Plug-In Electric Vehicles: Motivation and Progress

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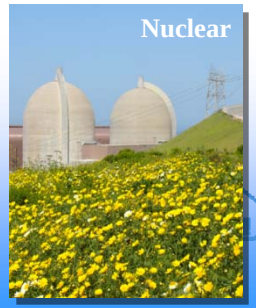
Idaho National Laboratory

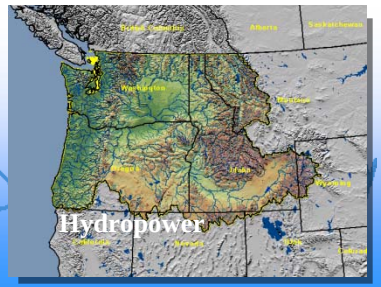
Presentation Outline

- Idaho National Laboratory (INL) / Advanced Vehicle Testing Activity (AVTA) backgrounds
- Motivation for Plug-In Electric Vehicles
- Grid connected vehicle charging infrastructure and charging levels
- American Recovery and Reinvestment Act (ARRA) – DOE's Transportation Electrification Demonstrations and Educations Programs
- DOE's Vehicle Electrification Project Data Collection
- OEM Electric Drive Vehicle Deployment Announcements
- Acknowledgement and AVTA Web Address (Test Reports / Fact Sheets)

Idaho National Laboratory

- Eastern Idaho based U.S. Department of Energy (DOE) Federal laboratory
- 890 square mile site with 3,600 staff
- Support DOE's strategic goal:
  - Increase U.S. energy security and reduce the nation's dependence on foreign oil
- Multi-program DOE laboratory
  - Nuclear Energy
  - Fossil, Biomass, Wind, Geothermal and Hydropower Energy
  - Advanced Vehicles and Battery Development
  - Energy Critical Infrastructure Protection



