Plug-in Electric Vehicles (PEVs)

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Plug-In Electric Vehicles

Agenda

- Motivation for alternatives to Gasoline/Diesel
- Types of PEVs
- PEV Refueling and PEV-Grid Interfaces
- PEV-Grid Interactions, Grid implications & Synergy
- The “Big Vision”
Motivations for Alternatives & Fuel Diversity

Economic Security = Continuity of Supply + Balanced Trade

Emissions

Problematic Petroleum Monopoly as Transportation fuel

Diversity of Fuel types and sources sound objective

Oil Price Spikes Strong correlation with recessions

Instability of Regions with greatest reserves

PetroDollars funding efforts counter to US Interests
Transportation Dominates Oil Consumption

Gas & Diesel advantages:
- High Energy Density
- Energy Carrier and Storage
- Plentiful
- Pervasive distribution
- Relatively Safe
- Acceptable Cost

Issues:
- CO₂ Emissions
- Energy Security
- Stable supply
- Source Countries
- Trade Deficit
- Cost of Energy

Source: Dr. Thomas Edgar
The University of Texas
Recessions often preceded by spikes in oil prices
Increasing demand from developing countries
Economic recovery increases demand/price, which then dampens recovery
Oil and the Trade Deficit

- The U.S. is losing its ability to generate export revenue from Advanced Technology.

- Advanced Technology thought to be the offset for importing goods such as oil. Source: Dr. Thomas Edgar, The University of Texas.

- Normally, currencies would adjust to re-establish equilibrium.

- Dollar not declining from “flight to safety” into U.S. Treasuries at this time.
Which Propulsion System has the most flexibility of Energy Resources?
Which Energy Carriers are likely to be low cost, secure, & wide spread?
Types of Plug-In Electric Vehicles
Earlier Attempts of Electric Vehicles

- **Electric Vehicles predate gasoline vehicles**
  - Early 1900s more EVs on the road than Gas powered cars
  - By late 1930s, EVs were dead
    - Superior energy density of liquid fuels
    - Electric Starter invented by Cadillac
    - Increasing range, speed, refueling advantages of gas powertrains
  - EV problems of range, speed, recharging not solved for most of 20th century

- **1990s: CARB ZEV Mandate forced R&D**
  - Modern electronics solved all problems (except Batteries)
    - Driven by advances in electronics by computer industry
    - AC conversion to DC for charging solved by modern electronics
  - Electronic controls: efficient, durable, lightweight, low cost
  - Electric Motors: highly efficient
  - ...but batteries still did not have sufficient energy storage...
PEVs: Plug-In Electric Vehicles

- Non-Range-Extended: BEV (Battery Electric Vehicles)

- Range-Extended vehicles: eREVs and PHEVs
  - eREV: Extended Range Electric Vehicle
  - PHEV: Plug-in Hybrid Electric Vehicle
  - Electric + gas combination to solve traditional BEV “Range Anxiety” problem & improve ICE Fuel Economy
## Types of Plug-In Electric Vehicles (PEVs)

### BEV (Battery Electric Vehicle)
- **Battery Size**: Very Large (24-53kWh)
- **Range**: Electric only: ~100-265 miles
- **Charging**
  - Home: Level-2 240V typically needed
  - Work/Public charging needed if distance is beyond range
- **No Home Charging Available?**: Either charge at work/public or not a viable vehicle for this driver
- **Key Advantages**
  - No internal combustion engine
  - Very low maintenance
  - No tailpipe emissions

### PHEV (Plug-In Hybrid Electric Vehicle)
- **Battery Size**: Large (~16kWh)
- **Range**: All Electric for 38 miles then 344 Miles on Petrol (range =/> Conventional vehicle)
- **Charging**
  - Home: Standard Wall Outlet sufficient but Level-2 240V can increase electrically driven miles
  - Work/Public charging not necessary but useful
- **No Home Charging Available?**: Either use as a conventional hybrid vehicle or charge at work/public location
- **Key Advantages**
  - No range limitation
  - Operates as BEV, then as a Hybrid

