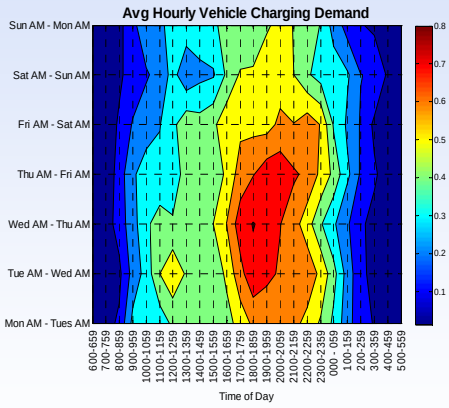
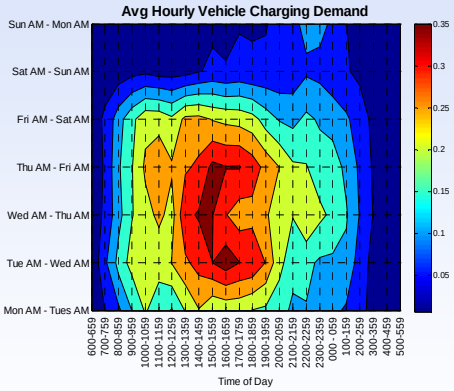
Commercial / Private Fleet Charge Demand

Private Fleet



Commercial Fleet



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HEV and MHV Testing

- 6 million total HEV testing miles
- 22 HEV models and 56 HEVs tested to date:
  - 6, 2001 Honda Insight
  - 6, 2002 Gen I Toyota Prius
  - 4, 2003 Gen I Honda Civic
  - 2, 2004 Chevrolet Silverado
  - 2, 2004 Gen II Toyota Prius
  - 2, 2005 Ford Escape
  - 2, 2005 Honda Accord
  - 3, 2006 Lexus RX 400h
  - 2, 2006 Toyota Highlander
  - 2, 2006 Gen II Honda Civic
  - 2, 2007 Saturn Vue
  - 2, 2007 Toyota Camry
  - 2, 2008 Nissan Altima
  - 2, 2008 GM 2-mode Tahoe
  - 2, 2010 Ford Fusion
  - 2, 2010 Toyota Prius
  - 2, 2010 Honda Insight
  - 2, 2010 Mercedes Benz S400
  - 2, Honda CRZ
  - 3, 2010 Smart Fortwo Pure Coupe
  - 2, 2010 MazDA 3 Hatchback
  - 2, 2010 Volkswagen Golf TDI.
- HEV testing includes beginning and high mileage HEV traction battery testing – HPPC, Static Capacity tests, as well as acceleration and fuel economy tests

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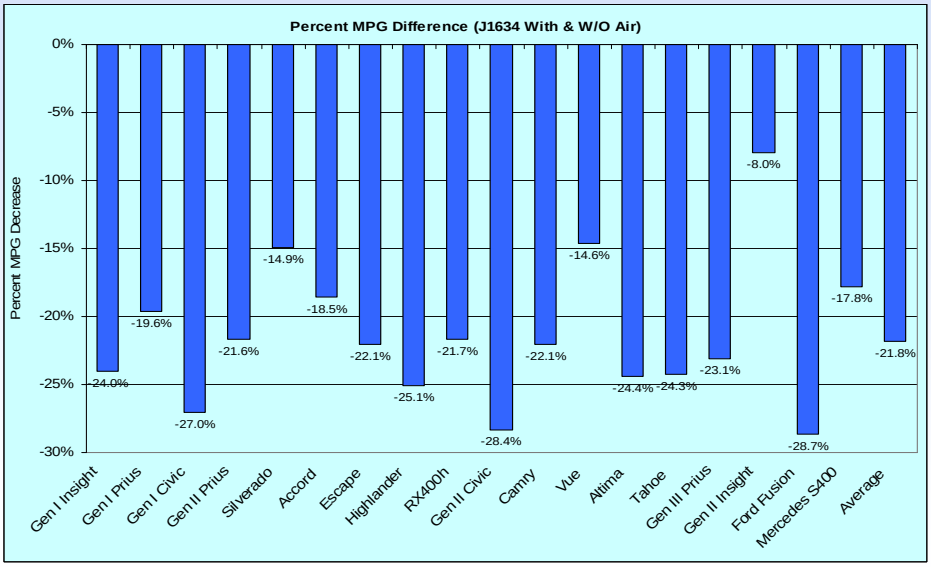
HEV Air Conditioning use MPG Impacts



