PV, EV and Your Home: How Transportation and Grid Integration Work Together

OST-R Transportation Innovation Series
U.S. Department of Transportation
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Outline

• FSEC Energy and Transportation Research and Education
• “PV, EV and Your Home” Interface Magazine of Electrochemical Society
• Energy Prices Today and in 2025
• Power Generation Capacity Additions 2010 – 2030
• Zero Energy Homes & PV for EV
• Switching Small Cars to EVs
• Utilities in Solar Transportation Business
• Transportation in Solar Infrastructure Business
• Wireless Charging, V2G/V2X, Electric Bus, Fuel Cell Vehicles w/Backup Power Capability
UCF’s FSEC Leads in Energy

PV, EVs, Energy Efficient Buildings, Load Management, Batteries, Alternative Fuels, Hydrogen, Fuel Cells, Smart Grid Electronics, V2X, Training & Education
PV, EV, and Your Home at Less Than $1 a Gallon
by James M. Fenton

Home Energy Efficiency Retrofits and PV Provide Fuel for Our Cars
by James M. Fenton

PV and Batteries: From a Past of Remote Power to a Future of Saving the Grid
by David K. Cicci

The Role of V2G in the Smart Grid of the Future
by Richard A. Rausch

Fuel Cell Vehicles as Back-Up Power Options
by Paul Brooker, Nan Qin, and Nahid Mahafizi

EV Fast Charging, an Enabling Technology
by Charles Bonsfeld and Andrea Edwards
DOT Sustainability/Energy

• Exceeded greenhouse gas reduction targets four years in a row (23% relative to FY2008)
• Doubled renewable energy use (19% of DOT’s electricity consumption)
• Exceeded Petroleum Reduction Target, three years in a row (865,000 gallons or 24% 2005)
• DOT has tripled its alternative fuel use since 2005.
• DOT has reduced building energy use by 113 billion BTUs (19% of FY2003).
• For the second year in a row, DOT exceeded its water reduction target (90 M gallons or 19% of FY2007).

Update June 2015
“Thinking Outside The Box”

Instructions: Connect all nine dots with four straight lines without lifting your pencil.

Watch out for the perceived boundaries of the problem!
Energy is Fungible

• Drive our Cars and Operate our Buildings with electricity from renewables and energy efficiency
• Cheaper than Gasoline Today!
• Fossil Fuel Prices Going Up, Solar and Wind Going Down!
• Reduce greenhouse gases
• PV, EVs, Energy Storage and Energy Efficient Buildings Integrated Together
  – Increase Renewable Energy Penetration thereby further decreasing costs
  – Reliability and Resiliency of Transportation and Grid Infrastructures Improved
<table>
<thead>
<tr>
<th>Fuel Efficiency</th>
<th>Fuel Price</th>
<th>Cost per Mile</th>
<th>Cost per 12,000 Miles</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gasoline Car</strong></td>
<td>24.9 mpg</td>
<td>$3.00 per gal</td>
<td>12.0¢ per mile</td>
</tr>
<tr>
<td><strong>Electric Car</strong></td>
<td>3 miles per kWh</td>
<td>11.88 ¢/kWh ($0.99 per gal equiv.)</td>
<td>3.96¢ per mile</td>
</tr>
</tbody>
</table>
## U.S. 232 M Cars and Light Trucks
(Gasoline: $3.00/gal; 12,000 miles/yr)

<table>
<thead>
<tr>
<th></th>
<th>Fuel Efficiency</th>
<th>U.S. Vehicle Use per year</th>
<th>U.S. Bill $ B/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cars</strong> (111 M)</td>
<td>24.9 mpg</td>
<td>53.6 B gal/yr</td>
<td>$161 B/yr</td>
</tr>
<tr>
<td><strong>Light Trucks</strong> (121 M)</td>
<td>18.5 mpg</td>
<td>78.4 B gal/yr</td>
<td>$235 B/yr</td>
</tr>
<tr>
<td><strong>Small Cars</strong> (61 M)</td>
<td>30 mpg</td>
<td>24.4 B gal/yr</td>
<td>$73 B/yr</td>
</tr>
<tr>
<td><strong>If EV Small Cars</strong> (61 M)</td>
<td>3 miles/kWh</td>
<td>244 TWh/yr</td>
<td>$29 B/yr</td>
</tr>
</tbody>
</table>