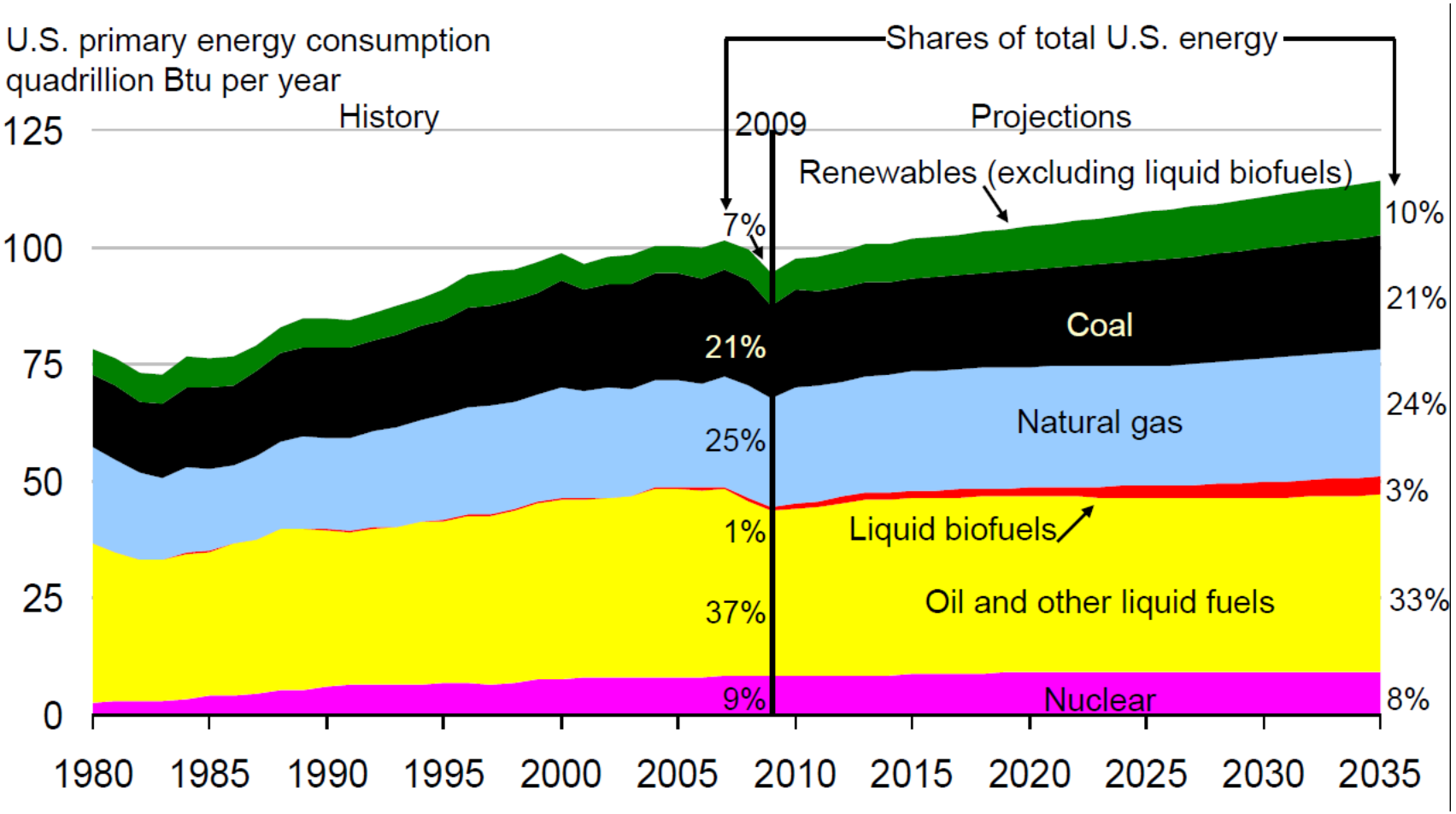


AVTA Description

- Advanced Vehicle Testing Activity (AVTA) is conducted by INL for DOE's Vehicle Technologies Program
- AVTA tests light-duty vehicles, battery subsystems, and fueling infrastructures that employ / support:
  - 100% Electric and dual-fuel electric drive systems
  - Advanced energy storage systems
  - Some ICE 100% Hydrogen and HCNG blended fuels
  - Advanced control systems (i.e., start/stop HEVs)
- Provide benchmarked vehicle and infrastructure testing results to R&D programs, modelers, OEMs, battery manufacturers, and target/goal setters (DOE)
- Assist early adaptor fleet managers and the general public in making informed vehicle purchase, deployment and operating decisions
- Presentations to industry groups, including via Clean Cities' sponsored webinars and symposiums

Motivation for Plug-In Electric Vehicles

Energy Consumption



Where does transportation fit in?

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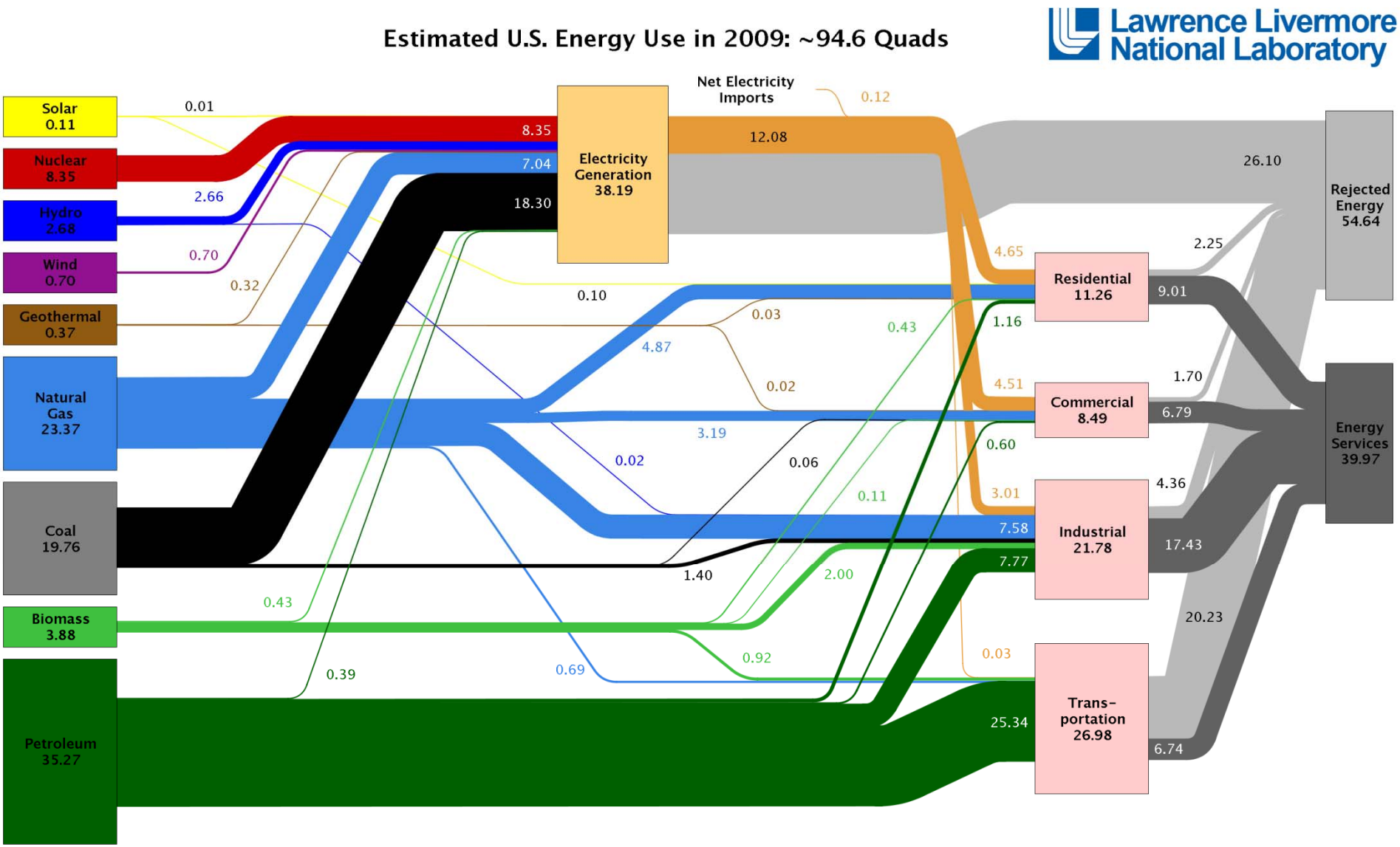
Source: *EIA, Annual Energy Outlook 2011*
<http://www.eia.doe.gov/oiaf/aeo/execsummary.html>