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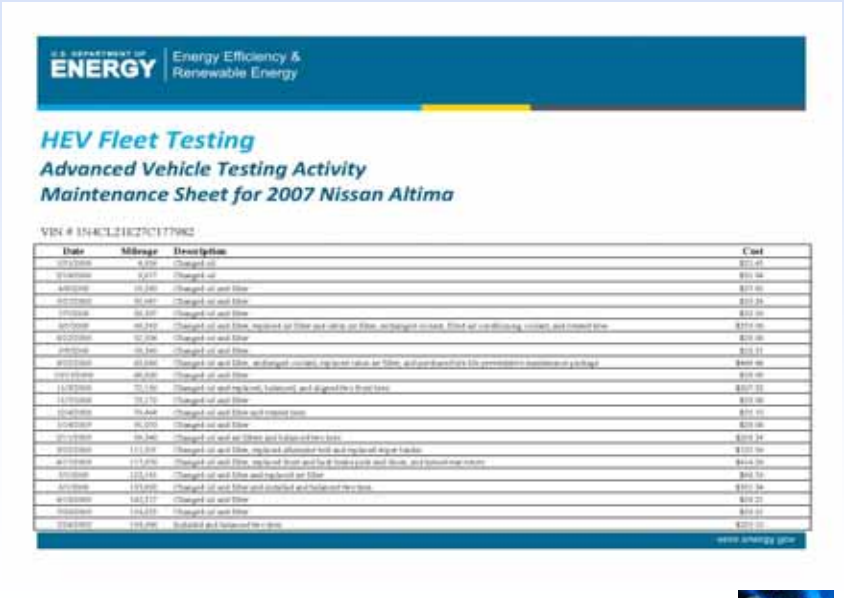
HEV Maintenance Sheets


ENERGY | Energy Efficiency & Renewable Energy

HEV Fleet Testing

Advanced Vehicle Testing Activity

Maintenance Sheet for 2007 Nissan Altima

VIN # 1N4CL21E27C177982

Date	Mileage	Description	Cost

www.energy.gov

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1-Page HEV Fleet Summary Sheets

- Life-cycle ownership costs per mile includes:
  - Purchase cost
  - Sales cost
  - Maintenance costs
  - Operating costs (insurance, fuel, taxes, registration, etc.)

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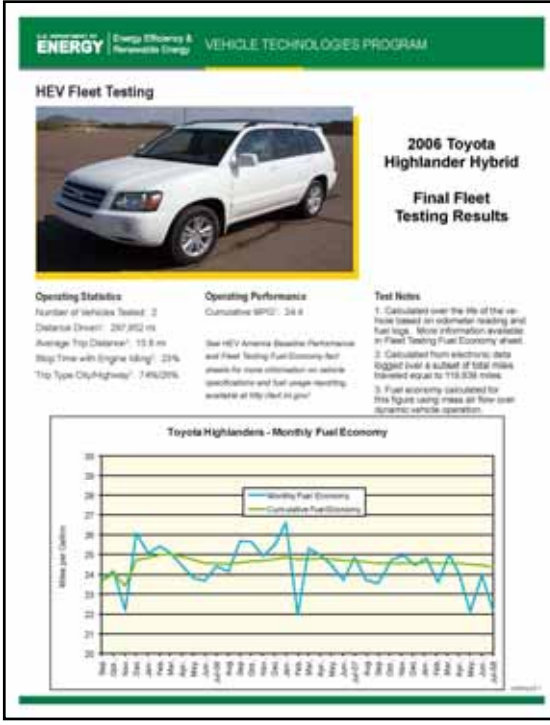

