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

Clean Cities Webinar – Electric Drive Vehicles and Their Infrastructure Issues (March 2010)

Jim Francfort and Don Karner

Advanced Vehicle Testing Activity
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This presentation does not contain any proprietary or sensitive information

Idaho National Laboratory

Presentation Outline

- AVTA Background and Testing
- Regulations, Codes & Standards
- OSHA, National Electric Code, UL, SAE
- Permitting
- Industry Status
- BEV, EREV, PHEV, HEV technologies
- Capital & Fuel Costs per Mile
- BEV & PHEV Announcements
- Smart Charging
- Fleet Infrastructure
- Acknowledgement & Questions

AVTA Background and Goals

- **Background**
  - **The Advanced Vehicle Testing Activity (AVTA) is part of DOE's Vehicle Technologies Program**
  - **The Idaho National Laboratory (INL) and Electric Transportation Engineering Corporation (ETEC) conduct the AVTA per DOE guidance**

- **The AVTA goals:**
  - **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 early adaptor vehicle purchase, deployment and operating decisions**

AVTA Testing Process

- **Testing includes:**
  - **Baseline performance via closed test tracks and dynamometers**
  - **Accelerated testing uses dedicated drivers to accumulate high mileage in compressed times**
  - **Fleet testing allows large numbers of vehicles to be tested in many environments / missions at low cost**
  - **Battery testing when appropriate at new and new of life**
- **Different testing methods are used to balance testing control and repeatability needs, sample size, cost, and technology capabilities**
- **Publish testing results in relevant ways to accurately document real-world petroleum reductions, fuel and infrastructure use, and life-cycle risks and costs**

AVTA Testing by Technology

- Plug-in hybrid electric vehicles (PHEVs)
  – 12 models, 259 vehicles, 1.5 million test miles
- Hybrid electric vehicles (HEVs)
  – 18 models, 47 vehicles, 5 million test miles
- Neighborhood electric vehicles (NEVs)
  – 23 models, 200,000 test miles

- Hydrogen internal combustion engine (ICE) vehicles
  – 7 models, 500,000 test miles

- Full-size battery electric vehicles (BEVs)
  – 41 EV models, 5+ million test miles
- Urban electric vehicles (UEVs)
  – 3 models, 1 million test miles
- 13 million test miles accumulated on 1,600 electric drive vehicles representing 97 different models

Regulations, Codes & Standards

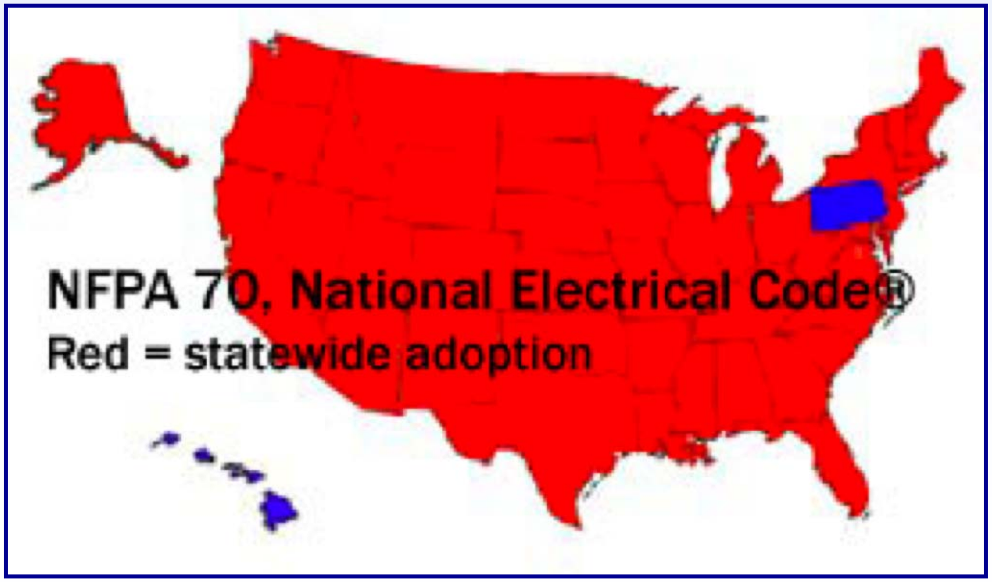
- System of safety & standardization
- Mandatory safety
  - Federal mandates
  - Local statutes
- Voluntary standardization
  - Industry standards
- Applicable authorities
  - Occupational Health & Safety Regulations
  - National Electric Code
  - Underwriters Laboratories Standards
  - Society of Automotive Engineers Standards

