Idaho National Laboratory

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

Clean Cities 2011 Stakeholders Summit - Electric Drive Vehicles and Charging Infrastructure Demonstrations, Analysis and Lessons Learned

Jim Francfort

U.S. DOE Clean Cities Stakeholders Summit
Indianapolis, Indiana
June 30, 2011

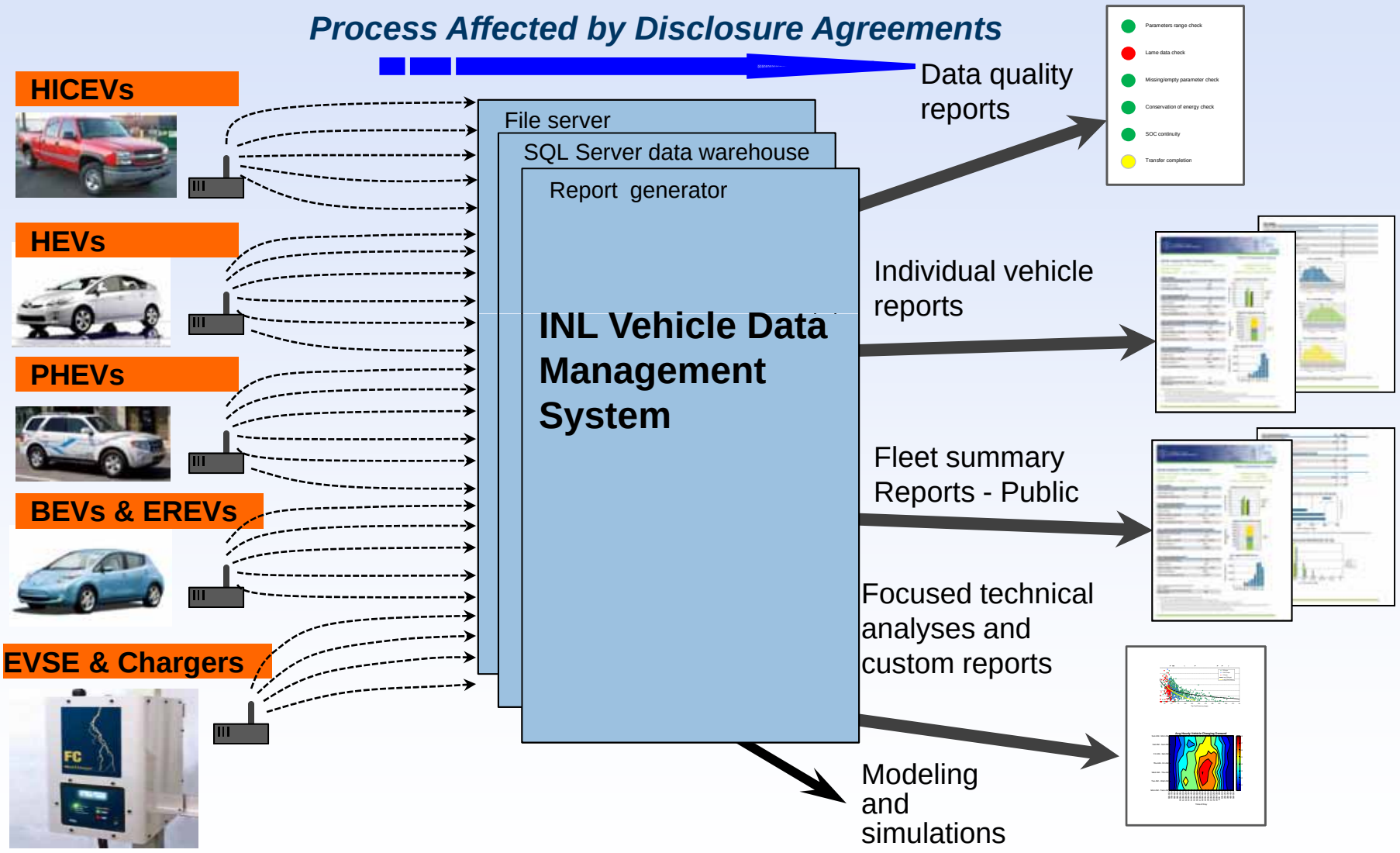
AVTA Participants and Goals

- **Participants**
  - **The Advanced Vehicle Testing Activity (AVTA) is part of DOE's Vehicle Technologies Program (EERE). The AVTA also supports Clean Cities activities**
  - **The Idaho National Laboratory (INL) conducts the light-duty vehicle portion of the AVTA per DOE guidance**
  - **100+ fleets and organizations as testing partners**
  - **Some of these testing activities are conducted with ECOtality North American**
- **The AVTA goal - Petroleum reduction and energy security**
  - **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 vehicle and infrastructure purchase, deployment and operating decisions**

Vehicle Testing Experience

- **Plug-in hybrid electric vehicles: 14 models, 430 PHEVs, 5 million test miles**
- **Extended Range Electric Vehicles: 1 model, 150 EREVs, 400,000 test miles**
- **Hybrid electric vehicles: 19 models, 50 HEVs, 6 million test miles**
- **Micro hybrid vehicles: 3 models, 7 MHVs, 200,000 test miles**
- **Neighborhood electric vehicles: 24 models, 372 NEVs, 200,000 test miles**
- **Battery electric vehicles: 47 models, 1,600 BEVs, 5 million test miles**
- **Urban electric vehicles: 3 models, 460 UEVs, 1 million test miles**
- **18 million test miles accumulated on 2,700 electric drive vehicles representing 110 models**