2-Page HEV Fleet Testing Fact Sheets

- Number of vehicles
- Total miles
- Average trip distance
- Stop time with engine idling
- Trip type: city/highway
- Fuel economy by vehicle speed

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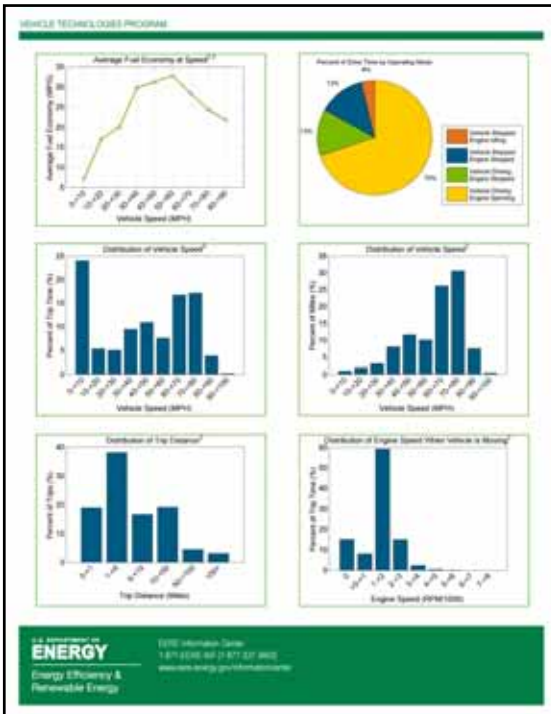

2-Page HEV Fleet Testing Fact Sheets – cont'd

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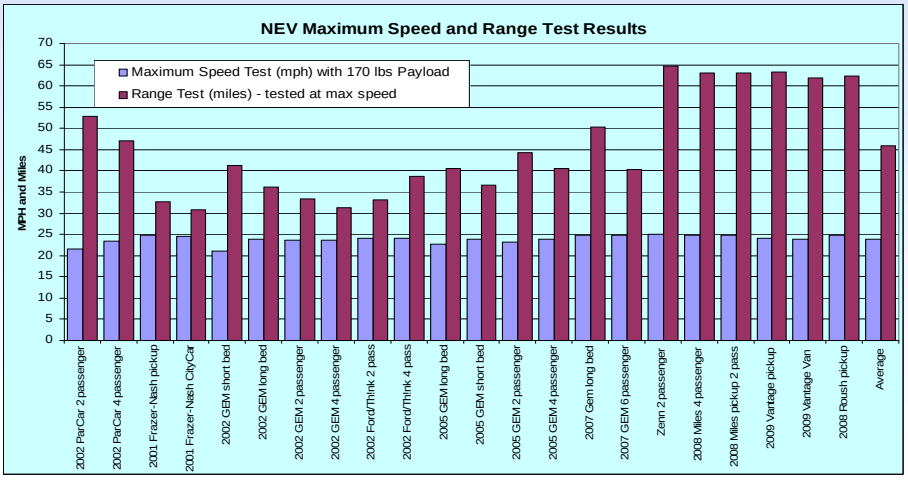
NEV Testing

- **CARB requires all NEVs be tested by AVTA to be eligible for incremental funding – 25 models tested to date**