Natural Gas, Bio-Fuels, Electricity << **Petroleum**

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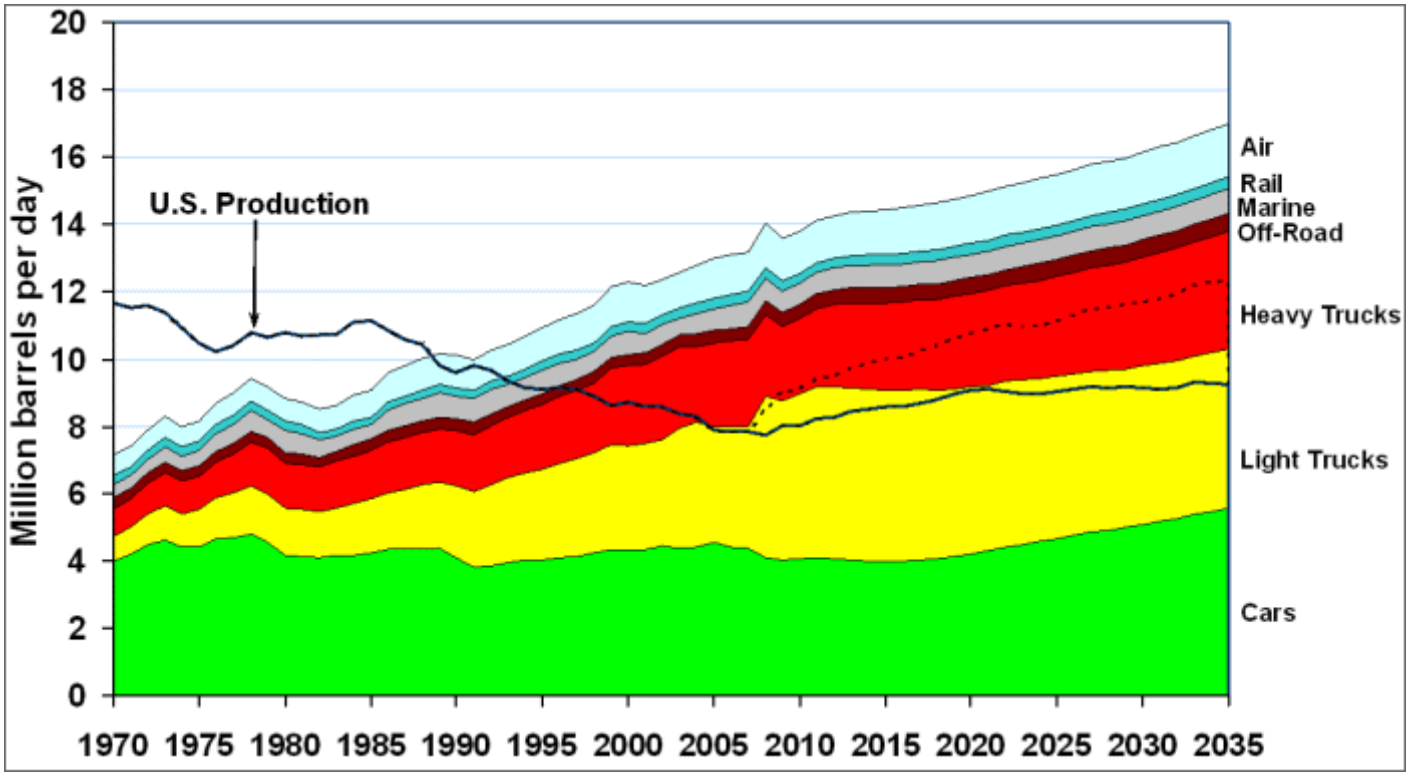
Source: *LLNL 2010*

< https://flowcharts.llnl.gov/content/energy/energy_archive/energy_flow_2009/LLNL_US_Energy_Flow_2009.png>

Petroleum Usage in Transportation, Outlook



Note: The U.S. Production has two lines after 2005. The solid line is conventional sources of petroleum, including crude oil, natural gas plant liquids, and refinery gains. The dashed line adds in other non-petroleum sources, including ethanol, biomass, liquids from coal, other blending components, other hydrocarbons, and ethers. The sharp increase in values between 2007 and 2008 are caused by the data change from historical to projected values.

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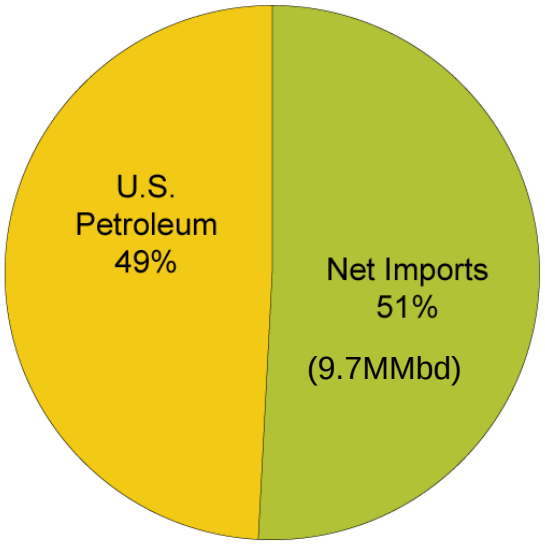
Source: *US DOE | EERE*
<http://www1.eere.energy.gov/vehiclesandfuels/images/facts/fotw609.gif>