INL Vehicle Data Management Process



Example: Vehicle/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

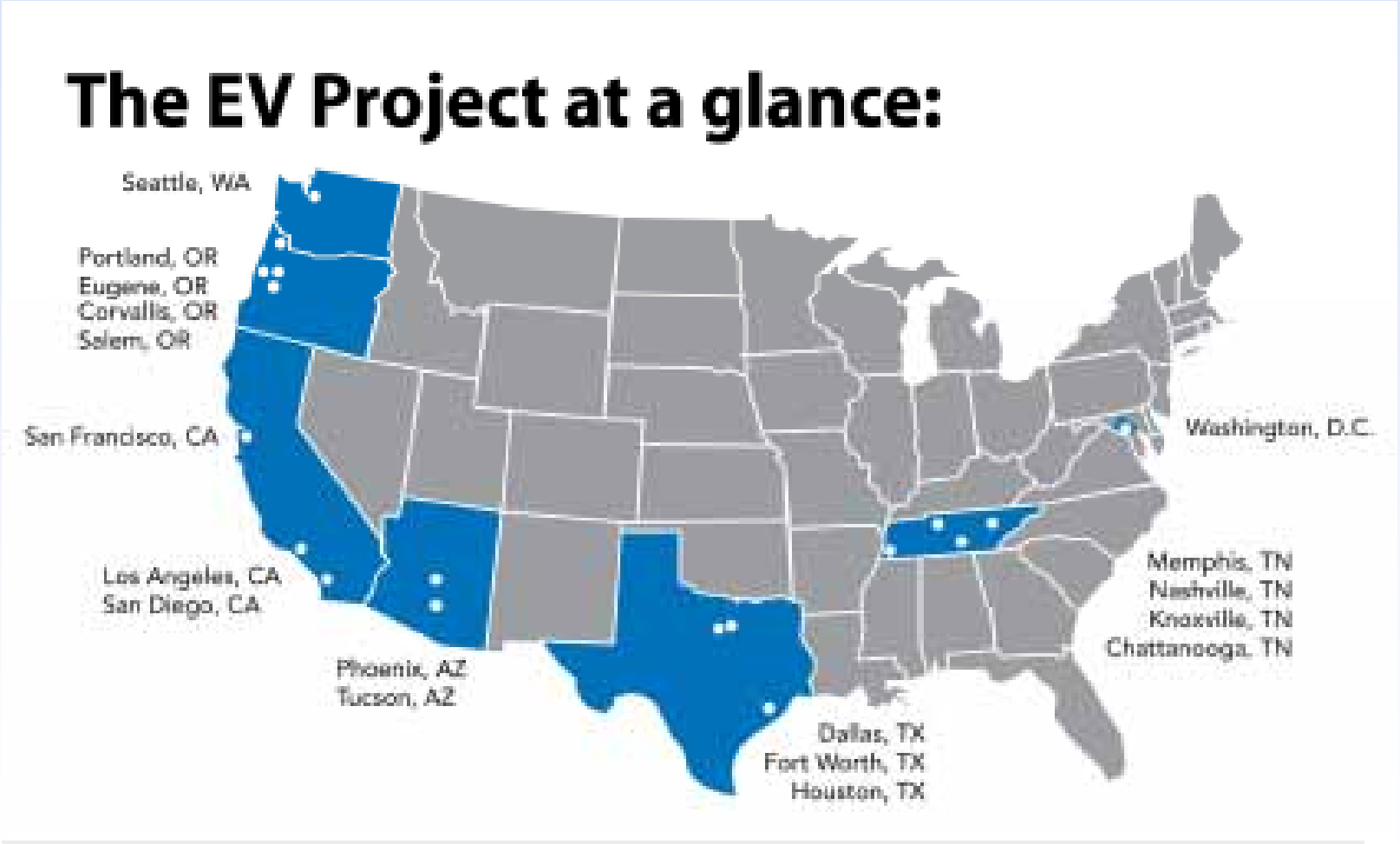
Data Collection: Harder Than You'd Think…..

- **Field data collection and processing is deceivingly complex due to remoteness, and the many technical, environmental and human variables**
  - **60 mpg PHEV in charge depleting mode and 130 mpg in charge sustaining mode - 6,000 foot mountain**
  - **60 hour trips - So quiet, does it shut itself off?**
  - **<-10 to >140ºF ambient conditions**
  - **Firmware, software and component upgrades**
  - **GPS and the advanced metal bucket technology**
  - **Is a Key-On event for rolling up a window or moving a vehicle ten feet considered a trip event?**
    - **53-foot rule = 40% trip reduction result and 0.1% impact**

Data Security and Protection

- **All raw vehicle and EVSE data, and personal information protected by NDAs (Non Disclosure Agreements) or a CRADAs (Cooperative Research And Development Agreements), resulting in:**
  - **Limitations on how the proprietary data can be distributed, stored, and used**
  - **No raw data can or will be distributed by INL**
  - **Raw data, in both electronic and printed formats, cannot be shared with DOE in order to avoid exposure to FOIA**
- **Vehicle and EVSE data collection would not occur unless the above limitations are strictly adhered by INL**
- **INL can bin data results into usable information formats for analysis in research partnerships (electric utilities and DOE labs?)**
- **No raw data can be shared by INL**

EV Project Locations (Largest Data Collection Activity)



EV Project Residential Infrastructure

- **Deploy 8,300 battery electric vehicles with data loggers**
  - **5,700 Nissan Leaf battery EVs**
  - **2,600 Chevrolet Volt extended range EVs**
- **Install 8,300 level 2 residential EVSE with data loggers**

EV Project Commercial Infrastructure

- **Install ~5,300 level 2 EVSE with data loggers**
  - **Retail locations**
  - **Municipal locations**
  - **Employer locations**
- **Deploy 200 Dual Port DC Fast Chargers with data loggers**

EV Project – Eleven Infrastructure Data Parameters Collected per Charge Event

- Date/Time Stamp
- Unique ID for Charging Event
- Unique ID Identifying the EVSE – may not change
- Connect and Disconnect Times
- Start and End Charge Times
- Maximum 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 – Seven Vehicle Data Parameters Collected per Start/Stop Event

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

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EV Project Nissan Leaf Vehicle Summary Report

THE EV Project

Region: All

Number of vehicles: 35

Reporting period: January 2011 through March 2011

Vehicle Usage

Number of trips	3,364
Total distance traveled (mi)	21,706
Avg trip distance (mi)	5.8
Avg distance traveled per day when the vehicle was driven (mi)	32.5
Avg number of trips between charging events	3.3
Avg distance traveled between charging events (mi)	21.5
Avg number of charging events per day when the vehicle was driven	1.5

Charging Location and Type

	Home charging location	Away-from-home charging locations		
	AC level 2 charging	AC level 2 charging	DC fast charging	Non-EV Project charging[1]
Total number of charging events	800	0	0	208
Percent of all charging events	79%	0%	0%	21%
Total time plugged-in (hr)	8,126	0	0	–
Percent of all time plugged-in at EV Project charging units	100%	0%	0%	–
Total electricity consumed (AC MWh)	5.25	0	0	–
Percent of all electricity consumed from EV Project charging units	100%	0%	0%	–

