THE SEARCH FOR SUSTAINABLE TRANSPORT: ANTICIPATING AMERICANS’ VEHICLE & TRAVEL CHOICES

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Introduction

- **Climate & energy security** are key concerns for most countries.

- **Per-capita GHG emissions in U.S.** are **four times the world average**, with transportation accounting for 30% of the nation’s total.

- **Plug-in electric vehicles (PEVs)** have emerged as important alternatives.

Some key questions:

- What are emerging **PEV designs**?
- **Who** will be buying & driving **PEVs**?
- What are typical **use patterns**?
- What are the emissions **impacts**?
# Some PEV Designs

<table>
<thead>
<tr>
<th>Make &amp; Model</th>
<th>Release Date</th>
<th>Retail Price (after credit)</th>
<th>Body Type</th>
<th>Battery (kWh)</th>
<th>Estimated SOC</th>
<th>AER (miles)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Range-Extended PEVs</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chevy Volt eREV</td>
<td>2010</td>
<td>$33,500</td>
<td>4-door sedan</td>
<td>16</td>
<td>65%</td>
<td>35</td>
</tr>
<tr>
<td>Toyota Prius PHEV</td>
<td>2012</td>
<td>$29,500</td>
<td>4-door sedan</td>
<td>4.4</td>
<td>Est 50%</td>
<td>11</td>
</tr>
<tr>
<td>Ford CMAX Energi</td>
<td>2013</td>
<td>Est $30,000</td>
<td>4-door CUV</td>
<td>Est 10</td>
<td>Est 70%</td>
<td>Est 20-25</td>
</tr>
<tr>
<td><strong>Battery-Electric Vehicles (BEVs)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tesla Roadster</td>
<td>2009</td>
<td>$101,500</td>
<td>2-door sports car</td>
<td>53</td>
<td>80%+</td>
<td>240</td>
</tr>
<tr>
<td>Nissan LEAF</td>
<td>2010</td>
<td>$25,250</td>
<td>4-door sedan</td>
<td>24</td>
<td>90%+</td>
<td>73</td>
</tr>
<tr>
<td>Mitsubishi i (MiEV)</td>
<td>2011</td>
<td>$21,625</td>
<td>4-door sedan</td>
<td>16</td>
<td>TBA</td>
<td>100</td>
</tr>
<tr>
<td>Ford Focus</td>
<td>2012</td>
<td>$31,700</td>
<td>4-door sedan</td>
<td>23</td>
<td>TBA</td>
<td>100</td>
</tr>
<tr>
<td>Tesla Model S</td>
<td>2012</td>
<td>$49,900</td>
<td>4-door sedan</td>
<td>42</td>
<td>80%+</td>
<td>160</td>
</tr>
</tbody>
</table>
Extended-Range EVs (eREVs)

- **Battery +** internal combustion engine (ICE).
- Electrical energy provided by battery initially, & by ICE when battery is depleted.

**Example:** **Chevy Volt** (2010)

- Price: $33,500 (after credit)
- Electric Range: 35 miles (EPA)
Battery Electric Vehicles (BEVs)

- **Large on-board battery** provides all motive power.
- **Charge while parked** via electric power cord.
- **Range anxiety** is an issue.
- **Example:** *Nissan Leaf* (2011)
  - MSRP: $25,250 (after credit)
  - Range: **73 miles** (EPA)
Plug-in Hybrid EVs (PHEVs)

- **Similar to HEVs**, but bigger batteries & **can be charged using power grid**.
- Typically operates in **blended mode**, with both gas engine & electric motor working simultaneously.
- **Example**: **Prius PHEV** (2012)
  - Price: $29,500 (after credit)
  - Electric Range: **11 miles**
Motivation: **We need to know...**

- **How many** households can “make do” with a range-limited BEV?
- What **share** of a household’s **VMT** will be electrified when adopting a PHEV?
- What **cost savings** can households expect from a PEV?
- How quickly will **households be buying** these?
- What effect will they have on **GHG emissions**?

- Such info allows manufacturers to better **predict demand**, many consumers to **overcome** range & cost concerns, & policymakers to **make decisions**.
Seattle’s Multi-day GPS Data

- Multi-day data reflect Americans’ great variability in day-to-day vehicle use.
- GPS data collected from 424 vehicles (264 households) in Seattle region between November 2004 & April 2006, for about 340 days each.
- Average miles-driven per day is 25.4 ± 12.3 miles (across all vehicles & days).
- Population weights were used to reflect Seattle population.
Analysis Framework

Household

Single-vehicle household
- Switch to a BEV (Case 1)
  - What percentage of the days can all mileage be covered?
  - The vehicle that travels less on average (Case 3)
    - What percentage of the days can the entire mileage be covered?

