Plug-in 2011: Initial PEV and Charging Infrastructure Test Results

Jim Francfort

Idaho National Laboratory

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Presentation Outline

- INL and AVTA (DOE) Participants and Goals
- Vehicle Testing Experience
- INL data handling experiences and methods
- EV Project what is it about
- EV Project data collection parameters
- EV Project results to date
- Ford PHEV data collection results to date
- Other data collection activities
AVTA Participants and Goals

• Participants
  – The Advanced Vehicle Testing Activity (AVTA) is part of DOE’s Vehicle Technologies Program (EERE)
  – The Idaho National Laboratory (INL) conducts the AVTA per DOE guidance
  – 100+ fleets and organizations as testing partners
  – Some of these ATVA vehicle 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, and target and goal setters
  – Assist fleet managers in making informed vehicle and infrastructure purchase, deployment and operating decisions via groups such as Clean Cities
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, 370 NEVs, 200,000 test miles
- Battery electric vehicles: 47 models, 1,900 BEVs, 5 million test miles (includes 500+ USPS BEVs)
- Urban electric vehicles: 3 models, 460 UEVs, 1 million test miles
- 18 million test miles accumulated on 2,900 electric drive vehicles representing 110 models
Vehicle/EVSE Data Management Process

- Process Affected by Disclosure Agreements

- Data quality reports

- INL Vehicle Data Management System

- Individual vehicle reports

- Fleet summary Reports - Public

- Focused technical analyses and custom reports

- Modeling and simulations

- HICEVs
- HEVs
- PHEVs
- BEVs & EREVs
- EVSE & Chargers
## 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)

Protected Data

Vehicle and Charger Data

Access restricted by firewall rules

EV Project FTPS/SFTP Server

INL pulls with encrypted transmission

OEM Data Management Systems

OEM pushes using FTPS/SFTP

INL transmits reports to DOE and OEMs

INL Protect Enclave - EV Project member access only

INL Internal firewall

INL DMZ Firewall – Public has access to AVT.INL.GOV

OEM Data Management Systems

Fleet summary reports - public

INL Data Management System

INL Pulls with encrypted transmission

Protected Data

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INL Internal firewall

INL DMZ Firewall – Public has access to AVT.INL.GOV
INL Data Management System - Pull (ECOtality, Ford, conversion PHEVs, HEVs, HICEs)

Protected Data

- Vehicle and Charger Data
- Protected Data
- EV Project Team
- Parameters range check
- Lame data check
- Missing/empty parameter check
- Conservation of energy check
- SOC continuity
- Transfer completion
- Internal data quality reports

INL pulls with encrypted transmission

INL pulls with encrypted transmission

INL Protect Enclave - EV Project member access only

INL Internal firewall

INL DMZ Firewall – Public has access to AVT.INL.GOV

Reports posted on WWW

INL transmits reports to DOE And OEMs

Fleet summary reports - public

AVT.INL.GOV

OEM Data Management Systems

INL  Internal firewall

INL DMZ Firewall – Public has access to AVT.INL.GOV
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 (CD) mode and 130 mpg in charge sustaining (CS) mode - 6,000 foot mountain
  - 60 hour trip - So quiet, does it shut itself off?
  - < -10 to > 140 degrees F
  - 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% 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 CRADA (Cooperative Research And Development Agreement), 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 (both electronic and printed) 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)

The EV Project at a glance:

Seattle, WA
Portland, OR
Eugene, OR
Corvallis, OR
Salem, OR
San Francisco, CA
Los Angeles, CA
San Diego, CA
Phoenix, AZ
Tucson, AZ
Dallas, TX
Fort Worth, TX
Houston, TX
Memphis, TN
Nashville, TN
Knoxville, TN
Chattanooga, TN
Washington, D.C.
EV Project Residential Infrastructure

- Deploy 8,300 battery electric vehicles
  - 5,700 Nissan Leaf battery EVs
  - 2,600 Chevrolet Volt extended range EVs
- Install 8,300 level 2 residential EVSE
EV Project Commercial Infrastructure