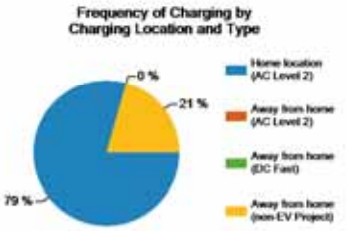
Charging Completeness

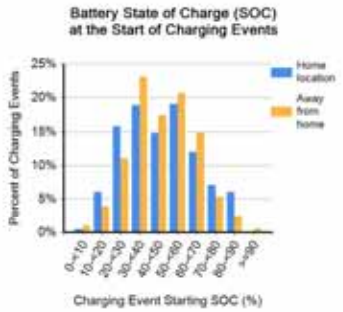
	Home charging location	Away-from-home charging locations		
	AC level 2 charging	AC level 2 charging	DC fast charging	Non-EV Project charging[1]
Number of complete charging events[2]	199	0	0	54
Percent of charging events of the same type and location	43%	0%	0%	26%
Number of partial charging events[3]	268	0	0	154
Percent of charging events of the same type and location	57%	0%	0%	74%

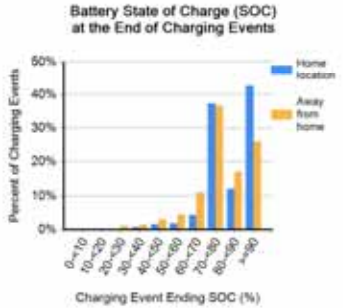
[1] Charging level, time plugged-in, and electricity consumed are not available from Non-EV Project charging units. Charging level could be AC level 1, AC level 2, or DC fast charging.

[2] Complete charging events end with battery state of charge at 90% to 100% (for charging events with SOC reported)

[3] Partial charging events end with battery state of charge below 90% (for charging events with SOC reported)







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EV Project – Nissan Leaf Usage Report

- **Overall project profiles**

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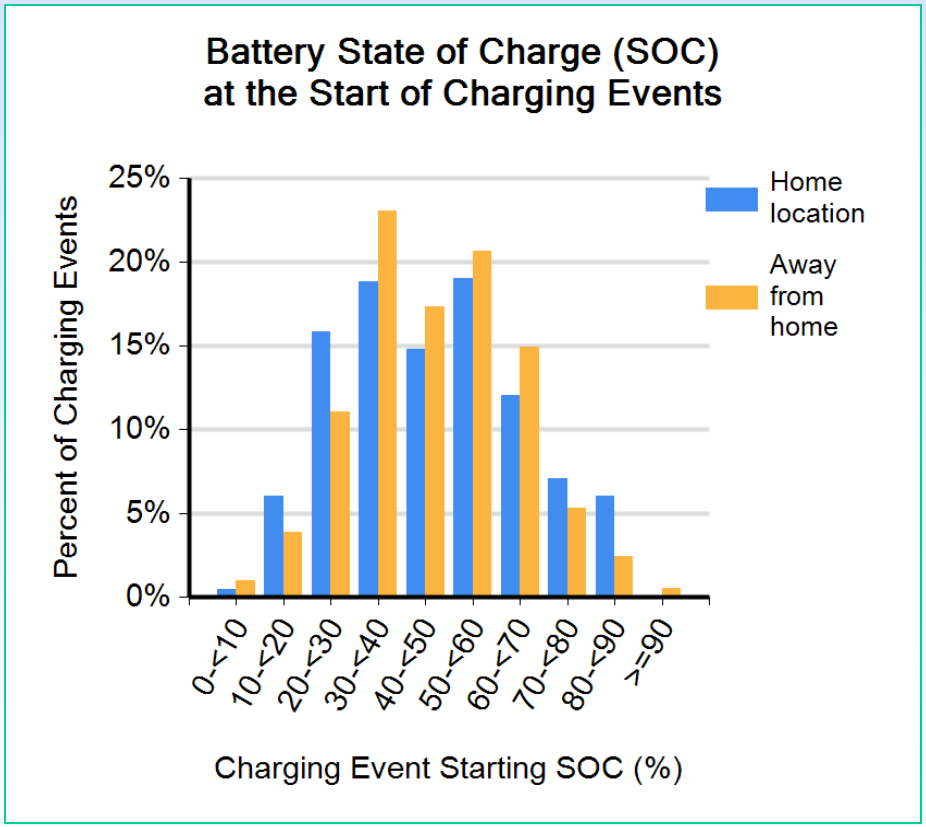
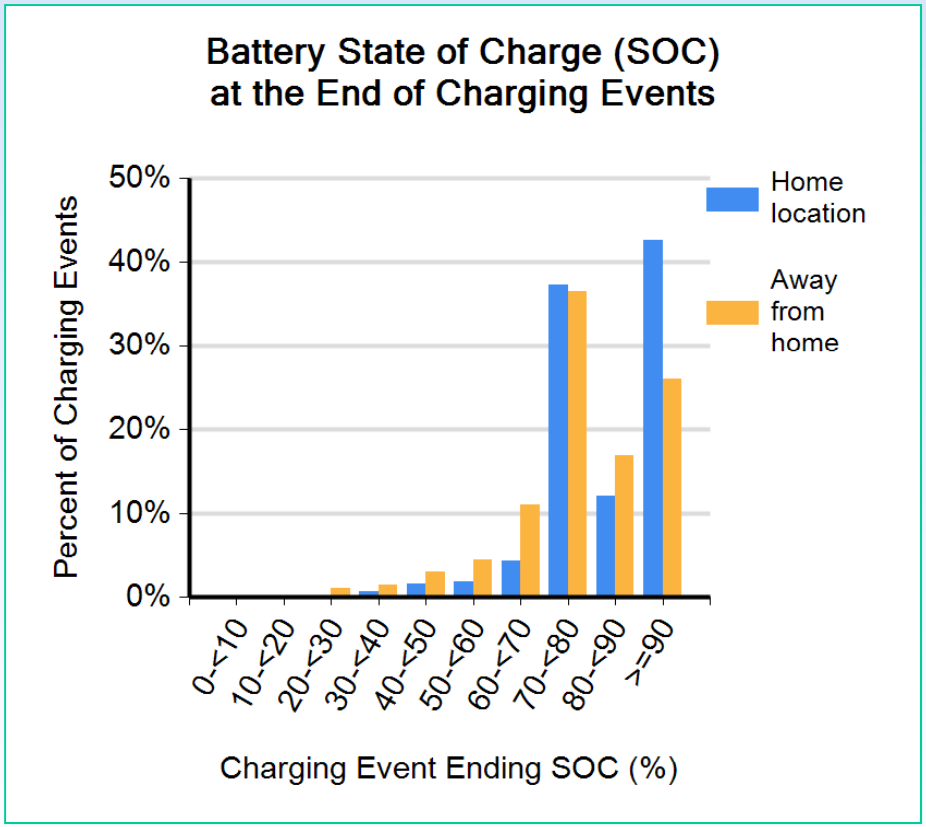
EV Project – Nissan Leaf Usage Report