Dependence on Foreign Oil

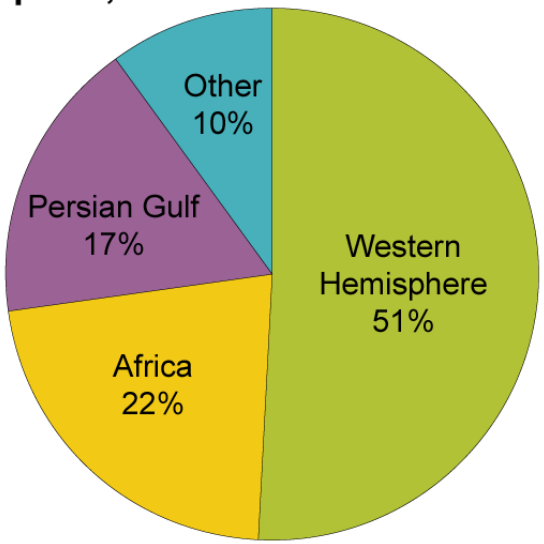
"Although we are the third largest crude oil producer, about half of the petroleum we use is imported"

Net Imports and Domestic Petroleum as Shares of U.S. Demand, 2009



Source: U.S. Energy Information Administration, *Petroleum Supply Annual 2009* (July 2010).

Sources of U.S. Net Petroleum Imports, 2009



Source: U.S. Energy Information Administration, *Petroleum Supply Annual 2009*.

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Source: *EIA* <http://www.eia.doe.gov/energy_in_brief/foreign_oil_dependence.cfm>

Petroleum Fuel Issues

Imported Petroleum as Fuel	All Petroleum as Fuel
U.S. mobility vulnerable to supply disruptions	Combustion in engines generates air pollution (Transportation accountable for about 1/3 of CO_2 in U.S.)
Economic cost – vulnerable to economically harmful price shocks	Environmental risks of drilling, exploration
	Finite Resource
	Combustion engines inefficient

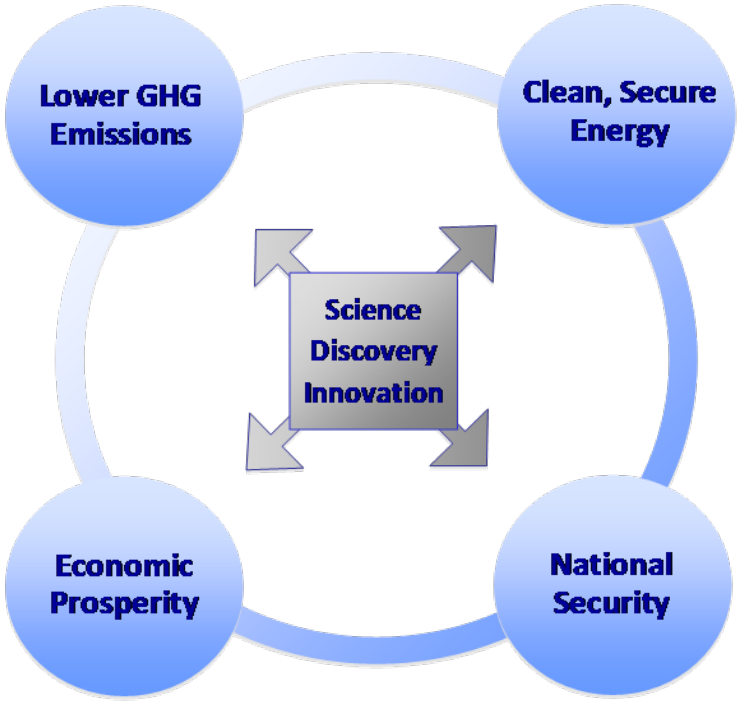
President's Vision for a Clean Energy Economy

Environmental

- Closing the carbon pollution loophole.
- Protecting American consumers by returning carbon-generated revenues to them.

Economic

- Creating new jobs in the clean energy economy.
- Promoting U.S. competitive-ness as we address climate change.



Energy Security

- Investing in the next generation of energy technologies.
- Promoting energy efficiency.
- Breaking our dependence on oil.
- Producing more energy at home.

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Source: *EIA* <http://www1.eere.energy.gov/vehiclesandfuels/images/facts/fotw609.gif>

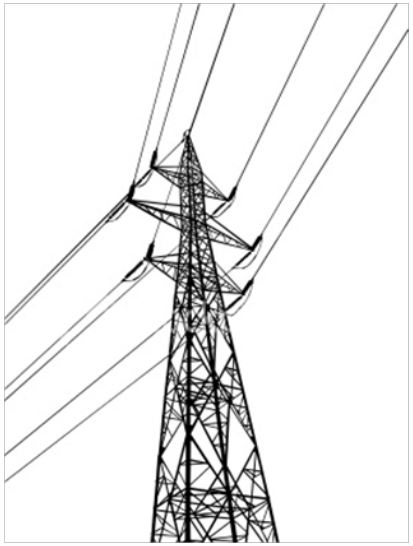
How Different Vehicle Technologies Address Petroleum Fuel Issues