- Install ~5,300 level 2 EVSE
  - Retail locations
  - Municipal locations
  - Employer locations
- Deploy 200 Dual Port DC Fast Chargers
EV Project Data Collection & Reporting

Vehicle Data
- EV & EREV
  - Nissan GDC
  - GM OnStar

EVSE Data
- EVSE
  - ECOtality Data Center

INL MATCH INL
- EV Project Participant
- Non EV Project EVSE
- EV Project Participant
- Non EV Project Participant
- EV Project EVSE
- EV Project EVSE
• Document electric drive vehicle technology’s ability to reduce petroleum use by collecting data on:
  – Vehicle performance
  – Operational profiles and ambient conditions
  – Charging profiles
• Document fueling infrastructure technology, including:
  – Sitting
  – Use
  – Time-of-day pricing
  – Charging level (I, II, fast charging) utilization
  – Public vs. private charging
  – At-home vs public charging
  – Micro versus macro grid issues / impacts
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
EV Project – Nissan Leaf Usage Report

- 3 EV Project report types produced to date
- All available via the AVTA www site
- See next slides for details
- Initially, all reports produced quarterly
EV Project – Nissan Leaf Usage Report - cont’d

• 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

• This report requires matching 35 Leafs and EVSE data
### Charging Location and Type

<table>
<thead>
<tr>
<th>Level 2 Home Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total number of charging events</td>
</tr>
<tr>
<td>Total time plugged in</td>
</tr>
<tr>
<td>Total electricity consumed</td>
</tr>
</tbody>
</table>

### Charging Completeness

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of complete charging events (SOC reported)</td>
<td>199</td>
</tr>
<tr>
<td>Number of partial charging events (SOC reported)</td>
<td>268</td>
</tr>
</tbody>
</table>

- **This report will also include Away-from-home charging locations:** EV Project Level 2 and DC fast charging as well as non-EV Project charging
Battery State of Charge (SOC) at the Start of Charging Events

- Home location
- Away from home

Battery State of Charge (SOC) at the End of Charging Events

- Home location
- Away from home
EV Project – Overview Report

- Status report
- Charging infrastructure
  - # units installed
  - # charging events
  - AC MWh consumed
- Vehicles
  - # enrolled
  - # trips
  - Distance driven
- Results provided by EV Project region
### 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**
- **See next 2 slides**

#### Charging Unit Usage

<table>
<thead>
<tr>
<th>Charging Unit Usage</th>
<th>Residential Level 2</th>
<th>Private Nonresidential Level 2</th>
<th>Publicly Available Level 2</th>
<th>Publicly Available DC Fast</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of charging units</td>
<td>35</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>35</td>
</tr>
<tr>
<td>Number of charging events</td>
<td>800</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>800</td>
</tr>
<tr>
<td>Electricity consumed (AC MWh)</td>
<td>5.25</td>
<td>0.00</td>
<td>0.06</td>
<td>0.00</td>
<td>5.25</td>
</tr>
</tbody>
</table>

#### Percent of time with a vehicle connected to charging unit

- 36% for residential units
- 0% for private nonresidential units
- 0% for publicly available level 2 units
- 0% for publicly available DC fast units

#### Percent of time with a vehicle drawing power from charging unit

- 7% for residential units
- 0% for private nonresidential units
- 0% for publicly available level 2 units
- 0% for publicly available DC fast units

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*Includes all charging units that were in use by the end of the reporting period

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

*Consider the connection status of all charging units every minute

*Based on 15 minute rolling average power output from all charging units
EV Project - Charging Infrastructure Summary Report - cont’d

- Power demand range for any time during reporting quarter
- Yellow line is daily profile for the day with quarterly peak demand
- Both graphs in AC MW
- Based on 15 minute rolling average MW demand
EV Project - Charging Infrastructure Summary Report - cont’d

- Range of charging units with a vehicle connected (but not necessarily charging)
- Yellow line is for day with peak power demand
- Both graphs percent of charging units
Residential Level 2 Electric Vehicle Supply Equipment (EVSE)