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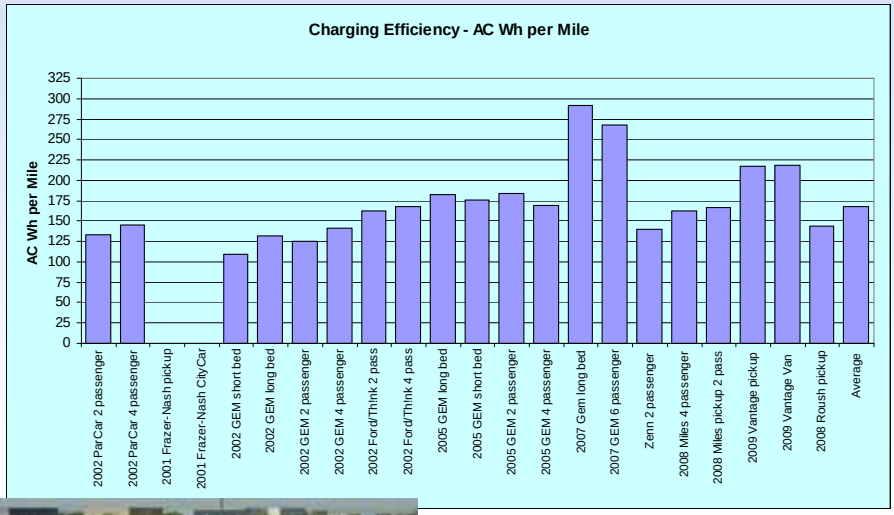
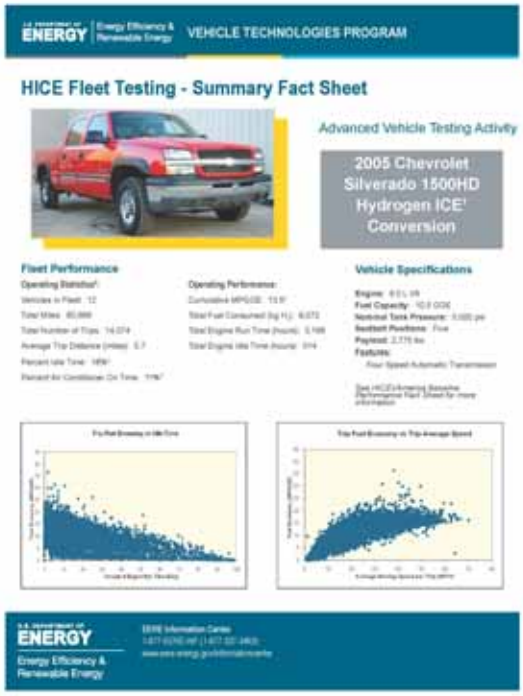
NEV Testing – cont'd





HICE Testing Accomplishments

- 12 H_2 internal combustion engine vehicles
- Averaged 13.5 miles per gasoline gallon equivalent (mpgge)
- 80,899 test miles
- 14,074 fleet trips
- Very low-cost data collection effort as no DOE funds were used to purchase, fuel, maintain or operate the HICE vehicles
- Task completed

INL Data Collection Activities in Support of DOE's Vehicle Electrification Projects

INL ARRA / TADA Data Collection Support

- INL tasked with data collection, analysis and reporting for five light-duty vehicle and infrastructure deployment projects funded by DOE via ARRA and Technology Acceleration and Demonstration Activity (TADA):
  - EV Project: 8,300 Leaf EVs and Volt EREVs, and 15,300 eTec Level 2 EVSE and fast chargers. All 23,600 pieces of equipment are equipped with data loggers (DLs)
  - 140 Chrysler Ram PHEV Pickups with DLs
  - 125 General Motors EREV Volts with DLs
  - 21 Ford Escape PHEV SUVs with DLs
  - 4,000 Level 2 EVSE deployed by Coulomb with DLs
- Raw data and personal information protected by numerous NDAs (Non Disclosure Agreements) with participant partners