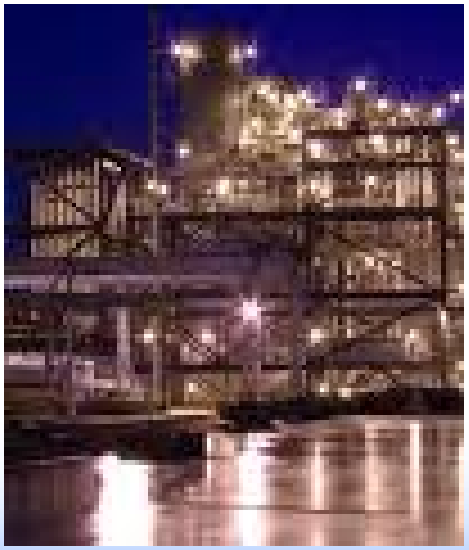
Technology	Possible Benefits
Advanced Combustion	Lowered emissions and increased engine efficiency
Biofuels	Domestic production, decreased carbon emissions
Materials	Increased vehicle efficiency from lighter, stronger structures
Hybrid Electric	Increased drive train efficiency, lowered emissions
Plug-In Electric	**Offset petroleum consumption, low or zero tailpipe emissions, utilize domestically produced energy**

Grid Connected Vehicle Charging Infrastructure Overview

Vehicle Electrification: Grid Impacts

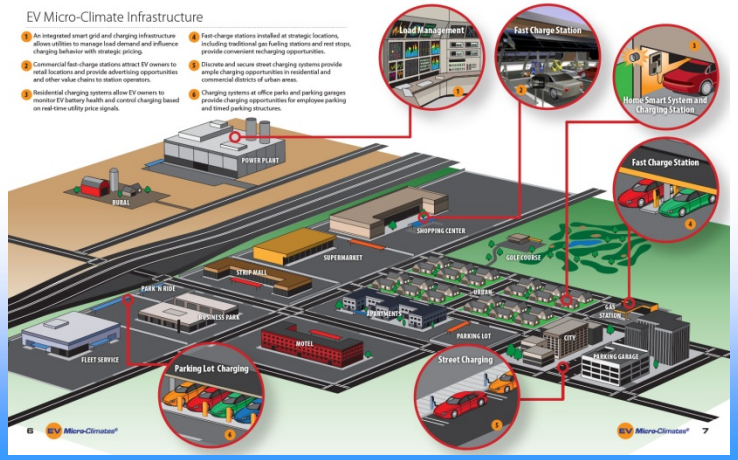
- In the U.S., current grid capacity could supply electricity for 70% of our vehicles without adding capacity, but assumes:
  - Vehicles would only charge off-peak
  - “Perfect” distribution of electricity
  - No local impacts such as overburdening neighborhood transformers
- EVs and PHEVs will not cause 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



Innovative Approaches

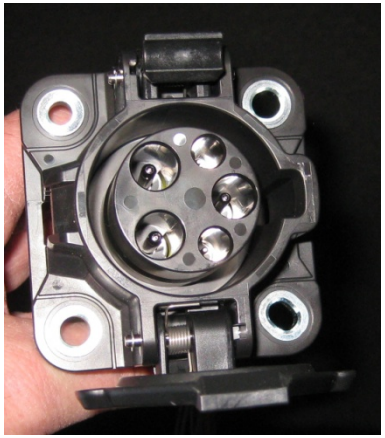
- Battery swapping
  - Requires OEM buy-in
- Fast Charging (becoming less innovative)
- Innovative Financing
- Secondary use of batteries
  - Utility ancillary services
  - Bulk energy storage
  - Present value
- Vehicle to Grid (V2G)

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
  - NEV 9 to 13 hours

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 breaker current)
  - 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)



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 and NEVs due to small relative battery sizes

American Recovery and Reinvestment Act (ARRA) – DOE's Transportation Electrification Demonstrations and Educations Programs

American Recovery and Reinvestment Act (ARRA)

- $2B in DOE grants to establish advanced battery, power electronics and motors manufacturing
- $400M for Transportation Electrification Demonstration, Infrastructure, and Education
  - 8 Awards totaling over $360M for grid-connected vehicle and infrastructure demonstrations
    - 13,000 vehicles from 9 OEMs and over 22,000 charging stations will be deployed across America
    - Vehicle performance and grid impact data will be gathered and analyzed to support the development of vehicle technologies and grid infrastructure
  - 10 Grants totaling $39M - establish comprehensive educational and outreach programs to educate first responders and emergency personnel for dealing with EV and PHEV accidents
    - Also, public outreach

Transportation Electrification Demonstration Activities

Electric Transportation Engineering Corporation - AWARD: $114.8M

- Demonstration of 5,700 Nissan Leaf EVs and 2,600 Chevy Volt EREVs
- Deployment of 15,000 Level 2 electric vehicle supply equipment (EVSE) charging Stations (EVSE) and 300 fast chargers, in 16 metropolitan areas
- Full instrumentation of vehicles and infrastructure for comprehensive data-collection and analysis effort

Chrysler, LLC - AWARD: $48M

- Development, validation, and deployment of 140 PHEV Dodge Ram pickups
- Deployment of vehicles through 11 partner fleets across a wide range of geographic, climatic, and operating environments

Transportation Electrification Demonstration Activities (cont'd)

South Coast Air Quality Management District - AWARD: $45.4

- Development of a fully integrated production PHEV system for Class 2-5 vehicles (8,501-19,500 lbs GVWR).
- Demonstration of 378 trucks and shuttle buses through network of partner fleets
- SCAQMD based in Diamond Bar, CA; Manufactured in Galesburg, MI, and Elizabethtown, KY