EVSE Usage

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

Vehicles Charged

<table>
<thead>
<tr>
<th></th>
<th>Nissan Leaf</th>
<th>Chevrolet Volt</th>
<th>Non-EV Project vehicles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percent of charging events</td>
<td>100%</td>
<td>7%</td>
<td>0%</td>
</tr>
<tr>
<td>Percent of electricity consumed</td>
<td>100%</td>
<td>9%</td>
<td>0%</td>
</tr>
</tbody>
</table>

Individual Charging Event Statistics

<table>
<thead>
<tr>
<th></th>
<th>Weekday (WD)</th>
<th>Weekend (WE)</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average length of time with vehicle connected per charging event (hr)</td>
<td>9.8</td>
<td>11.1</td>
<td>10.2</td>
</tr>
<tr>
<td>Average length of time with vehicle drawing power per charging event (hr)</td>
<td>1.5</td>
<td>1.6</td>
<td>1.5</td>
</tr>
<tr>
<td>Average electricity consumed per charging event (AC kWh)</td>
<td>6.8</td>
<td>6.6</td>
<td>6.6</td>
</tr>
</tbody>
</table>

• To be produced for each “charger” type
• Detailed charging event breakdowns
• Graphs on next page
• Data shown for residential Level 2 EVSE
Distribution of Electricity Consumed per Charging Event

Distribution of Length of Time with a Vehicle Connected per Charging Event

Distribution of Length of Time with a Vehicle Drawing Power per Charging Event
# EV Project – Number of Units

## 1st Quarter 2011 Report Leaf and EVSE Units with Data

<table>
<thead>
<tr>
<th>Description</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Leafs</td>
<td>50</td>
</tr>
<tr>
<td>Number of Blink EVSE</td>
<td>107</td>
</tr>
<tr>
<td>Total number of units providing data</td>
<td>157</td>
</tr>
</tbody>
</table>

## June 27, 2011 Leaf and EVSE Units with Data

<table>
<thead>
<tr>
<th>Description</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Leafs</td>
<td>1,010</td>
</tr>
<tr>
<td>Number of Blink EVSE (2 commercial)</td>
<td>1,023</td>
</tr>
<tr>
<td>Total number of units providing data</td>
<td>2,033</td>
</tr>
</tbody>
</table>

1,398 Leaf VINs & 1,966 Blink ID’s (7 commercial) received to date (3,364 total)
Ford Escape Advanced Research Fleet

Number of vehicles: 21
Number of vehicle days driven: 5,731

All Trips Combined
- Overall gasoline fuel economy (mpg): 36
- Overall AC electrical energy consumption (AC Wh/mi)\(^1\): 100
- Overall DC electrical energy consumption (DC Wh/mi)\(^2\): 66
- Total number of trips: 26,077
- Total distance traveled (mi): 316,745

Trips in Charge Depleting (CD) mode\(^3\)
- Gasoline fuel economy (mpg): 53
- DC electrical energy consumption (DC Wh/mi)\(^4\): 170
- Number of trips: 14,033
- Percent of trips city / highway: 64% / 16%
- Distance traveled (mi): 80,286
- 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)\(^6\): 50
- Number of trips: 4,610
- Percent of trips city / highway: 30% / 62%
- Distance traveled (mi): 140,169
- Percent of total distance traveled: 46%

Trips in Charge Sustaining (CS) mode\(^7\)
- Gasoline fuel economy (mpg): 32
- Number of trips: 6,227
- Percent of trips city / highway: 65% / 35%
- Distance traveled (mi): 96,286
- Percent of total distance traveled: 31%

Notes: 1, 7. Please see http://lmi.illinois.edu/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.*