EV Project - Overview

- **$230 million total project funded by a US Department of Energy grant ($115 million) via the American Recovery and Reinvestment Act (ARRA)**
- **Partners cost share match greater than $115 million**
- **Lead by Electric Transportation Engineering Corporation (eTec) (renamed Ecotality NA)**
- **Data will be collected by INL via data streams from eTec (charging infrastructure), and Nissan and General Motors/OnStar (vehicles)**
- **EV Project purpose is <u>to build and study mature electric vehicle charging infrastructure</u> in eight regions – 16 cities**
- **Product: Take the lessons learned from the deployment of these first 8,300 EVs and the 15,300 charging infrastructure units supporting them, to <u>enable the streamlined deployment of the next 5,000,000 EVs</u>**

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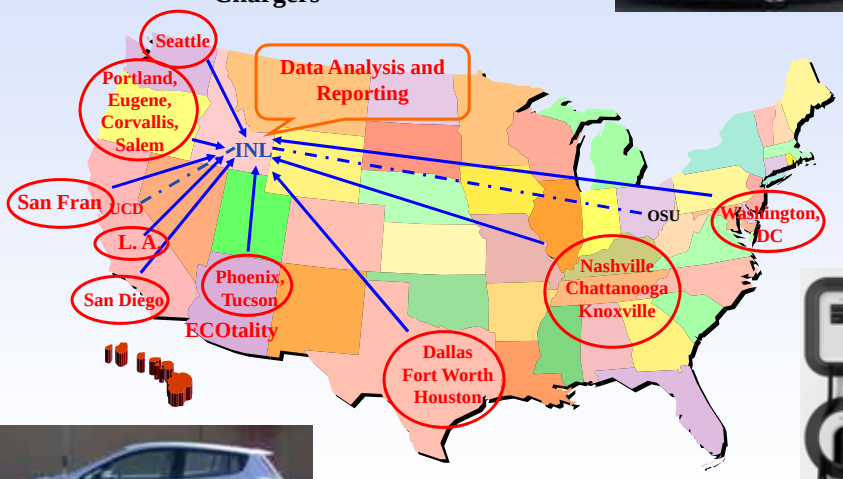
EV Project Partner Locations

Level II EVSE & Fast Chargers



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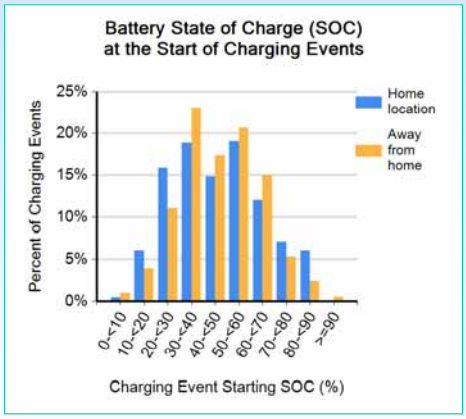
EV Project - Infrastructure Data Collected per Charge Event

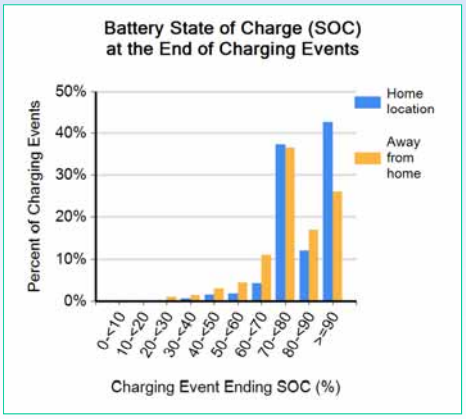
- Date/Time Stamp
- Unique ID for Charging Event
- Unique ID Identifying the EVSE – may not change
- Connect and Disconnect Times (plugged in and out)
- Start and End Charge Times
- Max Instantaneous Peak Power
- Average Power
- Total energy (kWh) per charging event
- Rolling 15 Minute Average Peak Power
- And other non-dynamic EVSE information (GPS, ID, type, contact info, etc.)