## U.S. 127 M Residential Electricity Customers
(paying $0.1188 per kWh)

<table>
<thead>
<tr>
<th></th>
<th>Use per year</th>
<th>Bill per year</th>
<th>U.S. Use per year</th>
<th>U.S. Electric Bill $ B per year</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Residential Energy (Elec. + Thermal)</strong></td>
<td>Elec.: 10,836 kWh/yr</td>
<td>Elec. ($1,287) + Thermal ($713) = $2000</td>
<td>Elec: 1,376 TWh/yr</td>
<td>$163.5 B/yr</td>
</tr>
</tbody>
</table>
Price of Gasoline?

LIGHT-DUTY VEHICLE FUEL ECONOMY, 1975-2025

- US Retail Gasoline Price
- Average Price for Year
- Predicted Price
- CARS AND LIGHT TRUCKS COMBINED, MPG
- CAFE AVERAGE IN 2025, MPG

$6.83 per gallon, 2025
$5.20 per gallon, 2020
$3.00 per gallon
PV Grid Parity?

- US Residential Electricity Price
- Residential PV LCOE
- Residential PV LCOE w/ ITC
- Poly. (US Residential Electricity Price)
- Expon. (US Residential Electricity Price)

TODAY

- 14.5 ¢/kWh
- 9 ¢/kWh
- 8 ¢/kWh

Year


US Residential Electricity Price, cents/kWh

18
16
14
12
10
8
6
4
2
0
GASOLINE PRICE EQUIVALENT (Cost Per Mile) LIGHT-DUTY VEHICLES and ELECTRIC VEHICLES

Costs are relative to cost of $3.00 per gallon gasoline at a vehicle efficiency of 25 mpg
Utility Solar Cheaper than Gas CC (in 2014 w/ITC; 2017 w/o ITC)

Source: Adapted from Lazard's Levelized Cost of Energy Analysis Version 8.0 September 2014

Legend estimates:
(a) Low end represents single-axis tracking. High end represents fixed-tilt installation. Assumes 10 MW fixed-tilt installation in high insolation jurisdiction (e.g., Southwest U.S.).
(b) Diamonds represent estimated implied levelized cost of energy in 2017, assuming $1.25 per watt for a single-axis tracking system.
GLOBAL GROSS POWER GENERATION CAPACITY ADDITIONS, 2010–30 (GW)

FOSSIL FUEL

Forecast

Clean Energy

Forecast

Source: Bloomberg New Energy Finance

Note: Underlying data is from GREMO 2014
Cost Effective Zero Energy Homes & PV for EV

Monthly Cost Differences with Respect to Base House (Retrofits, +PV for Zero Electric Home, +PV for EV)

<table>
<thead>
<tr>
<th>Location</th>
<th>Retrofit House minus Base House</th>
<th>Zero Electric House minus Base House</th>
<th>Zero Electric House + Car PV minus Base House</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baltimore (4)</td>
<td>€60</td>
<td>€80</td>
<td>€60</td>
</tr>
<tr>
<td>San Francisco (9)</td>
<td>€40</td>
<td>€60</td>
<td>€40</td>
</tr>
<tr>
<td>New York (4)</td>
<td>€20</td>
<td>€40</td>
<td>€20</td>
</tr>
<tr>
<td>Miami (1)</td>
<td>€0</td>
<td>€20</td>
<td>€0</td>
</tr>
<tr>
<td>Houston (2)</td>
<td>€-20</td>
<td>€-40</td>
<td>€-20</td>
</tr>
<tr>
<td>Phoenix (2)</td>
<td>€-40</td>
<td>€-60</td>
<td>€-40</td>
</tr>
<tr>
<td>Ft. Worth (3)</td>
<td>€-60</td>
<td>€-80</td>
<td>€-60</td>
</tr>
<tr>
<td>Minneapolis (6)</td>
<td>€-80</td>
<td>€-100</td>
<td>€-80</td>
</tr>
<tr>
<td>Los Angeles (9)</td>
<td>€-100</td>
<td>€-120</td>
<td>€-100</td>
</tr>
<tr>
<td>Denver (5)</td>
<td>€-120</td>
<td>€-140</td>
<td>€-120</td>
</tr>
<tr>
<td>St. Louis (4)</td>
<td>€-140</td>
<td>€-160</td>
<td>€-140</td>
</tr>
<tr>
<td>Atlanta (3)</td>
<td>€-160</td>
<td>€-180</td>
<td>€-160</td>
</tr>
<tr>
<td>Detroit (5)</td>
<td>€-180</td>
<td>€-200</td>
<td>€-180</td>
</tr>
<tr>
<td>Seattle (no PV) (4)</td>
<td>€-200</td>
<td>€-220</td>
<td>€-200</td>
</tr>
<tr>
<td>Seattle (4)</td>
<td>€-220</td>
<td>€-240</td>
<td>€-220</td>
</tr>
</tbody>
</table>
**Annualized Energy and Investment Costs**