Switch to a PHEV (Case 2)
  - What percentage of miles are electrified?

Multiple-vehicle household
- Switch a vehicle to a BEV
  - Which vehicle to switch?
    - The vehicle that travels less on any given day (Case 4)
      - What percentage of the days can the entire mileage be covered?

Switch a vehicle to a PHEV
  - Which vehicle to switch?
    - The vehicle that travels more on average (Case 5)
      - What percentage of miles are electrified?
    - The vehicle that travels more on any given day (Case 6)
      - What percentage of miles are electrified?
BEV Accommodation: 1-vehicle HHs

Maximum Possible Single-vehicle Household Accommodation Shares with BEVs in Seattle (Case 1)

- 90% of days
- 95% of days
- 99% of days

Nissan Leaf (73 mi AER)
BEV Accommodation: Multi-vehicle HHs

Maximum Possible Multiple-vehicle Household BEV Accommodation Shares in Seattle, with **BEV Replacing the Lower Overall-VMT Vehicle** (Case 3)
Average Shares of **Total** Household Miles Electrified (with Std. Devs.) using PHEVs in Multiple-vehicle Seattle Households
### Annual Cost Savings: Volt vs. Cruze

<table>
<thead>
<tr>
<th>Electricity Prices (ct/kWh)</th>
<th>Annual Savings</th>
<th>Gas Price Assumptions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$2.50/gallon</td>
<td>$3.50/gallon</td>
</tr>
<tr>
<td>Vehicle driven on average ≤ 15 miles/day, &amp; 4,315 miles/year</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.0</td>
<td>$252</td>
<td>$383</td>
</tr>
<tr>
<td>11.2</td>
<td>$188</td>
<td>$319</td>
</tr>
<tr>
<td>16.0</td>
<td>$128</td>
<td>$259</td>
</tr>
<tr>
<td>Vehicle driven on average between 15 &amp; 30 miles/day, &amp; 8,056 miles/year</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.0</td>
<td>$453</td>
<td>$686</td>
</tr>
<tr>
<td>11.2</td>
<td>$340</td>
<td>$573</td>
</tr>
<tr>
<td>16.0</td>
<td>$235</td>
<td>$468</td>
</tr>
<tr>
<td>Vehicle driven on average more than 30 miles/day, &amp; 14,886 miles/year</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.0</td>
<td>$734</td>
<td>$1,105</td>
</tr>
<tr>
<td>11.2</td>
<td>$567</td>
<td>$937</td>
</tr>
<tr>
<td>16.0</td>
<td>$412</td>
<td>$783</td>
</tr>
</tbody>
</table>

Note: $33,500 Volt (after $7,500 credit) uses 36 kWh per 100 miles, & enjoys a 37 mpg (once battery is depleted). The $22,225 Cruze LTZ is rated for 28 mpg. Cruze navigation system costs $995. Net price difference is $9,560.
## Net Present Value: LEAF vs. Versa

### 15yr/150k mile

<table>
<thead>
<tr>
<th>Gasoline Price ($/Gallon)</th>
<th>Replacement Battery Price ($ per kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$0 No Battery Replacement</td>
</tr>
<tr>
<td>$7.00</td>
<td>$18,128</td>
</tr>
<tr>
<td>$6.50</td>
<td>$16,398</td>
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<tr>
<td>$6.00</td>
<td>$14,668</td>
</tr>
<tr>
<td>$5.50</td>
<td>$12,938</td>
</tr>
<tr>
<td><strong>$5.00</strong></td>
<td><strong>$11,208</strong></td>
</tr>
<tr>
<td>$4.50</td>
<td>$9,478</td>
</tr>
<tr>
<td>$4.00</td>
<td>$7,748</td>
</tr>
<tr>
<td>$3.50</td>
<td>$6,018</td>
</tr>
<tr>
<td><strong>$3.00</strong></td>
<td><strong>$4,288</strong></td>
</tr>
<tr>
<td>$2.50</td>
<td>$2,558</td>
</tr>
</tbody>
</table>
Findings from Seattle GPS Study

- BEVs appear feasible for significant shares of households, with relatively little behavioral adjustment.
- Electrified-miles shares are sizable.
- Without tax credits, the relative NPVs are typically negative at $3/gallon (gas prices at time of analysis).
- Cost savings may be substantial for longer-distance drivers who electrify more of their miles and is estimated to be strongly positive for those in higher-fuel-cost regions (e.g., Germany at $7 to $8 per gallon).
Who supports what, & what may our fleet look like in 30 years?
Austin Energy, Travel & Vehicle Surveys

Survey Design & Distribution in Fall 2008 & Spring 2009

- **Hard copy + Online versions**

- **Topics:** Travel Choices, Vehicle Ownership, Home Design & Energy Use, Energy Policy Opinions, Vehicle Purchase & Retirement Plans, & Demographic Attributes

- **Sample Attributes vs. Austin PUMS:** Workers under-represented & students over-represented → **Sample corrected via weights** across income, gender, age, household size, & worker & student status
What Should We Do about Climate Change?