Ford Escape PHEV 3-Page Report

- 21 Ford Escape PHEVs
- 319,000 test miles and 25,000 trips
- All trips, 38 mpg, 100 AC Wh/mi & 66 DC Wh/mi
- Charge Depleting (CD), 53 mpg & 170 DC Wh/mi
- Charge Sustaining (CS), 32 mpg
- Plugging in = 66% increase in overall MPG when comparing CD to CS trips
- 25% of miles in CD trips
- 31% of miles in CS trips
- 44% of miles in CD/CS trips
### Ford Escape PHEV 3-Page Report

- **Highway and city cycle impacts**
- **CD city**, 49 mpg, 171 DC Wh/mi
- **CD highway**, 58 mpg, 169 DC Wh/mi
- **CS city**, 30 mpg
- **CS highway**, 32 mpg
- Plugging in = 63% increase in city and 84% increase in Hwy MPG (compare CD to CS)
- During CD trips 38% City & 13% Hwy miles engine off
- During CS trips 23% City & 4% Hwy miles engine off

### VEHICLE TECHNOLOGIES PROGRAM

<table>
<thead>
<tr>
<th>Trips in Charge Depleting (CD) mode</th>
<th>City</th>
<th>Highway</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline fuel economy (mpg)</td>
<td>40</td>
<td>58</td>
</tr>
<tr>
<td>DC electrical energy consumption (DC Wh/mi)</td>
<td>171</td>
<td>189</td>
</tr>
<tr>
<td>Percent of miles with internal combustion engine off</td>
<td>38%</td>
<td>13%</td>
</tr>
<tr>
<td>Average trip driving intensity (Wh/mi)</td>
<td>206</td>
<td>304</td>
</tr>
<tr>
<td>Average trip distance (mi)</td>
<td>3</td>
<td>17</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Trips in Charge Depleting and Charge Sustaining (CD/CS) mode</th>
<th>CD</th>
<th>CS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline fuel economy (mpg)</td>
<td>43</td>
<td>36</td>
</tr>
<tr>
<td>DC electrical energy consumption (DC Wh/mi)</td>
<td>78</td>
<td>52</td>
</tr>
<tr>
<td>Percent of miles with internal combustion engine off</td>
<td>30</td>
<td>5%</td>
</tr>
<tr>
<td>Average trip driving intensity (Wh/mi)</td>
<td>276</td>
<td>325</td>
</tr>
<tr>
<td>Average trip distance (mi)</td>
<td>9</td>
<td>41</td>
</tr>
</tbody>
</table>

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

![Graph showing the effect of driving intensity on fuel economy.](image1)

![Graph showing trip fuel economy distribution by trip type.](image2)
Ford Escape PHEV 3-Page Report

- 46 charge events per month when driven
- 3.1 charge events per day when driven
- 17.9 miles per charge event
- 1.4 trips per charge event
- 6.2 hours plugged in per charge event
- 1.3 hours charging per charge event
- 1.8 kWh per charge event
- 83 AC kWh per month per vehicle
Hymotion Prius
PHEV Conversion

- 184 Hymotion PHEV Prius conversions
- 2.7 million miles and 287,000 trips
- CD 62 mpg and 142 DC Wh/mi
- CS 43 mpg
- Plugging in = 44% increase in overall MPG when comparing CD to CS trips
- 20% trip miles in CD
- 60% trip miles in CS
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
• Five USPS electric long life vehicle (ELLV) conversions
  – ELLVs required five customized onboard data loggers
  – Testing to USPS and AVTA test procedures and cycles, including track and dynamometer testing, and Washington DC area delivery routes with data loggers
Other INL Data Collection Projects – cont’d

• 150 Chevy Volts data collection (July reporting)
• 140 Ram PHEV pickups – same report format as Ford Escape PHEVs (August reporting)
• 20 Lithium PHEV Escape Quantum conversions (SCAQMD) – same format as Ford (August 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
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 84% mpg improvements 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 more than five 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

- 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!!!
Acknowledgement

The Advanced Vehicle Testing Activity work is supported by the U.S. Department of Energy’s EERE Vehicle Technologies Program

Argonne and Oak Ridge National Laboratories provide dynamometer and other testing support

More Information

http://avt.inl.gov