*Atlanta_1600sf-1sty-Crwl-Frm-HP_ReFi*

- **Cost of Doing Nothing**
- **2010 Residential PV $6.50 W Installed**
- **2015 Residential PV $3.73 W Installed**

**Rate Parameters:**
- Gen Inflation = 2.39%
- Energy Inflation = 4.42%
- Discount Rate = 4.39%
- Mortgage Rate = 4.00%

**2010 Prices:**
- Elect. = $0.1007/kWh
- Gas = $1.564/therm

**Drive EV for Free on $475 Savings**

**Incremental Measures**

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**FLORIDA SOLAR ENERGY CENTER — A Research Institute of the University of Central Florida**
Switching U.S.’s Small Cars to PEVs

- 12,000 m/yr
- 30 mpg
- $3.00/gal
- $73 B/yr

12,000 m/yr
3 m/kWh
11.88¢/kWh
$29 B/yr

26% of U.S.’s vehicles (61M) are small cars

Saves 18% of Gasoline
Switching U.S.’s Small Cars to PV PEVs

- 163 GW of PV Would Power ALL Small Cars
  - Utility-Installed PV
    $1.77/W w/ ITC = $202B
    [2.8 yrs of Gasoline Savings]
  - Utility-Produced PV
    5.6¢/kWh w/ITC = $0.47 gallon equivalent

Utilities Should Be in the Solar Transportation Fuel Business!
Transportation Should Be in the Solar Infrastructure Business?
Aerial view of Oregon DOT's Solar Highway Demonstration Project
Photo credit: Oregon DOT

German 2.8 MW solar array on the roof of a 2.7 km long noise-barrier tunnel on the A3 highway near Aschaffenburg, Germany. Photo source: www.ralos.de

Florida Turnpike’s Solar Demonstration Project under construction in 2012

Solar EV Charging Station, UCF
U.S. Interstate System is 46,876 miles long
Assuming 10 feet width of Highway Right-of-Way for solar and 10W/ft²
Fuel for 9.3 M EVs
Produced at $0.47/gal
Benefits of Switching to EVs

Consumer Fuel Savings
300k EVs today = $265 M
4 M EVs in 10 years = $3.5 B
50% Gov. fleet = $265 M

Annual Societal Benefits (4 M EVs)
Urban Air Pollution = $1.5 Billion
Human Health = 43,900 (DALY)
Employment = 136,000 jobs
U.S. GDP = $16.6 Billion
Business Profit = $10 Billion
Additional Income = $5.8 Billion

DALY – disability-adjusted life year
Dynamic Wireless Charging can be installed beneath the top surface of the roadway. Utah State University.
V2G Use of PEV Batteries

Chevrolet

Nissan

Tesla/SolarCity
UCF V2X Integration Technology

- Operative EV charger with computer controlled two-way feature
- Laboratory demonstration of two-way feature with Nissan Leaf
- V2X in lab environment
UCF’s FSEC Public Charging
Utility Demand Modifications at UCF Charging Station

SEP 2.0 Communications Test
June 19, 2015

SEP 2.0 – Smart Energy Profile V2.0 Communication Standard

Workplace Charger Power (kW)

Time (HHMM, EST)

100% Power Output
75%, 30-min
50%, 30-min
50%, 20-min
initiated w/ direct server communication
Tallahassee StarMetro Electric Bus

UCF Program
Elec. vs Diesel
Route Analysis
Demand Strategies
Battery R&D

University of Hawai‘i
- Cell level testing
- Accelerated durability tests

Tuskegee University
Physics Lab
- Li-Ion Polymer Battery Lab
Toyota Mirai Fuel Cell Car