Coulomb Technologies - AWARD: $15M

- Deployment of approximately 4,000 public and private charging stations in up to 9 U.S. Cities
- Locations will be coordinated with OEM deployment of 400 grid connected vehicles

Transportation Electrification Demonstration Activities (cont'd)

Navistar, Inc. - AWARD: $39.2M

- Develop, validate, deploy 950 advanced Battery Electric delivery trucks (12,100 lbs GVWR) with a 100-mile range
- Manufacturing in Elkhard Co., IN; Deployment in Portland, Chicago, and Sacramento

Cascade Sierra Solutions - AWARD: $22.2M

- Deployment of truck stop electrification infrastructure at 50 sites along major US interstate corridors
- Provide 5,450 rebates of 25% of the cost for truck modification to incorporate idle reduction technologies

Transportation Electrification Demonstration Activities (cont'd)

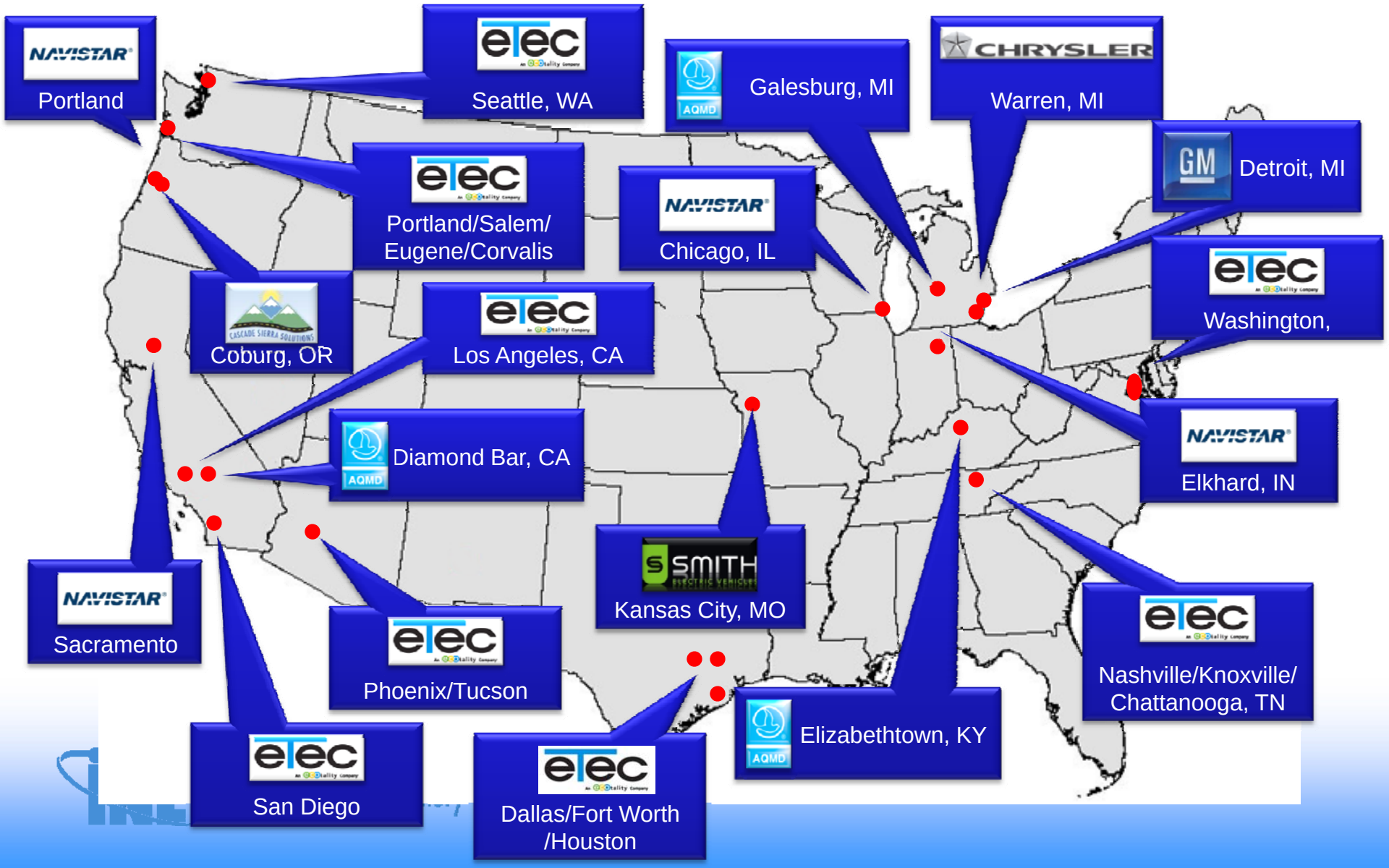
General Motors - AWARD: $30.5M

- Develop, analyze, and demonstrate 125 Chevy Volt EREVs for electric utilities and 500 Volt EREVs to consumers
- Manufacturing in Detroit, MI; Deployment in conjunction with several utility partners

Smith Electric Vehicle - AWARD: $32M

- Develop and deploy up to 500 medium-duty electric trucks.
- Manufacturing in Kansas City, MO; Deployment in conjunction with 20 launch partners representing a range of commercial and public sector markets, geographies, and climates