- **Vehicle Usage – 1st quarter 2011**
  - **Number of Trips** — **3,364**
  - **Total distance traveled (miles)** — **21,706 mi**
  - **Ave trip distance** — **5.8 mi**
  - **Ave distance per day when driven** — **32.5 mi**
  - **Ave # trips between charging events** — **3.3**
  - **Ave distance traveled between charging events** — **21.5 mi**
  - **Ave # charging events per day when a vehicle was driven** — **1.5**
  - **Petroleum used** — **0 gallons**

- **This report requires matching Leaf and charging data**

EV Project – Nissan Leaf Usage – cont'd





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EV Project Overview Report

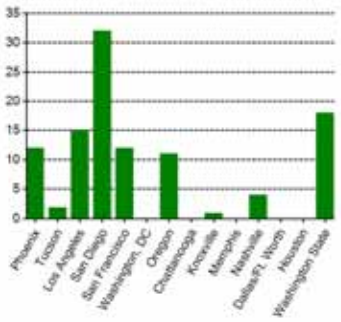
Project to Date through March 2011

THE EV Project

Charging Infrastructure

Region[1]	Number of EV Project Charging Units Installed To Date	Number of Charging Events Performed	Electricity Consumed (AC MWh)
Phoenix, AZ Metropolitan Area	12	143	0.74
Tucson, AZ Metropolitan Area	2	40	0.28
Los Angeles, CA Metropolitan Area	15	249	1.61
San Diego, CA Metropolitan Area	32	483	3.23
San Francisco, CA Metropolitan Area	12	85	0.55
Washington, D.C. Metropolitan Area	0	0	0.00
Oregon	11	210	1.28
Chattanooga, TN Metropolitan Area	0	0	0.00
Knoxville, TN Metropolitan Area	1		
Memphis, TN Metropolitan Area	0	0	0.00
Nashville, TN Metropolitan Area	4	44	0.36
Dallas/Ft. Worth, TX Metropolitan Area	0	0	0.00
Houston, TX Metropolitan Area	0	0	0.00
Washington State	18	322	2.02
Total	107	1,582	10.13

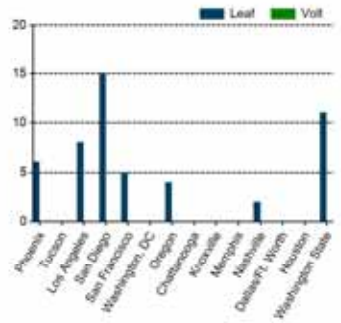
Charging Unit Installation to Date by Region



Vehicles

Region[1]	EV Project Nissan Leafs Enrolled to Date[2]	EV Project Chevrolet Volts Enrolled to Date[3]	Number of Trips	Distance Driven (mi)
Phoenix, AZ Metropolitan Area	6	—	929	5,689
Tucson, AZ Metropolitan Area	0	—	0	0
Los Angeles, CA Metropolitan Area	8	0	656	6,018
San Diego, CA Metropolitan Area	15	0	2,095	15,349
San Francisco, CA Metropolitan Area	5	—	246	2,702
Washington, D.C. Metropolitan Area	—	0	0	0
Oregon	4	—	662	3,368
Chattanooga, TN Metropolitan Area	0	—	0	0
Knoxville, TN Metropolitan Area	0	—	0	0
Memphis, TN Metropolitan Area	0	—	0	0
Nashville, TN Metropolitan Area	2	—	238	1,813
Dallas/Ft. Worth, TX Metropolitan Area	—	0	0	0
Houston, TX Metropolitan Area	—	0	0	0
Washington State	11	—	1,517	9,528
Total	51	0	6,343	44,467

Vehicle Enrollment to Date By Region



Note: EV Project charging units may be used by vehicles that are not part of the EV Project. Likewise, EV Project vehicles may connect to non-EV Project charging units. Therefore vehicle and charging infrastructure usage shown on this report are not directly comparable.

[1] Regions: Oregon region includes the Greater Corvallis, Eugene, Portland, and Salem Metropolitan Areas
Washington region includes the Greater Seattle and Olympia Metropolitan Areas

[2] Vehicle enrollment numbers refer to the EV Project only. Numbers do not reflect total regional or national vehicles sales or production.

[3] Enrollment of EV Project Chevrolet Volts is expected to begin in the second quarter of 2011.

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EV Project – Overview Report

- **Vehicles and charging infrastructure deployed**
- **Charging infrastructure**
  - **# units installed**
  - **# charging events**
  - **AC MWh consumed**
- **Vehicles**
  - **# enrolled**
  - **# trips**
  - **Distance driven**
- **Results provided by EV Project region**

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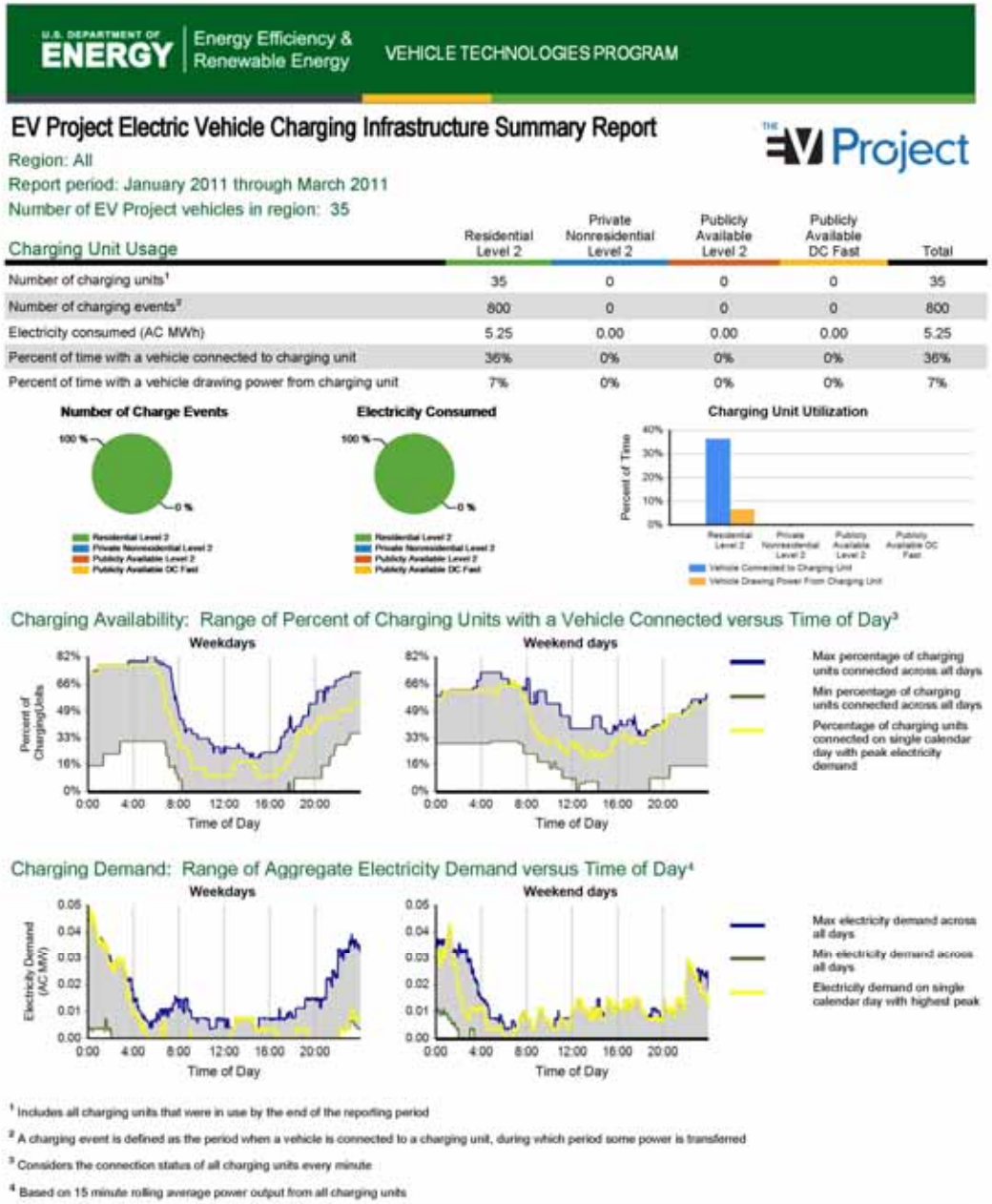