- Do Not Do Anything: 2.99%
- Global Warming is not a Problem: 5.19%
- Adapt to a Warmer Climate: 28.61%
- Regulations Imposed by the Government: 56.06%
- Research and Development: 69.29%
- Lifestyle Changes: 83.93%
Key Austin Energy Survey Findings

- **Policy of adaptation** (to climate change) more often preferred by workers & households owning many vehicles.

- **Regulation of energy use** more often preferred by women & homeowners.

- **Caps on household energy use** preferred to taxes.

- **Long-term behavioral changes** are difficult to implement.

- Most agree that climate change is a concern, but are unwilling to change their own behavior.

- Increasing **income & education** levels lead to greater (stated) concern about one’s impact on the environment.
Vehicle Survey: Top Three Attributes

![Graph showing the top three attributes of vehicles based on respondent priorities. The graph uses bars to represent the percent of respondents (weighted) for each attribute, with labels for fuel economy, purchase price, vehicle type/class, overall visual appeal, reliability, resale value, maintenance cost, amenities, cabin room/interior size, and other. Different colors indicate first, second, and third priority.](image-url)
With gas at $5/gallon, Prius HEV was top choice (27%).

At $7/gal, Prius PHEV with 40 AER was topper (29%).

When providing info on environmental costs, PHEV (25%) was top choice, followed by Compact cars (23%).
Unfortunately, simulation predicts almost a **TRIPLING** of person-travel-related **GHG emissions vs. base year**, under TREND.
The Nation’s Fleet Evolution

Modeling Household Choice Behavior over the Long Run
US Fleet Evolution: Some Survey Results

- 18%, 5.5%, & 2.3% of American households state that they intend to **acquire** a vehicle, **replace** a vehicle, or **dispose** a vehicle within **1 year**.

- **High purchase price** is top reason for not buying certain vehicles they had considered recently.

- 42% would **consider paying $3,000 more to buy a HEV version** of a conventional vehicle.

- 36% expressed **interest in buying a PHEV** at $6,000 more than comparable ICE (vs. 56% Austinites).

- 56% have **power access** in a garage or carport.

- Just **29%** of respondents **support a feebate** policy (vs. 63% of Austinites).
Stated-preference questions **offered 12 vehicles** (with info on price & fuel economy, plus links to online details): 9 conventional (above) + Prius **HEV**, Prius **PHEV30**, & **SmartCar**.
Coming Vehicle Choices

- **Environmental-cost scenario’s results closely mimic** those of $5/gal scenario, though environmental costs presented are far lower.

- **Simple labeling or astute advertising** may shift perceptions quickly in the direction of a cleaner fleet.
Analysis of the Choice Data

- A variety of behavioral model specifications were estimated (e.g., MNL for transaction, NL for vehicle choice, & WLS or Heckit for use).

- Households in survey sample were scaled up using population weights to generate a synthetic population of 50,000 households.

- The simulation anticipates each household’s vehicle holding decisions & type of vehicle to be acquired/disposed, along with use (annual VMT), on a yearly basis, relying on Monte Carlo draws.
Modeling Framework

HH Population at Time $t$

HH Exit Model (Out-Migration & Death)

HH Transitions Marriage, Divorce, Child Birth & Leaving Home

HH Birth Model (In-Migration, Divorce & Leaving Home)

Vehicle Ownership Model

Transaction Decision Model

Buy

Stated Preference Vehicle Choice Model

Sell

Lowest Utility Vehicle Disposal

Replace

Lowest Utility Vehicle Disposal

Do Nothing

Stated Preference Vehicle Choice Model

Update Household Vehicle File, HH Population at time $t +1$

Vehicle Usage Model & GHG Emissions
Simulating the Future

- Micro-simulation predicts future fleet mix, overall usage, & associated emissions from 2010 through 2035.