EV Project - Vehicle Data Collected per each Start / Stop Event

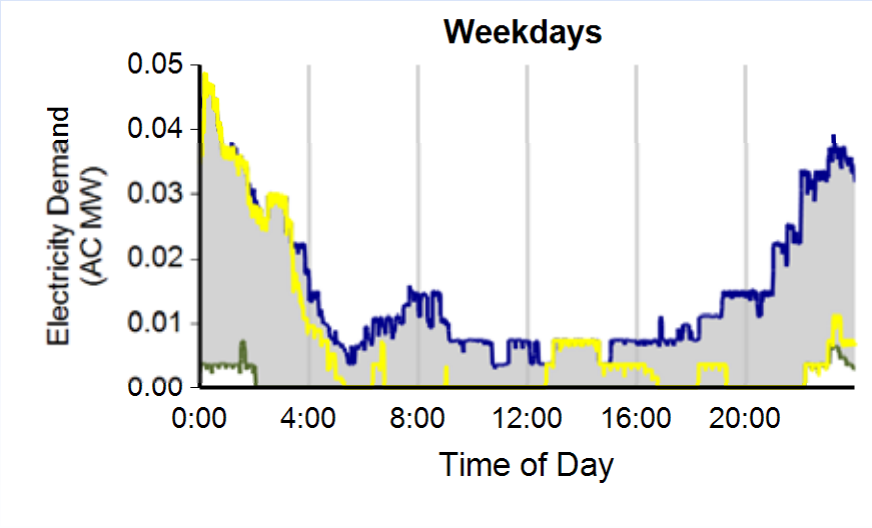
- Vehicle ID
- Date/Time Stamp
- Event type (key on / key off)
- Odometer
- Battery state of charge
- GPS (longitude and latitude)
- Liquid fuel consumption (some vehicles)
- Recorded for each key-on and key-off event