### eREV (Series PHEV)
- **Battery Size**: Medium (4-12kWh)
- **Range**: Electric for 11-25 miles below 62-80mph & light acceleration “Blended mode” (range =/> Conventional Vehicle)
- **Charging**
  - Home: Standard Wall Outlet sufficient but Level-2 240V can increase electrically driven miles
  - Work/Public charging not necessary but useful
- **No Home Charging Available?**: Either use as a conventional hybrid vehicle or charge at work/public location
- **Key Advantages**
  - No range limitation
  - Smallest battery fastest charge

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The Potential of Plug-In Vehicles

- 70% of U.S. drivers travel less than 33 miles/day

- Li-Ion batteries
  - Driven by consumer electronics
    - “Tipping Point” technology now for PHEV
  - Safety, durability, cost challenges are surmountable

- 50-70% lower cost per mile to operate: electricity cheaper than gas

- Synergy with the electric grid
  - Charge during valley when grid is underutilized & wind is strongest
  - Centralized & remote emissions
  - V2G/V2H: energy storage & backup for the grid

- Lower CO2 emissions

- Reduced oil imports
Hybridization of Internal Combustion Engines

- Internal Combustion Engine + Electric Motors + Electronics + Batteries

- Hybrid Electric Vehicles (HEVs)
  - Toyota Prius, Ford Escape, Honda Insight, Civic, Accord, Chevy Tahoe
    - Also, “mild-hybrids”: Saturn Vue Greenline, Saturn Aura, Mercedes S-class

- Brake energy recapture, start/stop, variable displacement engine/motor combination

- Proved the viability of electrified vehicles: Electronics + Big Batteries + Motors
PEV Charging & Interfaces to the Grid
PEV Refueling
Enabling A Different Paradigm

Gasoline/Diesel:
i) Drive to a special refueling location that you don’t really want to be at, but at least refuel fairly quickly

Electric Vehicles
i) Charge at a location you are naturally going to be at, but the vehicle is refueled at a slower rate (but still by departure time)
   >140M PEVs can charge at home* particularly overnight

ii) Drive to a special refueling location that you don’t really want to be at, but at least refuel fairly quickly (e.g. DC-Fast Charging for PEV Streetparkers)

iii) Wireless charging by autonomous PEVs: vehicle drives itself and parks over a wireless charging spot, charges, and then picks driver up when desired

*Note: US has ~240M vehicles, 140M of 240M = 58% PEV penetration
Where Are the Cars?

Fleet Distribution during week

Source of Data - 2001 National Household Travel Survey; GM Data Analysis (Tate/Savagian) - SAE paper 2009-01-1311
PEV Charging Locations

Public
- DC-Fast Charging
- Level-2 240V
- Level-1 120V

Workplace & Fleets
- DC-Fast Charging
- Level-2 240V
- Level-1 120V

Home:
- Level-2 240V
- Level-1 120V
Automotive Grade Industry Standard Couplers
Why Not Just Use an Extension Cord to Plug-In?

PEV Charging – Safety & Durability

- Receptacle and cord plug
  - Specified to comply with international standards including:
    - J1772™
    - IEC 62196
    - UL 2251
    - Electrical safety
    - 10,000 cycle life with exposure to dust, salt and water
    - Vehicle drive over does not expose a hazard
    - Sealing
    - Corrosion resistance
    - Touch temperature limits
Grid-Vehicle Interfaces

Charge Couplers

- **Configuration A**
  - AC Connector: Japan
  - SAE J1772™
  - DC Connector: CHADEMO
  - Japan

- **Configuration B**
  - AC Connector: China
  - DC Connector: CHADEMO
  - China

- **Configuration C**
  - AC/DC Connector: IEC 62196-3
  - EU Combo 2
  - AC/DC Connector: SAE J1772™
  - NA Combo 1

Universal Level-1&2 Coupler
PEV-Grid Interactions, Grid implications & Synergy
How the Grid Works

- Load varies every second of every day
- Grid Operator adjusts generation to equal Load
  - Various sources of energy & types of electricity generators
  - Each with different capacities, ramp rates, costs, emissions
  - Total electricity comes from combining numerous generators

- Grid Reliability Regions create a mesh network of sub-grids
  - Provides back-up (Reliability), scale economies (cost)
- Independent System Operators (ISOs) responsible for grid reliability and market functions
Attractive Opportunity with Plug In Electric Vehicles (PEVs) and Renewable Generation on the Grid