Transportation Electrification Distribution



Transportation Electrification Education Program

Award Recipient	DOE Award	Project Locations	Project Focus
West Virginia University (National Alternative Fuels Training Consortium)	$6.9M	Morgantown, WV State of South Carolina	•Educational programs for: Graduate, Undergraduate and Secondary Students; Teachers; Technicians; Emergency Responders; General Public •Partnering with: NAFTC Headquarters and members; West Virginia Department of Education; South Carolina Department of Education; Greater New Haven Clean Cities Coalition; Innovation Drive, Inc.; Advanced Vehicle Research Center; Auto Exposure LLC; Big Fish Advertising and Public Relations; MotorWeek; Sabre Engineering; Northeast Utilities
Purdue University	$6.1M	State of Indiana West Lafayette, IN	•Educational programs for: Graduate, Undergraduate and Secondary Students; Teachers; Technicians; General Public •Partnering with: University of Notre Dame; Indiana University Purdue University at Indianapolis (IUPUI); Purdue University – Calumet; Indiana University – Northwest; Ivy Tech Community College
Colorado State University	$5M	State of Colorado State of Georgia Fort Collins, CO Boulder, CO Atlanta, GA	•Educational programs for: Graduate, Undergraduate and Secondary Students; Teachers; Technicians; Emergency Responders; General Public •Partnering with: CSU; Georgia Institute of Technology; Arapahoe Community College; Douglas County School System; Nissan NA; KShare; Ricardo; AM General; Motion Reality, Inc.
Missouri University of Science & Technology	$5M	Rolla, MO Warrensburg, MO Linn, MO St. Louis, MO Kansas City, MO Lee's Summit, MO	•Educational programs for: Graduate, Undergraduate and Secondary Students; Teachers; Technicians; Mechanics; Emergency Responders; General Public •Partnering with: University of Central Missouri; Linn State Technical College; St. Louis Science Center; Smith Electric Vehicles U.S. Corporation (SEV-US); Kokam America Inc.

Transportation Electrification Education Program (cont'd)

Award Recipient	DOE Award	Project Locations	Project Focus
Wayne State University	$5M	Detroit, MI Warren, MI	•Educational programs for: Graduate, Undergraduate and Secondary Students; Teachers; Technicians; Emergency Responders; General Public •Partnering with: NextEnergy; Macomb Community College
National Fire Protection Association	$4.4M	Quincy, MA	•Educational programs for: Emergency Responders •Partnering with: Fire Protection Research Foundation; Automotive Alliance; NREL
Michigan Technological University	$2.98M	Houghton, MI (Western Upper Peninsula of MI)	•Educational programs for: Graduate, Undergraduate and Secondary Students; General Public •Partnering with: Argonne National Laboratory; AVL; GM; Eaton; Horiba; MathWorks; Schweitzer Engineering Laboratories; Woodward
University of Michigan	$2.5M	Detroit, MI Ann Arbor, MI Dearborn, MI Flint, MI	•Educational programs for: Graduate, Undergraduate and Secondary Students; Teachers; General Public •Partnering with: University of Michigan – Dearborn; Kettering University; Ford; GM; Chrysler; Eaton Corp; DTE Energy; Mentor Graphics; Ballard; Quantum Technologies; A123 Systems
J. Sargeant Reynolds Community College	$0.72M	Commonwealth of Virginia and Neighboring Mid-Atlantic States	•Educational programs for: Secondary Students; Technicians •Partnering with: James Madison University; Virginia Department of Education; Ford; GM; Toyota; Firestone/Bridgestone
City College of San Francisco	$0.5M	San Francisco, CA	•Educational programs for: Secondary Students; Service Personnel, Technicians •Partnering with: Chabot College; Central Shops; Pat's Garage; Perfect Sky Inc.