OSHA

- Requires certification of workplace equipment
- Establishes Nationally Recognized Testing Laboratory (NRTL) requirements – 29CFR1910
  - Independent safety testing and product certification
  - Specific scope of accreditation by OSHA
  - Registered certification “mark”
  - Certify to US based test standards
  - UL standards listed for electrical equipment
  - UL 2202 listed for EVSE (electric vehicle supply equipment)
- NRTL list maintained by OSHA
  - CSA accredited for UL 2202
  - UL accredited for UL 2202

National Electric Code

- National Fire Protection Agency (NFPA) 70
- Fire protection focus
- Revised every three years – 2008
- Adopted by local jurisdictions as part of IBC
- Invokes “listing” by Nationally Recognized Testing Laboratory (NRTL)



NEC Article 625

- Electric Vehicle Charging Systems
  - Defines charging requirements or permanently installed equipment – not vehicles
  - Requires “listing” by NRTL
- Key requirements
  - Wiring methods
  - EVSE coupler
  - EVSE control and protection
  - EVSE location
- Applied by local building inspectors
  - NRTL “mark”
  - Physical requirements – installed equipment

UL

- **Develops certification standards**
  - **Electric shock focus**
  - **Adopted by OSHA**
- **UL 2202 – Electric Vehicle Charging System Equipment**
  - **Construction**
  - **Protection of Users Against Injury**
  - **Performance**
  - **Ratings**
  - **Markings**
  - **Instructions**
  - **Manufacturing and Production Tests**
  - **Outdoor Use Units**
- **UL is one of several NRTLs**

SAE

- Develops vehicle standards
  - Voluntary compliance
  - No certification
- SAE J1772 – Electric Vehicle and Plug in Hybrid Electric Vehicle Conductive Charge Coupler
  - Adopted January 2010
  - Physical coupler configuration
  - Coupler electrical ratings
    - Level 1 – 120 VAC, single phase, up to 16 A
    - Level 2 – 240 VAC, single phase, up to 80 A
  - EVSE – Vehicle communications protocol

Permitting

- Process of controlling building changes
  - Process required by IBC
  - Supports code compliance
  - Enforces local planning requirements
  - Maintains accurate tax base
  - Generates fee income
- Permitting procedure varies by jurisdiction
  - Online permit
  - Over-the-counter permit
  - Plan check
  - Planning review
- Inspection required
  - Authorized 3rd party
  - Authority Having Jurisdiction (AHJ)

EVSE Permitting

- Residential EVSE permitting
  - Typically involves addition of a branch circuit
  - May involve service upgrade
  - May require a load calculation
- Commercial EVSE permitting
  - Requires one or more additional branch circuits
  - Requires load calculation
  - Requires planning review if outside
- Residential process streamlining
  - Online permitting using installation details
  - Self or 3rd party inspection using qualifications

Industry Status

- Stakeholders
  - Automakers
    - Market
    - Emissions
    - Carbon reduction
  - Government
    - Energy independence
    - Emissions
    - Carbon reduction
    - Jobs creation/maintenance
    - Local needs
  - Electric Utilities
    - Resource impacts to generation & distribution
    - Sales

Industry Status – cont'd

- Legislation
  - Federal
    - GHG cap & trade
    - ARRA
    - Department of Energy budget
    - Congressionally directed
      - E-Drive bill – USPS
      - Advanced Vehicle Technology Act
      - Smart Grid/Energy Independence
      - Senate Energy Bill
  - State
    - California – regulation of charge infrastructure
    - Washington – recovery of road tax

Industry Status – cont'd

- Regulation
  - Environmental protection
    - Fuel economy
    - Battery recycle
  - Energy
    - Smart grid integration
    - Utility resource planning
  - Tax
    - Vehicle credit
    - Road tax recovery
    - Carbon credits

Battery Electric Vehicle (BEVs)

- Battery is only onboard energy storage
- Battery powers one or more electric motors
- Charged from an off-board electricity source, mostly from power plants via the electric grid
- Captures energy during regenerative braking: electric motor(s) acts as a generator
- No vehicle-based emissions: depending on the power plant, offboard emissions unless renewables are used
- Examples include: Nissan Leaf, Mitsubishi iMiEV, BMW Mini-E, and Tesla Roadster

BEV Advantages and Disadvantages

- **BEV advantages**
  - **No vehicle emissions**
  - **Domestically produced fuel**
  - **May lower overall electricity costs**
  - **Lower fuel and operating costs**
- **BEV Disadvantages**
  - **Need to understand and install public charging infrastructure**
  - **Limited range per charge: “Range anxiety”**
  - **Battery improvements still needed**
  - **Long-term battery performance unknown**
  - **No large-scale domestic battery industry**

Extended Range EVs (EREVs)