Potential Benefits of Intelligent PEV charging
- Avoid aggravating peak demand, energy storage for load shifting
- Lessen ramp rate of thermal to compensate for Wind/other renewables
- Load Curtailment when large wind (or any) generation output reductions occur
- Reduce curtailment (after transmission constraints removed)

PEVs are a new type of load for the Electric Grid
-- Large, potentially intelligent and Flexible
-- Grid Storage (2-way powerflow)
Huge Amount of off-Peak Grid Capacity

Spring, Fall, Winter seasons have even more spare capacity

- The region has plenty of off-peak capacity
Radical Wind Drop-off (Tail Event)

Example: Over 50% reduction of Wind generation output in <30 minutes
- 4/30/2009: Observed with Synchrophaser data phase angle changes
Slowing Ramp Rate required of Coal to improve efficiency/reduce emissions

Source: John Dumas, ERCOT

2013 High Wind Week - Generation by Fuel Type

Note – no changes to existing reserves required

Source: John Dumas, ERCOT
PEV-Grid Intelligent Interactions:

**Motivations**

**Consumers: Help the Environment and/or Save Money**
- To reduce emissions from Grid Generation
- Reduced electricity costs to charge vehicle
- Shift charging to avoid upgrading home electric service/panels

**Utilities: Demand Response Programs**
- Peak reduction for 4CP measurement (4 Coincident Peak for transmission cost allocation)
- Load shifting for lower wholesale price
- Insurance against losses from $9k ERCOT System Wide Offer Cap (SWOC)
- Reduce stress on Distribution Transformer
- PV intermittency buffering

**ISO/Utilities: Ancillary Services**
- EILS/ERS: Emergency Load Curtailment for grid operator
- Ramp Rate Moderation of grid thermal generation
- Wind Curtailment Reduction

**Region: Non-attainment air quality/emissions reductions**

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PEV Charging Demand Response Capability
(Using only G2V 1-way powerflow)

Charging at Maximum Rate

<table>
<thead>
<tr>
<th>Time</th>
<th>Charge Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.6kW</td>
<td>PHEV 0.6hr</td>
</tr>
<tr>
<td>0 kW</td>
<td>eREV 2.0hr</td>
</tr>
<tr>
<td>3.3kW</td>
<td>BEV 2.4hr</td>
</tr>
<tr>
<td>0 kW</td>
<td>PHEV 1.1hr</td>
</tr>
<tr>
<td>1.65kW</td>
<td>eREV 4.0hr</td>
</tr>
<tr>
<td>0 kW</td>
<td>BEV 4.7</td>
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</tbody>
</table>

Charging with varied rate

<table>
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<th>Time</th>
<th>Charge Rate</th>
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</thead>
<tbody>
<tr>
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<td>6.6kW</td>
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<tr>
<td>3.3kW</td>
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</tr>
<tr>
<td>1.65kW</td>
<td>1.65kW</td>
</tr>
<tr>
<td>0 kW</td>
<td>0 kW</td>
</tr>
</tbody>
</table>

Charging based on usage (not only battery size)

<table>
<thead>
<tr>
<th>All Electric Range*</th>
<th>Ev Battery Size(kWh)</th>
<th>Ev Miles per Day***</th>
<th>Gas Miles per Day</th>
<th>kWh per Day**</th>
<th>Minimum Charge Time @ Max Charge Rate (hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BEV 73</td>
<td>20</td>
<td>41</td>
<td>0</td>
<td>15.6</td>
<td>2.4</td>
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<tr>
<td>eREV 35</td>
<td>10.4</td>
<td>35</td>
<td>6</td>
<td>13.3</td>
<td>4.0</td>
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<tr>
<td>PHEV 13</td>
<td>3.25</td>
<td>13</td>
<td>28</td>
<td>3.7</td>
<td>6.0</td>
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</tr>
</tbody>
</table>

* Source: U.S. EPA window sticker for Chevrolet Volt & Nissan Leaf, Toyota claim for PHEV
** Includes 12% charging losses
*** PHEV Blended mode approximated as pure 13 mile AER (All Electric Range)
Assumes 15,000 miles/year = 41 miles per day, 3 miles/kWh
V2G: Vehicle To Grid

CalCar’s Felix Kramer’s V2H

http://www.udel.edu/V2G/V2Gconcept.html

The V2G concept is that EVs, PHEVs, or FCVs all can send power back to the electric grid. EVs & PHEVs already have the power connection. A connection must be added for pure FCV. Red arrows indicate electric flow from the vehicle to the grid.
The Usual Questions