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

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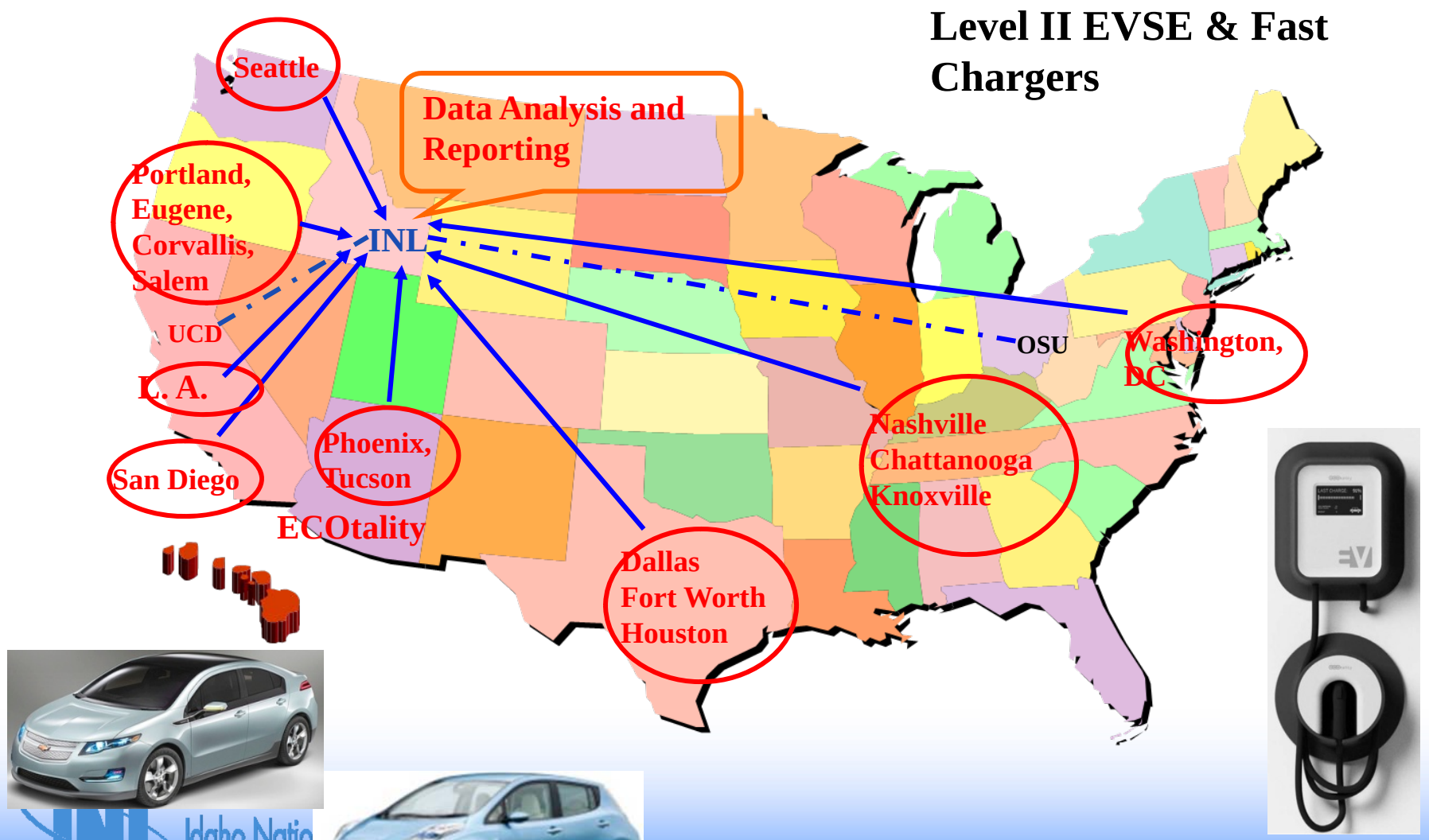
INL ARRA / TADA Data Collection Support

- **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 to build and study mature electric vehicle charging infrastructure 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 enable the streamlined deployment of the next 5,000,000 EVs**

EV Project Partner Locations



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 - Reporting

- **INL will analyze and report on the charging infrastructure utilization (Level II EVSE units and fast chargers) by the 8,300 Leaf and Volt drivers**
- **INL will report on driver/vehicle charging patterns, and charging infrastructure utilization patterns**
- **Many of the 42+ EV Project partners are electric utilities with high interest in demand / smart charging controls, including multitier time-of-day pricing and micro grid analysis**
- **Reporting targets include: DOE/governments, OEMs, electric utilities, public, etc.**
- **Specialty analyses will include micro grid and other variable influences**

EV Project - Fact Sheet Reporting

- Driving (by reporting period)
  - Number of trips
  - Distance driven (miles)
  - Average number of trips between charging events
  - Average distance between charging events
- Charging Infrastructure
  - EV Project vehicle charging
    - Number of charging events
    - Percent of all charging events
    - Total time plugged in (hours)
    - Percent of all time plugged in
  - Non-EV Project vehicle charging events
    - Number of charging events
    - Percent of all charging events

EV Project Summary

- **Provide feedback on infrastructure deployment decisions**
- **Reporting can not begin until after November/December 2010 start to vehicle and infrastructure roll-outs, and data analyzed**
- **Successful grid-connected electric drive vehicle deployment is dependent on successful infrastructure deployment**
- **Future charging infrastructure deployments must be based on real-world travel and charging patters**
- **Goal is to replace internal combustion engine vehicles with grid connected, and infrastructure dependant, electric drive vehicles**

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		

Other INL Data Collection Projects

- Data collection for Ford's PHEV SUVs and Chrysler Ram Pickups include 25+ onboard parameters, such as charging and driving profiles, and vehicle performance; collected via the CAN and data loggers
- Other OEM vehicles may be added to EV Project
- Five USPS electric long life vehicle (ELLV) conversions
  - ELLVs required five customized onboard data loggers
  - Testing to USPS and AVTA test procedures and cycles
- Development of vehicle-based battery test-bed mule

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

This presentation can be found @

http://avt.inel.gov/pdf/prog_info/Seattle_NAFA_Presentation_March2010.pdf

Backup Slides

Advantages and Challenges of Vehicle Electrification

Advantages

- Electric Drive more efficient than IC engine - ‘tank to wheels’ efficiency
- Low maintenance – fewer moving parts than IC engine with transmission
- Low or Zero Tailpipe Emissions – Power generation at plant is cleaner per unit of energy and better controlled

Challenges

- Cost - Energy Storage
  - US ABC/DOE goals: <$150/kWh for EV, $3400 for PHEV40 Battery Pack
- Range
  - Cost and Volume of energy storage restrict range – investigate need for distributed EVSE infrastructure
- ‘Smart Grid’ – Ensure reliability of electric grid by coordinating vehicle charging
- Life – Energy storage devices lose capacity when cycled (discharged, charged), temperature extremes, high power, etc