- Onboard battery and internal combustion engine (ICE)
- Operates in series mode: ICE charges the battery and the battery powers the electric motor(s)
- Operates in all-electric mode until battery is discharged, then ICE turns on to charge the battery. No propulsion energy goes directly from the ICE to the vehicle's wheels
- Captures energy during regenerative braking
- Must be plugged into the electric grid to fully recharge its propulsion battery
- Examples include the Chevrolet Volt and Renault Kangoo (2003 model)
- Similar advantages and challenges as PHEVs

Plug-in Hybrid EVs (PHEVs)

- Both onboard battery and ICE
- Series or parallel design
- In parallel mode, ICE and battery (via an electric motor) power the vehicle usually through the transmission
- ICE sometimes recharges the battery
- Uses electric grid to recharge the propulsion battery
- Accepts regenerative braking energy
- Original equipment manufacturer (OEM) designs are anticipated to have a single PHEV propulsion battery
- Some conversions (HyMotion) keep the original HEV battery and add a second “mule” PHEV battery. The mule battery can only be recharged from the grid
- Most OEMs have PHEV plans. Ford Escape PHEV, and Chrysler building Ram PHEV

PHEV Operating Modes

- Charge sustaining (CS) mode: from start to finish of trip, there is no energy available for electric propulsion in the PHEV battery. The battery state-of-charge (SOC) is sustained
- Charge depleting (CD) mode – from start to finish of trip, there is energy available for partial or full electric propulsion in the PHEV battery. The battery SOC is being depleted during the entire trip
- Mixed CD/CS mode – there is energy in the battery at the start of a single trip, but the PHEV battery is fully depleted before the trip ends
- Electric propulsion is either in the form of all-electric or electric-assist (the ICE provides propulsion power)
- One PHEV design has eight operating modes, making fuel use measurement difficult with a single test

PHEV Advantages and Disadvantages

- **PHEV Advantages**
  - Reduced fuel consumption and vehicle emissions
  - Smaller battery packs to manage and pay for
  - Gasoline fueling infrastructure exists
  - Minimal electric grid changes needed - add EVSE
  - At home battery charging, well below cost of gasoline
  - Potential for off-peak charging
- **PHEV Disadvantages**
  - Cost, complexity and weight of two powertrains
  - Higher initial cost
  - Drivers adapting to dual-fueling scenario
  - Component availability - batteries, powertrains, power electronics (early challenge)

Hybrid EVs (HEVs)

- Small onboard battery (<1.5 kWh) and an ICE
- Normally parallel design, some with other drive axle propulsion, some start - stop
- Most HEV batteries last 150,000+ miles due to narrow battery charge / discharge range
- No offboard charging required
- Battery charged by ICE and regenerative braking
- Most OEMs offer HEVs or plan to. Many examples

HEV Advantages and Disadvantages

- HEV advantages
  - Reduced fuel use and vehicle emissions
  - Recovers regenerative braking energy
  - Uses existing gasoline infrastructure
  - No electric grid charging required
  - No range anxiety
- HEV Disadvantages
  - Complexity and cost of two powertrains
  - Components such as batteries, powertrains and power electronics are still not produced in very large numbers
  - Higher initial costs

Battery Systems

- <u>Lead Acid</u> is currently used for applications where weight and space limitations are outweighed by cost considerations. Battery of choice in early to mid 1990's. Limited cycle life of 600 to 1,000 cycles
- <u>Advanced Lead Acid</u> R&D activities suggest a possible revival of lead chemistries due to new production processes and materials
- <u>Nickel Metal Hybrid</u> is used primarily as power battery in HEVs, with 500,000+ cycle life. HEVs are an accepted technology due to NiMH durability
- <u>Lithium</u> is viewed as the most commercially viable energy storage option due to potential for much higher energy and power densities. Economically viable demonstrated successes are needed for high energy lithium batteries before a large penetration of PHEVs and a full transition to BEVs can take place

Current Capital and Fuel Costs per Mile

Technology	MSRP ($$$$)	MPG Gas	kWh / Mile	Gas Cost / Mile (Cents)	Electricity Cost / Mile (Cents)	Capital Cost / Mile (Cents)	Total Cost / Mile (Cents)
ICEV	21,825	25		11.0		14.6	25.6
HEV	22,800	45		6.1		15.2	21.3
BEV	35,000		0.290		2.90	23.3	26.2
PHEV Conversion	34,800	70	0.125	3.9	1.25	23.3	28.45

Notes

- **ICEV, HEV, and PHEV conversion capital costs are based on known costs. BEV capital cost is an educated guess. PHEV conversion cost includes base vehicle capital cost.**
- **All capital costs per mile are based on 150,000 miles of depreciation, with zero financing costs assumed.**
- **Gasoline cost of $2.75 / gallon and electricity cost of 10 cents / kWh used.**
- **Battery life is unknown. Other maintenance costs are not included. BEV maintenance costs should be lower, but no documentation currently exits.**