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EV Project Electric Vehicle Charging Infrastructure Summary Report

The EV Project

Region: All
Report period: January 2011 through March 2011
Number of EV Project vehicles in region: 35

Charging Unit Usage	Residential Level 2	Private Nonresidential Level 2	Publicly Available Level 2	Publicly Available DC Fast	Total
Number of charging units[1]	35	0	0	0	35
Number of charging events[2]	800	0	0	0	800
Electricity consumed (AC MWh)	5.25	0.00	0.00	0.00	5.25
Percent of time with a vehicle connected to charging unit	36%	0%	0%	0%	36%
Percent of time with a vehicle drawing power from charging unit	7%	0%	0%	0%	7%

Charging Availability: Range of Percent of Charging Units with a Vehicle Connected versus Time of Day[3]

Charging Demand: Range of Aggregate Electricity Demand versus Time of Day[4]

[1] Includes all charging units that were in use by the end of the reporting period

[2] A charging event is defined as the period when a vehicle is connected to a charging unit, during which period some power is transferred

[3] Considers the connection status of all charging units every minute

[4] Based on 15 minute rolling average power output from all charging units

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EV Project – EV Charging Infrastructure Summary Report

- **Charging unit usage**
- **Percent charging units with a vehicle connected by time of day**
- **Range of aggregate electricity demand versus time of day**

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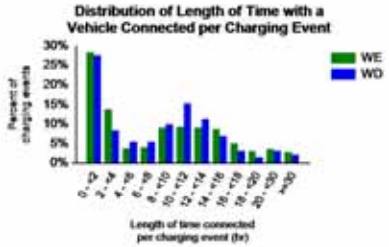
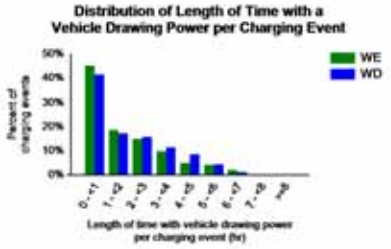
Residential Level 2 Electric Vehicle Supply Equipment (EVSE)

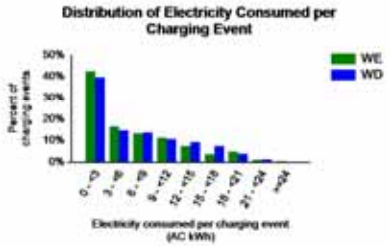
EVSE Usage	Weekday	Weekend	Overall
Number of charging events	593	207	800
Electricity consumed (AC MWh)	4.01	1.24	5.25
Percent of time with a vehicle connected to EVSE	36%	38%	36%
Percent of time with a vehicle drawing power from EVSE	7%	7%	7%
Average number of charging events started per EVSE per day	0.9	0.8	0.9
Average number of distinct vehicles charged per EVSE per day (EV Project vehicles only)	1.0	1.0	1.0

Vehicles Charged	Nissan Leaf	Chevrolet Volt	Non-EV Project vehicles
Percent of charging events	100%	0%	0%
Percent of electricity consumed	100%	0%	0%

Individual Charging Event Statistics	Weekday (WD)	Weekend (WE)	Overall
Average length of time with vehicle connected per charging event (hr)	9.8	11.1	10.2
Average length of time with vehicle drawing power per charging event (hr)	1.9	1.8	1.9
Average electricity consumed per charging event (AC kWh)	6.8	6.0	6.6