Energy content is 165 kWh (Tesla S = 85 kWh)

Power connection can provide 60 kWh to household in power outage

2016 Toyota Marai hydrogen fuel cell car, New Port Beach, CA, November 2014 (Photo: www.greencarreports.com)
Buildings can “Island” from the Grid using Electric Vehicles with Range Extenders (gasoline, then renewable hydrogen fuel cell)

**Grid-Connected**
- Solar Panels
- Grid
- energy-efficient Buildings
- Fleet of FC-REVs
- Electrolyzer
- H₂ storage tanks

**Grid-Disconnected**
- Solar Panels
- Resilient Buildings
- Fleet of FC-REVs
- Vehicle to Grid, V2G
- H₂ storage tanks
- Electrolyzer
Most Fueling at Home or From Building

Princeton Power System bi-directional charger at LA AFB (Photo: Tech Sgt Sarah Corrice, AFSC)

Nissan LEAF to home. (Photo: Nissan.)
Summary

• Cars and Buildings can operate on PV electricity, less than $1 a gallon
• PV Grid Parity is today, PV Gasoline Parity is a “long distance in the rearview mirror”
• New Electric Power Renewable Generation Capacity Additions are Greater than Fossil Fuel Additions, 2013 – 2030
• By Integrating PV, EVs, Energy Storage and Energy Efficient Buildings
  – Reduced costs
  – Increase Reliability and Resiliency
  – Reduce Greenhouse Gases
• Utilities in Solar Transportation Business, Production at < $0.47/gal
• Transportation in Solar Infrastructure Business, Production at < $0.47/gal
• EVTC Research in: Wireless Charging, V2G/V2X, Electric Bus, Fuel Cell Vehicles w/Backup Power Capability helping to take Transportation and the Grid into a “Bright Future”

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EXTRA SLIDES
Estimated U.S. Energy Use in 2014: ~98.3 Quads

Source: LLNL 2015. Data is based on DOE/EIA-0035(2015-03), March, 2014. If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports consumption of renewable resources (i.e., hydro, wind, geothermal and solar) for electricity in BTU-equivalent values by assuming a typical fossil fuel plant "heat rate." The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 65% for the residential and commercial sectors 80% for the industrial sector, and 21% for the transportation sector. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527
Estimated U.S. Carbon Emissions in 2014: ~5,410 Million Metric Tons

Source: LLNL 2015. Data is based on DOE/EIA-0035(2015-03), March, 2015. If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Carbon emissions are attributed to their physical source, and are not allocated to end use for electricity consumption in the residential, commercial, industrial and transportation sectors. Petroleum consumption in the electric power sector includes the non-renewable portion of municipal solid waste. Combustion of biologically derived fuels is assumed to have zero net carbon emissions – the lifecycle emissions associated with producing biofuels are included in commercial and industrial emissions. Totals may not equal sum of components due to independent rounding errors. LLNL-MI-410527
VTO Battery R&D Progress: Cost Reduction & Energy Density

DOE/USABC reduced the cost of PEV batteries by 70% and doubled their energy density during the past 5 years

- Current cost of advanced PHEV battery technology estimates average $325/kWh, useable
- Results based on prototype cells & modules meeting DOE/USABC performance targets.
- Detailed USABC battery cost model used to estimate the cost of PEV battery packs assuming that 100,000 batteries are manufactured annually.

- Batteries ranged from PHEV 40 packs (~14 kWh) to EV packs (40kWh).
- These battery development projects focus on advance cathodes, processing improvements, cell design and pack optimization.
- Standard electrolyte & graphite anode were used.
UCF’s FSEC Office & Lab Building Utility Demand Charges

July 1, 2014 Monthly Peak

- **UCF measured demand**: 345.3 kW
- **One DCFC Impact, 30 kW if above peak @ $11/kW = $330**
- **Nissan Leaf Full Charge 18 kWh @ $0.05/kWh = $0.90**

**Electricity Cost** = $0.05/kWh, **Demand** = $11/kW
US CAPACITY BUILD, 2008–20 (GW)

Notes: Bloomberg New Energy Finance base case build forecasts; historical build from EIA Form 860

Source: Bloomberg New Energy Finance
Economic Cost Optimization Value
Atlanta_1600sf-1sty-Crwl-Frm-HP_ReFi

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