EV Project – Nissan Leaf Reporting

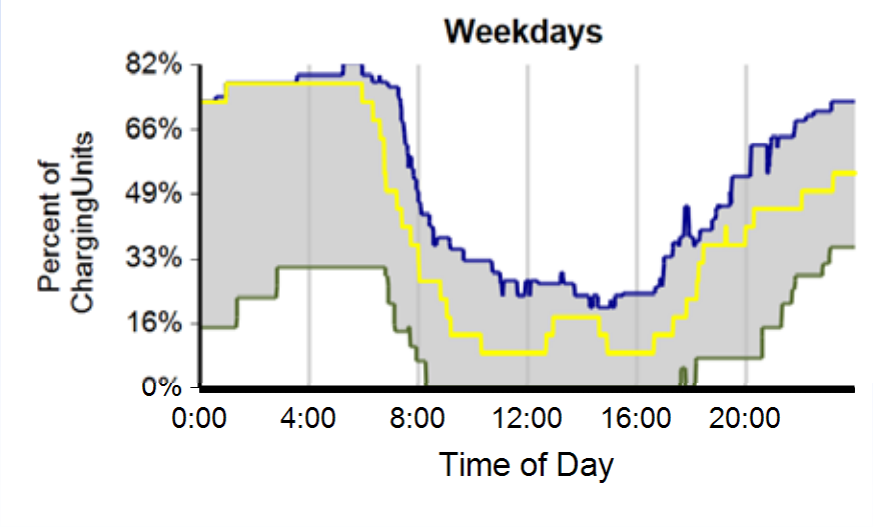




EV Project – Nissan Leaf Reporting



EV Project – Nissan Leaf Reporting



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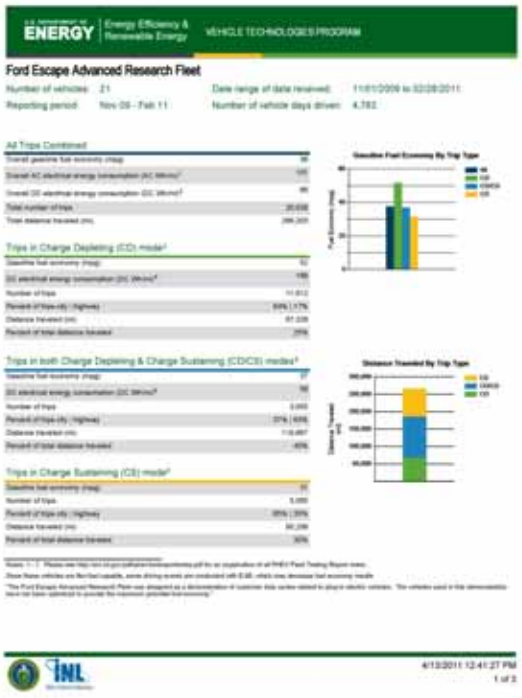
Ford Escape PHEV 3-Page Report


Ford Escape Advanced Research Fleet

- Reports 266,000 test miles and 21,000 trips
- Report by charge mode:
  - Charge depleting (CD)
  - Charge sustaining (CS)
  - Mixed (CD/CS)
- All trips, 38 mpg, 101 AC Wh/mi & 66 DC Wh/mi
- CD, 52 mpg & 169 DC Wh/mi
- CD/CS, 37 mpg & 56 DC Wh/mi
- CS, 31 mpg

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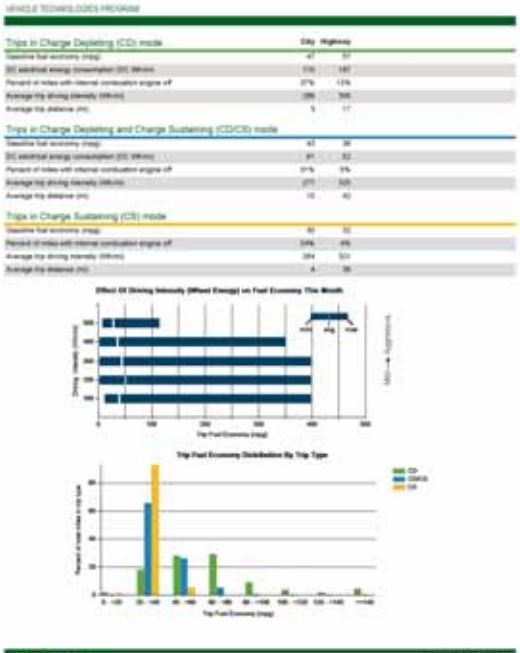

Ford Escape PHEV 3-Page Report

- Report fuel use by highway/city cycles and driver style
- CD city, 47 mpg, 170 DC Wh/mi
- CD highway, 57 mpg, 167 DC Wh/mi
- CS city, 30 mpg
- CS highway, 32 mpg

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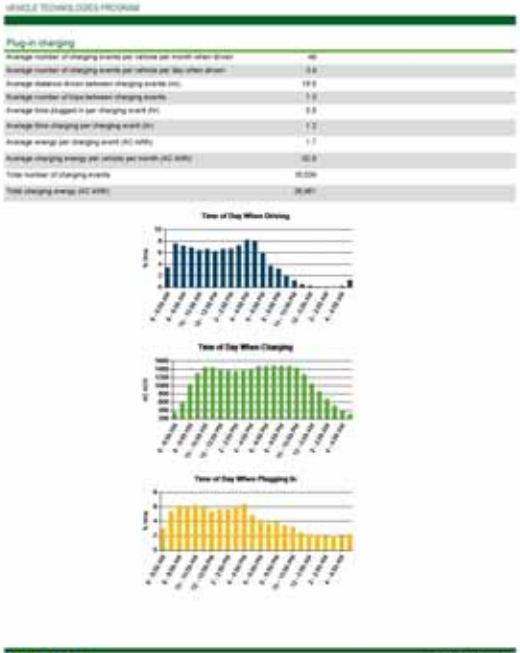