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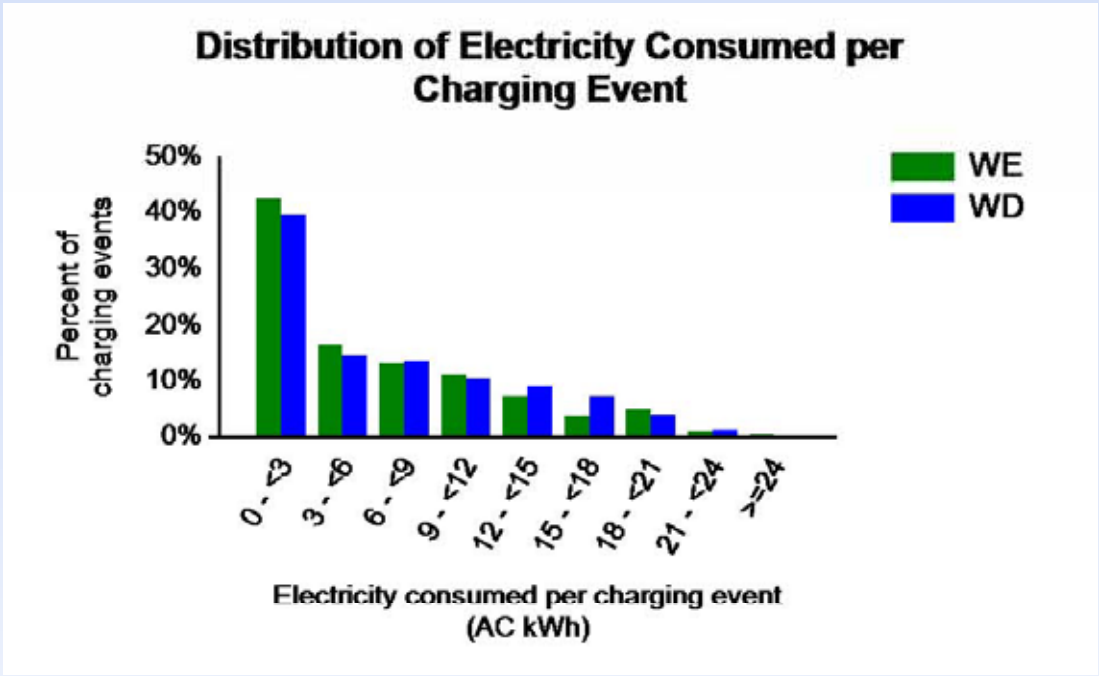
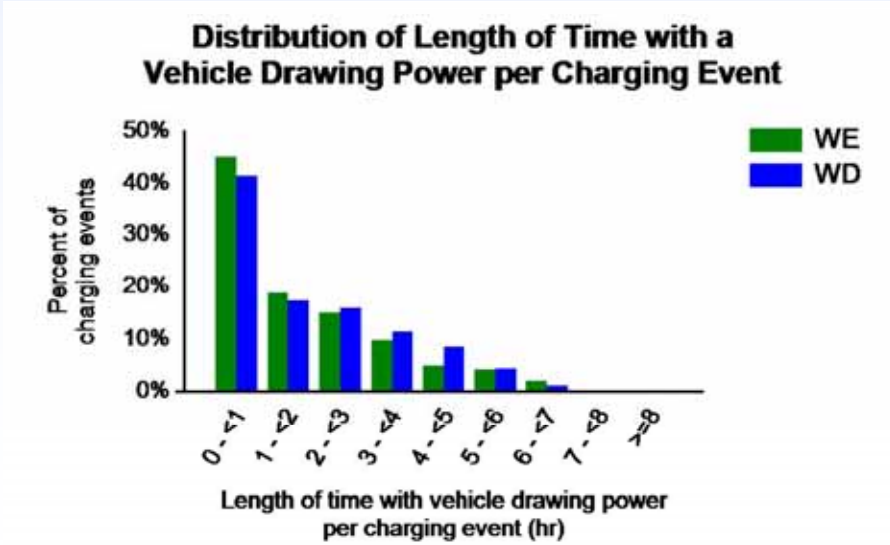
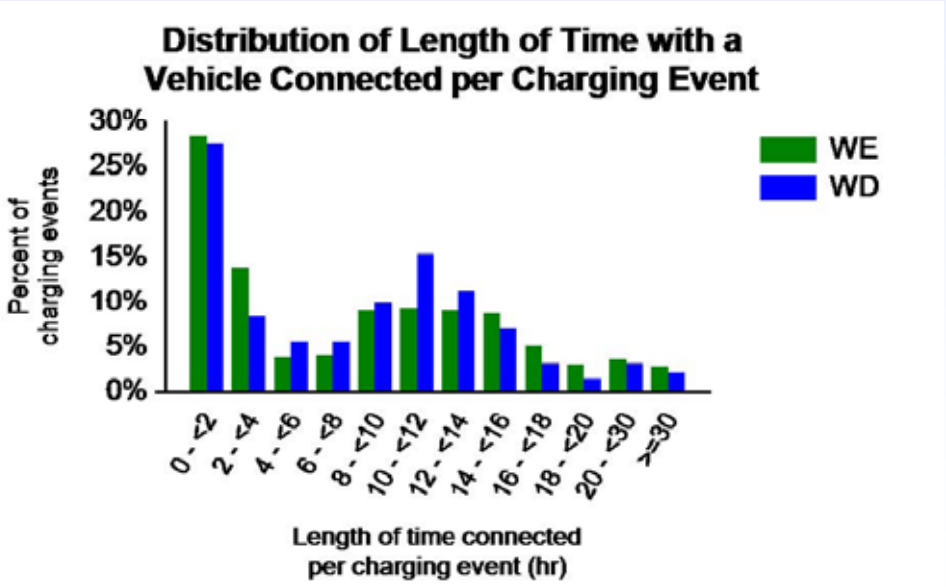
EV Project – EV Charging Infrastructure Summary Report – cont'd

- **Detailed charging event breakdowns**
- **Graphs on next page**
- **Data shown for residential Level 2 EVSE**

EV Project – EV Charging Infrastructure Summary Report – cont'd







EV Project – Number of Units

1st Quarter 2011 Report Leaf and EVSE Units with Data	
Number of Leafs	50
Number of Blink EVSE	107
Total number of units providing data	157

June 27, 2011 Leaf and EVSE Units with Data	
Number of Leafs	1,010
Number of Blink EVSE (2 commercial)	1,023
Total number of units providing data	2,033

1,398 Leaf VINs & 1,966 Blink ID's (7 commercial) received to date (3,364 total)

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Ford Escape Advanced Research Fleet

Number of vehicles: 21 | Date range of data received: 11/01/2009 to 04/30/2011
Reporting period: Nov 09 - Apr 11 | Number of vehicle days driven: 5,425

All Trips Combined

Overall gasoline fuel economy (mpg)	38
Overall AC electrical energy consumption (AC Wh/mi)[1]	101
Overall DC electrical energy consumption (DC Wh/mi)[2]	66
Total number of trips	23,548
Total distance traveled (mi)	299,960

Trips in Charge Depleting (CD) mode[3]

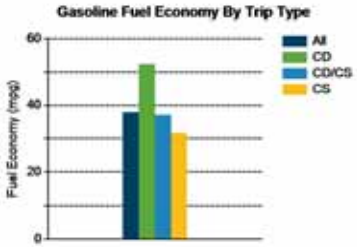
Gasoline fuel economy (mpg)	52
DC electrical energy consumption (DC Wh/mi)[4]	170
Number of trips	13,205
Percent of trips city | highway	84% | 16%
Distance traveled (mi)	75,997
Percent of total distance traveled	25%

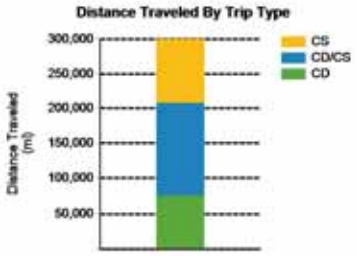
Trips in both Charge Depleting & Charge Sustaining (CD/CS) modes[5]

Gasoline fuel economy (mpg)	37
DC electrical energy consumption (DC Wh/mi)[6]	55
Number of trips	4,506
Percent of trips city | highway	38% | 62%
Distance traveled (mi)	131,484
Percent of total distance traveled	44%

Trips in Charge Sustaining (CS) mode[7]

Gasoline fuel economy (mpg)	32
Number of trips	5,831
Percent of trips city | highway	65% | 35%
Distance traveled (mi)	92,478
Percent of total distance traveled	31%





Notes: 1 - 7. Please see http://avt.inl.gov/pdf/phev/fordreportnotes.pdf for an explanation of all PHEV Fleet Testing Report notes.