- Scenarios
  - **TREND**: Status quo/business-as-usual.
  - **LOWPRICE**: Price of PHEV lowered by $4,100.
  - **FEEBATE**: Rebates/fees to vehicles over/under 30 mpg at an average rate of $200 per mpg.
  - **FEEBATE2**: Rebates/fees to vehicles over/under 30 mpg at an average rate of $400 per mpg.
  - **HI-DENSITY**: Quadrupled job & household densities.
  - **LAYERING** of LOWPRICE, FEEBATE, & FEEBATE2 scenarios with GASPRICE at $5 per gallon.
  - **GASPRICE$7**: Gasoline at $7 per gallon.
US Fleet-Mix Predictions for 2035

- Trend
- Low Price
- FeeBate
- FeeBate2
- Hi-Density
- Low Price + Gas5
- FeeBate + Gas5
- FeeBate2 + Gas5
- Gas Price $7
2035 US Greenhouse Gas Emissions

- TREND
- LOWPRICE
- FEEBATE
- FEEBATE2
- HI-DENSITY
- LOWPRICE+GA...
- FEEBATE+GAS$5
- FEEBATE2+GAS...
- GASPRICE$7

CO2e Emissions (Million Pounds)
$7/gallon gas prices had greater impact on vehicle ownership & miles than any other policy examined (including feebates & combined feebate-PHEV price drop).

Changes in fleet mix, VMT, & emissions predicted via simulation are far less than needed to tackle environmental & energy security issues.

More widespread use (of PEVs & HEVs) may emerge with strategic & pronounced marketing, technological advances (lower prices), as well as other incentives (e.g., HOV lane & fast-charge access) & greater awareness of energy & climate issues.
Urban Systems Forecasting

Modeling Household & Firm Location Choices, Land Use Patterns, Land Development, Travel Choices, Emissions & Air Quality
Austin Policy Scenarios

- Business as Usual or trend scenario (BAU)
- Urban Growth Boundary (UGB)
- Increase Travel Costs ($6/gallon & toll 10 cents/mile) (PRICING)
- Doubled Capacity of Austin’s IH-35 (EXPCAP)
- Introduction of a New East-side Freeway (SH130).
Results: **Land Use Statistics** (year 2030)

<table>
<thead>
<tr>
<th></th>
<th>BAU</th>
<th>UGB</th>
<th>PRICING</th>
<th>EXPCAP</th>
<th>SH130</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CBD Accessibility</strong></td>
<td>962,045</td>
<td>1,020,487</td>
<td>929,141</td>
<td>937,912</td>
<td>938,026</td>
</tr>
<tr>
<td><strong>Count-weighted Household Density</strong></td>
<td>3,608</td>
<td>5,460</td>
<td>3,072</td>
<td>3,525</td>
<td>3,565</td>
</tr>
<tr>
<td><strong>Count-weighted Jobs Density</strong></td>
<td>14,810</td>
<td>15,093</td>
<td>14,288</td>
<td>16,893</td>
<td>14,460</td>
</tr>
</tbody>
</table>
### Year 2030 estimates…

<table>
<thead>
<tr>
<th></th>
<th>BAU</th>
<th>UGB</th>
<th>PRICING</th>
<th>EXPCAP</th>
<th>SH130</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TRANSPORTATION ENERGY</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Daily VMT (million)</td>
<td>94</td>
<td>81</td>
<td>90</td>
<td>100</td>
<td>103</td>
</tr>
<tr>
<td>Daily CO2 (million lbs/day)</td>
<td>95</td>
<td>83</td>
<td>91</td>
<td>101</td>
<td>98</td>
</tr>
<tr>
<td>CO2 emissions per capita (tons/yr)</td>
<td>5.51</td>
<td>4.82</td>
<td>5.28</td>
<td>5.86</td>
<td>5.69</td>
</tr>
<tr>
<td>Annual VMT per capita</td>
<td>10,293</td>
<td>8,993</td>
<td>9,859</td>
<td>10,943</td>
<td>10,618</td>
</tr>
<tr>
<td><strong>RESIDENTIAL ENERGY</strong></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>CO2 from electricity (million lb/yr)</td>
<td>18,648</td>
<td>17,018</td>
<td>18,569</td>
<td>18,578</td>
<td>18,974</td>
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<tr>
<td>CO2 from natural gas (million lb/yr)</td>
<td>2,868</td>
<td>2,777</td>
<td>2,840</td>
<td>2,857</td>
<td>2,833</td>
</tr>
<tr>
<td>CO2 emissions per capita (tons/yr)</td>
<td>4.16</td>
<td>3.83</td>
<td>4.14</td>
<td>4.15</td>
<td>4.22</td>
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<tr>
<td><strong>TOTAL CO2 per capita (tons/year)</strong></td>
<td>9.68</td>
<td>8.65</td>
<td>9.42</td>
<td>10.01</td>
<td>9.91</td>
</tr>
</tbody>
</table>
Ozone Modeling for Austin

UGB & Toll+Tax policies result in 15% savings in VMT, NOx & HC.
Thank you!

Questions & Suggestions?

Papers available at www.ce.utexas.edu/prof/kockelman