Announced BEV Introductions*

- 2009 Subaru 4 seat Stella or R1e (2 in New York now)
- 2009 Chrysler EVs (showing concepts)
- 2009 Smart for Two EV
- 2009 ZENN city BEV
- 2009 Chery (China, Berkshire Hathaway) BYD EV in China
- 2009 Tesla / Daimler Smart Car BEV
- 2010 BMW electric Mini (actually 2009)
- 2010 Chrysler EV
- 2010 Miles EV
- 2010 Mitsubishi \ Peugeot iMiEV BEV
- (* Presenter makes no accuracy claim for the above dates and products. Some info based on media reports)

Primary source: EDTA http://www.electricdrive.org/index.php?ht=d/sp/i/11551/pid/11551

Announced BEV Introductions* – cont'd

- 2010 Nissan BEV
- 2010 Ford Battery Electric Van
- 2011 Tesla Model S sedan
- 2011 BYD e6 Electric Vehicle
- 2011 Ford Battery Electric Sedan
- 2011 Opel Ampera Extended Range BEV (Europe)
- 2012 Toyota EV sedan
- ? Volkswagen and Toshiba EV develop letter of intent
- (* Presenter makes no accuracy claim for the above dates and products. Some info based on media reports)

Primary source: EDTA http://www.electricdrive.org/index.php?ht=d/sp/i/11551/pid/11551

Announced PHEV Introductions*

- **2009 Fisker Karma S Plug-in Hybrid (maybe 2010)**
- **2010 Saturn VUE Plug-in Hybrid**
- **2010 Toyota Plug-in Hybrid (?)**
- **2010 Chevrolet Volt Extended Range (actually EVRE)**
- **2010 Kia LPG and Electric “hybrid”**
- **2009 Chery (China, Berkshire Hathaway) BYD PHEV in Europe**
- **2011 BYD F3DM Plug-in Hybrid**
- **2012 Ford Escape Plug-in Hybrid**
- **2012 Hyundai PHEV**
- **? AFS Trinity SUV**
- **(* Presenter makes no accuracy claim for the above dates and products. Some info based on media reports)**

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Vehicle Selection Considerations

- Is it an OEM Vehicle or a conversion? If conversion ask:
  - Emissions been certified by CARB or the EPA, or received an exemption?
  - Crashed testing and FMVSS certified per NHTSA requirements?
  - Has the converter made the vehicle available to DOE’s AVTA for testing?
  - Conversions need crash testing – Don’t believe “its just another piece of luggage in the trunk”
- Always match the vehicle capabilities to missions
  - Consider range requirements and operating environment, including ambient temperature, terrain, payload, passenger numbers
  - Consider recharging requirements
  - Install the fueling infrastructure first

Charging Terms / Considerations

- Fast Charge – Not definitively defined. Generally returns 50% of a battery's capacity in 10+ minutes. For large batteries, usually at Level III charge level
- EVSE - Some "chargers" are not chargers at all, but electric vehicle supply equipment (EVSE). If a charger is onboard the vehicle, the EVSE houses the connector (plug) and cord set, and hopefully some intelligence, communication, and metering capability. EVSE bridges the gap between the vehicle charge post and the electric grid

Smart Charging

- Stand alone
  - Charging time-of-day
  - Staggered charging
- Smart grid interface
  - Off peak charging
    - Real time rates
    - Time-of-use rates
  - Demand response
    - Grid critical peaks
    - Distribution overload

Smart Charging – cont'd

- Charge network interface
  - Web portal
    - User preferences
    - Status monitoring
  - Mobile application
  - HAN interface
  - Network chargers
    - Charger status
    - Charger reservation

Installing Charging Infrastructure

- New building construction, install service panels and conduit in anticipation of 240 Volt, Level II charging
- Install SAE J1722 compliant connectors and UL Listed EVSE and offboard chargers
- Follow the National Electric Code requirements for electrical wiring and equipment (EVSE and chargers)
- Match infrastructure to vehicle requirements
- Level I, 120 volt only suitable for small PHEV battery packs or emergency charging
- Level II, 240 volt or higher is required for BEVs due to their large energy storage (kWh) and the time required to charge them

Fleet Infrastructure

- Vehicle mission
  - Configuration
  - Range
  - Charge time
  - Repeatability
  - Accountability
- Vehicle selection
  - Mission applicability
  - Technical support
- Operator training
  - Range determination
  - Charge infrastructure utilization
  - Roadside assistance

Fleet Infrastructure – cont'd

- Procedures
  - Vehicle maintenance
    - Electrical service
    - Technician qualification & certification
  - Roadside assistance
  - Vehicle recovery
- Charging infrastructure
  - What
  - Where
  - When
  - How
- Information requirements

Acknowledgement

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Additional Information

http://avt.inl.gov

Information sources include DOE, INL, eTec and the Electric Drive Transportation Association

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