Since these vehicles are flex-fuel capable, some driving events are conducted with E-85, which may decrease fuel economy results

"The Ford Escape Advanced Research Fleet was designed as a demonstration of customer duty cycles related to plug-in electric vehicles. The vehicles used in this demonstration have not been optimized to provide the maximum potential fuel economy."

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Ford Escape PHEV 3-Page Report

- 21 Ford Escape PHEVs
- 300,000 test miles and 24,000 trips
- All trips, 38 mpg, 101 AC Wh/mi & 66 DC Wh/mi
- Charge Depleting (CD), 52 mpg & 170 DC Wh/mi
- Charge Sustaining (CS), 32 mpg
- **Plugging in = 63% increase in overall MPG when comparing CD to CS trips**
- **56% of miles in CD trips**
- **25% of miles in CS trips**

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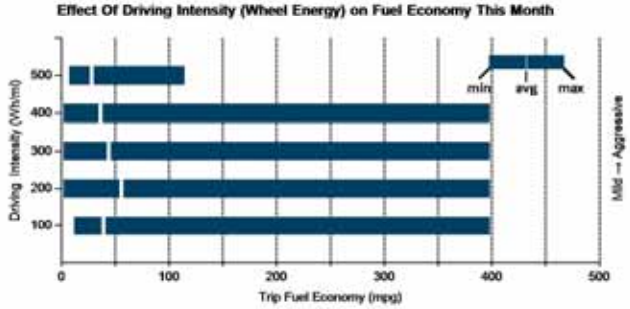
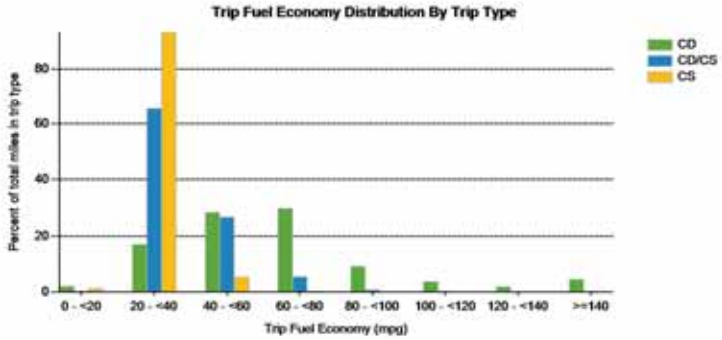
Trips in Charge Depleting (CD) mode	City	Highway
Gasoline fuel economy (mpg)	48	57
DC electrical energy consumption (DC Wh/mi)	171	169
Percent of miles with internal combustion engine off	37%	13%
Average trip driving intensity (Wh/mi)	265	305
Average trip distance (mi)	3	17

Trips in Charge Depleting and Charge Sustaining (CD/CS) mode		
Gasoline fuel economy (mpg)	43	36
DC electrical energy consumption (DC Wh/mi)	79	52
Percent of miles with internal combustion engine off	30%	5%
Average trip driving intensity (Wh/mi)	277	325
Average trip distance (mi)	9	41

Trips in Charge Sustaining (CS) mode		
Gasoline fuel economy (mpg)	30	32
Percent of miles with internal combustion engine off	23%	4%
Average trip driving intensity (Wh/mi)	266	321
Average trip distance (mi)	4	38





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Ford Escape PHEV 3-Page Report

- Highway and city cycle impacts
- CD city, 48 mpg, 171 DC Wh/mi
- CD highway, 57 mpg, 169 DC Wh/mi
- CS city, 30 mpg
- CS highway, 32 mpg
- Plugging in = 60% increase in city MPG and 78% increase in highway MPG (compare CD to CS)
- During CD trips, 50% of miles with engine off
- During CS trips, 27% of miles with engine off

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North American PHEV Demonstration

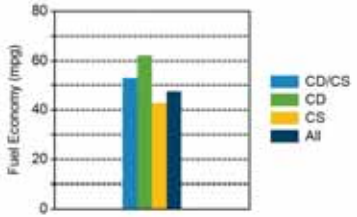
Vehicle Technologies Program

Fleet Summary Report: Hymotion Prius (V2Green data logger)
Number of vehicles: 184
Reporting Period: Apr 08 - May 11

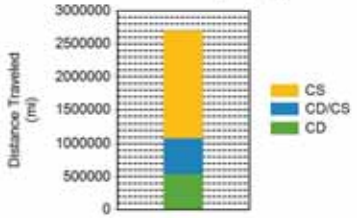
Date range of data received: 4/18/2008 to 5/31/2011
Number of days the vehicles were driven: 1132

All Trips Combined	
Overall gasoline fuel economy (mpg)	47
Overall AC electrical energy consumption (AC Wh/mi) [1]	53
Overall DC electrical energy consumption (DC Wh/mi) [2]	38
Total number of trips	287,310
Total distance traveled (mi)	2,691,319
Trips in Charge Depleting (CD) mode [3]	
Gasoline fuel economy (mpg)	62
DC electrical energy consumption (DC Wh/mi) [4]	142
Number of trips	116,236
Percent of trips city / highway	87% / 13%
Distance traveled (mi)	534,289
Percent of total distance traveled	20%
Trips in both Charge Depleting and Charge Sustaining (CD/CS) modes [5]	
Gasoline fuel economy (mpg)	53
DC electrical energy consumption (DC Wh/mi) [6]	49
Number of trips	20,745
Percent of trips city / highway	47% / 53%
Distance traveled (mi)	541,395
Percent of total distance traveled	20%
Trips in Charge Sustaining (CS) mode [7]	
Gasoline fuel economy (mpg)	43
Number of trips	150,320
Percent of trips city / highway	77% / 23%
Distance traveled (mi)	1,619,064
Percent of total distance traveled	60%
Number of trips when the plug-in battery pack was turned off by the vehicle operator [8]	12479
Distance traveled with plug-in battery pack turned off by the vehicle operator (mi) [9]	274,064