Ford Escape PHEV 3-Page Report

- Report charging stats, time of day driving, and charging profiles
- Average 3.4 charging event per day when PHEV driven
- 16.6 miles between charge events
- 1.3 trips between charge events
- 1.2 hours per charge
- 5.9 hours time plugged in per charge
- 1.7 AC kWh per charge event

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Original Equipment Manufacturer (OEM) Electric Drive Vehicle Deployment Announcements

Some OEM EDV Announcements

- **The below announcements and dates come from several sources and may change**

Introduction Year	Manufacturer / Model	Battery Technology
2010	Nissan / Leaf	BEV
2010	GM / Volt	EREV
2011	Coda / Coda	BEV
2011	Ford / Focus	BEV
2011	Ford / Transit (Van)	BEV
2011	BYD / e6	BEV
2011	Fisker / Karma	BEV
2011	Mitsubishi / i-MiEV	BEV

BEV – Battery Electric Vehicle
EREV – Extended Range Electric Vehicle
PHEV – Plug-in Hybrid Electric Vehicle
EDV – Electric Drive Vehicle

Some OEM EDV Announcements – con'td

- **The below announcements and dates come from several sources and may change**

Introduction Year	Manufacturer / Model	Battery Technology
2012	Smart / FORTWO	BEV
2012	Toyota / IQ-Based	BEV
2012	Tesla / S	BEV
2012	Toyota / Prius	PHEV
2012	Toyota-Tesla / RAV4	BEV
2012	Chrysler-Fiat / 500	BEV
2013	BMW / MegaCity	BEV
2013	Volkswagen / Eup	BEV
There have been another 50+ electric drive vehicle announcements beyond 2010 from Audi to Volvo		

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Other INL Data Collection Projects

- **Other OEM vehicles may be added to EV Project**
- **New EVs to be tested this year**
- **Five USPS electric long life vehicle (ELLV) conversions**
  - **ELLVs required five customized onboard data loggers**
  - **Testing to USPS and AVTA test procedures and cycles**
- **Start collecting data on SCAQMD's 20 Lithium PHEV Escape conversions**
- **Development of vehicle-based battery test-bed mule**

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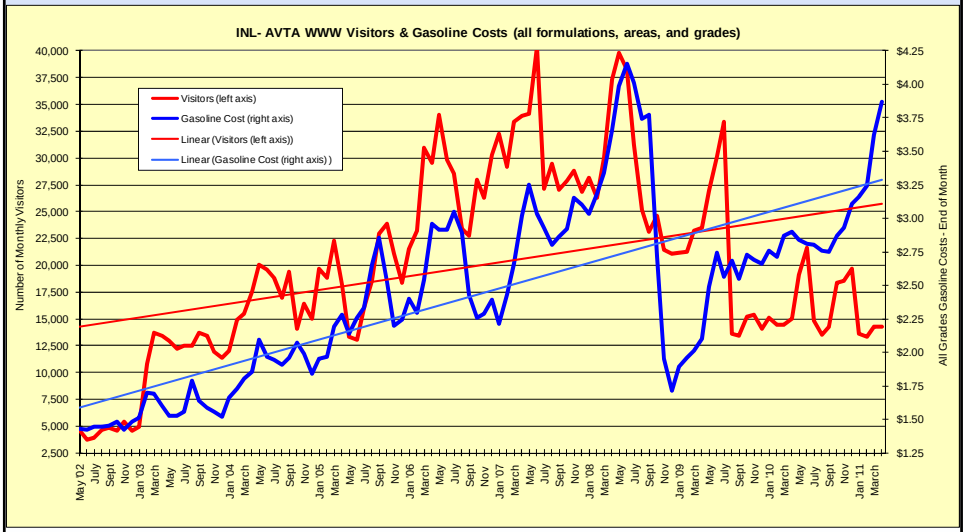
AVTA Summary – WWW Visitors



Acknowledgement and AVTA WWW Address

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

Additional AVTA Information, Reports, and Fact Sheets @

http://avt.inl.gov

INL/MIS-11-22115