“Coal Fired” Electric Vehicles
- Even with coal, PEVs still cleaner
- Grid is never only from one fuel source
- Coal is the dirtiest, mix only gets better
- Grid becoming cleaner over time

Trading “Petroleum Dependency” for “Lithium Dependency”
- Considerable global Lithium supply
- Lithium batteries can be recycled (not consumed like gasoline)

Trading “Petroleum Dependency” for “Rare Earth Metals” dependency
- Rare Earth metals for Permanent Magnet motors are not “rare”
- Chinese mines undercut competition given low labor costs & weak environmental protections
- Higher prices are now leading to US and other mines re-opening
- Can use Induction motors (As Tesla does) which do not require Rare Earth Metals

Lithium Batteries are not safe, cost too much, or will not last long enough
- Over 1 Billion Li-Ion batteries shipped per year
  - Cell phones, laptops, iPads, etc
- Rare to have issues if the batteries and system are designed & manufactured properly
- Li-Ion battery life greatly extended with shallow SOC window and thermal management
  - Note: 200,000 gasoline/diesel vehicles burn each year in the U.S.

Electric Vehicles will crash the grid
- Plenty of spare capacity on grid for off-peak charging
- No breakthroughs required for Intelligent charging to mitigate need for new grid capacity
- Grid economics can actually improve with intelligent PEV charging
- Build more capacity as needed with the additional revenue from PEV electricity sales(!)
Grid Generation Mix by Region
As the number of PEVs sold radically increases, there is the potential for “Clustering” of PEVs on home-end transformers

- Upstream in distribution and transmission system averaging effects eliminate PEV clustering specific concerns
- Trusted neighbors influence buying patterns (Prius, PV, Pools, large HDTVs) tending to get “clustering”

- The Solution is simple: dispatch a repair truck & Lineman replace & upgrade old transformer with a new larger one
  - A management issue, no technological breakthroughs required

-Who should pay for transformer upgrade?
  - Century+ old model is that costs of distribution are spread across entire customer base: too hard and not fruitful to partition
  - Transformer upgrades in past from new home loads from pools, room additions, appliances, HVAC never separately allocated
  - Divert a portion of new PEV electricity sales to pay for upgrades
  - Grid has been successively upgraded multiple times over the last century for Home Appliances, HVAC, Computers/Electronics
Li-Ion Batteries

- Batteries have been the limiting factor for decades
  - NiMH demonstrated automotive-grade durability in the Prius, debates about SOC Window
  - Lithium Ion: improved energy density over NiMH, demonstrated in consumer electronics
  - Numerous formulations of Lithium Ion with varied attributes (5+)
  - Key is achieving the smallest/lightest/least costly battery that meets safety/energy/durability needs
  - Expect improvements in composition, mfg, control algorithms, vehicle weight, HVAC/efficiency

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**Cycle Life of Different Batteries**

- Li-ion
- NiMH
- Potentially (Pb A5M)

**Envia vs. industry cost roadmap**

- NCA, NMC, LFP
- HCMR/Si, HCMR/Gr
- 180/KWh

**Fuel price, $ per gallon**

- Battery-electric vehicles are competitive
- PHEVs are competitive
- Hybrid-electric vehicles are competitive
- ICE vehicles are competitive

**Recent US conditions**

Source: Rooder, Newman, Roper, McKinley Quarterly, Battery Technology Charges Ahead
The “Big Vision”

Energy Efficiency
- Homes/Businesses (lighting, HVAC/Insulation)
- Transportation

De-Carbonize the Grid
- Zero (or much lower) Emissions Generation

Electrify Transportation (where possible)

Use Hydrocarbons for
- Recyclable Plastics, Fertilizer, Planes, Ships
An eREV in real use in Austin, Texas

3,864 miles over 4 months on 1 tank of gas
- Further than the distance from New York City to Los Angeles
- 8.1 gallons of gasoline + 1188kWh of electricity ($131 at Austin Energy rates)
  - ~3 miles/kWh energy consumption, Electricity = $0.11/kWh (U.S. Average ~ Austin Texas costs)
  - 35 to 42 miles/gallon when running on gasoline
- Typically fill up gas tank every 2 months or when taking an out-of-town trip
Questions??