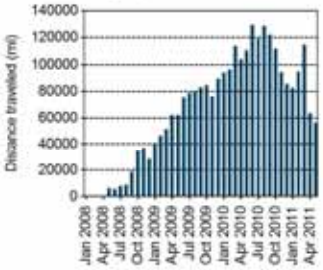
Gasoline Fuel Economy By Trip Type



Distance Traveled By Trip Type



Miles Logged by Month This Year



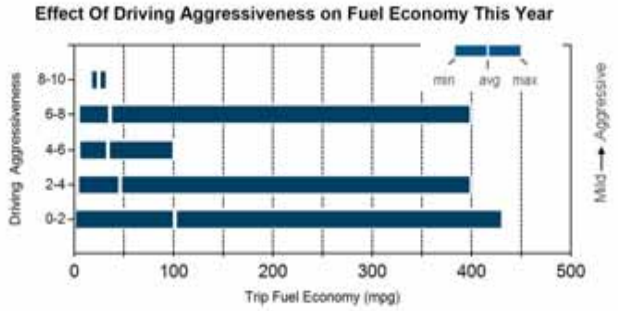
Notes: 1 - 9. Please see http://avt.inl.gov/pdf/phev/ReportNotes.pdf for an explanation of all PHEV Fleet Testing Report notes.

MonthlyReportAll Hymotion Prius (V2Green data logger) 1 6/13/2011 1:43:39 PM

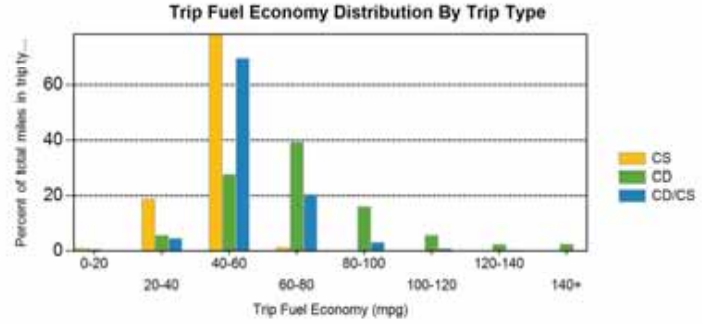
Hymotion Prius PHEV Conversion

- CD 62 mpg and 142 DC Wh/mi
- CS 43 mpg
- Plugging in = 44% increase in overall MPG when comparing CD to CS trips
- Only 20% miles in CD trips
- 60% miles in CS trips

Trips in Charge Depleting (CD) mode	City	Highway
Gasoline fuel economy (mpg)	60	66
DC electrical energy consumption (DC Wh/mi)	165	109
Percent of miles with internal combustion engine off	32%	15%
Average trip aggressiveness (on scale 0 - 10)	1.8	1.8
Average trip distance (mi)	3.0	15.1
Trips in both Charge Depleting and Charge Sustaining (CD/CS) modes		
Gasoline fuel economy (mpg)	53	53
DC electrical energy consumption (DC Wh/mi)	79	44
Percent of miles with internal combustion engine off	26%	9%
Average trip aggressiveness (on scale 0 - 10)	1.9	1.6
Average trip distance (mi)	8.7	41.5
Trips in Charge Sustaining (CS) mode		
Gasoline fuel economy (mpg)	36	46
Percent of miles with internal combustion engine off	22%	8%
Average trip aggressiveness (on scale 0 - 10)	2.0	1.7
Average trip distance (mi)	3.5	35.3



Aggressiveness factor is based on accelerator pedal position. The more time spent during a trip at higher accelerator pedal position, the higher the trip aggressiveness.



Hymotion Prius PHEV Conversion

- CD city, 60 mpg, 165 DC Wh/mi
- CD highway, 66 mpg, 109 DC Wh/mi
- CS city, 36 mpg
- CS highway, 46 mpg
- Plugging in = 67% increase in city MPG and 44% increase in highway MPG when comparing CD to CS trips
- CD trips 37% miles with engine off
- CS trips 30% miles with engine off

Other INL Data Collection Projects

- **140 Ram PHEV pickups – same report format as Ford Escape PHEVs (August reporting)**
- **20 Lithium PHEV Escape Quantum conversions (SCAQMD) – same format as above (August reporting)**
- **150 Chevy Volts data collection (July reporting)**
- **Federal fleet vehicle use profiles (~600 vehicles with data loggers and DOD Micro Climate studies)**
- **Development of vehicle-based battery test-bed mule for testing emerging battery technologies**
- **Developing wireless charging demo and testing program**
- **Five USPS electric long life vehicles (ELLV) conversions track, dynamometer, and fleet testing (with data loggers)**

Other INL Data Collection Projects – cont'd

- **Nissan Leaf fast charge study**
  - **Comparison of Fast versus Level 2 charging impacts on battery life in fleets and laboratory**
- **Coulomb EVSE data collection will be same parameters as the EV Project, but no vehicle data will be collected. Coulomb reports 525 EVSE installed to date**
- **Developing other EVSE data collection activities that also support Clean Cities funded demonstrations with:**
  - **Aerovironment**
  - **Eaton**
  - **Shorepower**

Lessons Learned

- Electric drive vehicles can provide significant vehicle-based petroleum-use reductions
  - BEVs = 100% vehicle-based petroleum reduction
  - PHEVs demonstrated mpg improvements up to 78% in some operating cycles when comparing CD to CS trips
- PHEV mpg improvements are highly dependant on
  - Missions (type [city vs. highway] and distance)
  - Operators charging or not charging the PHEVs (Duh!)
  - Ambient conditions
    - 178% increase in Hymotion Prius CD mpg at 20-30°C ambient conditions compared to <-20°C (engine off 26% of time versus engine never off)
    - 35% improvement in Ford Escape PHEV CD mpg during May 2011 versus December 2010 operations (temperature extremes not nearly as high as Hymotion Prius)

Lessons Learned – cont'd

- Th!nk cities demonstration project
  - 76% of private households driving Ford Th!nk cities had two to five, or more other household vehicles
  - 86% of households driving cities had household income greater than $100,000 (2004 dollars)
  - Most Th!nks were charged only using public infrastructure "free electricity" at train stations during weekday commutes (presenter memory)

- Ongoing INL/DOE data collection activities will provide 100 million miles of vehicle operations and charger use
  - Private versus public charging?
  - Level 2 versus fast charging?
  - Demonstrate different revenue models?
  - Important to wait for data results before drawing conclusions!!!

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More Information

http://avt.inl.gov

If interested in participating in the Federal fleet vehicle mission profile study, please contact: mindy.kirkpatrick@inl.gov

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