Modeling and Analysis of Plug-in Electric Vehicle Charging Infrastructure Supporting Shared Mobility

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Project Overview

Timeline

• Project end: Sept. 2019
• Completion: 20%

Barriers

• Infrastructure has long been a major barrier to alternative fuel vehicle (AFV) adoption
• Need cost-effective fueling infrastructure to support energy efficient shared mobility applications
• Limited understanding on energy impacts of shared mobility applications

Budget

<table>
<thead>
<tr>
<th></th>
<th>FY17</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>INL</td>
<td>$210K</td>
<td>$800K</td>
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<tr>
<td>ANL</td>
<td>$210K</td>
<td>$670K</td>
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<tr>
<td>NREL</td>
<td>$200K</td>
<td>$765K</td>
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<tr>
<td>ORNL</td>
<td>$50K</td>
<td>$395K</td>
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</table>

* Funding amount by lab is for this task only, not for the entire pillar

Partners

[Argonne National Laboratory][INL Idaho National Laboratory] [Oak Ridge National Laboratory] [NREL National Renewable Energy Laboratory]
### Project Overall Objectives/Relevance

Task 1 and 2 under Advanced Fueling Infrastructure Pillar

- Design fueling infrastructure networks to meet the needs of the future transportation system and assess the national energy and economic benefits

- FY17 focus on **near term, intra-city charging infrastructure for shared vehicles without full automation**

#### Study focus

<table>
<thead>
<tr>
<th>Task 1 – Estimation of potential national benefits of fueling infrastructure deployment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1 VMT, vehicle adoption, energy, emissions of <strong>near-term</strong> deployment</td>
</tr>
<tr>
<td>1.2 VMT, vehicle adoption, energy/emissions of <strong>mid/long-term</strong> deployment</td>
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<tr>
<td>1.3 Economic benefits</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Task 2 – Modeling and analysis of regional fueling infrastructure networks for positive ROI</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1 Modeling and analysis of <strong>near-term</strong> fueling infrastructure networks</td>
</tr>
<tr>
<td>2.2 Modeling and analysis of <strong>mid/long-term</strong> fueling infrastructure networks with respect to new technologies and trends</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Task 3 - Engineering feasibility assessment of advanced fueling infrastructure</th>
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</thead>
<tbody>
<tr>
<td>3.1 High-power DC fast charging</td>
</tr>
<tr>
<td>3.2 Unconventional hydrogen production/storage/distribution</td>
</tr>
<tr>
<td>3.3 Dynamic wireless power transfer</td>
</tr>
<tr>
<td>3.4 Integration of infrastructure with built environment</td>
</tr>
</tbody>
</table>
Task Objectives/Relevance

- **Task 1:** Estimate national energy and GHG impacts of near-term AFV infrastructure deployment to support intra-city travel based on regional results

- **Task 2:**
  - Use advanced tools to model near-term charging infrastructure deployment in 3 regions (Columbus, OH; Texas Triangle; Seattle, WA) supporting *intra-city car/ride-sharing* fleets
  - Consider the cost for both drivers and service providers

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**CAV**
- MaaS and CAV penetration rate
- Charging decision

**MDS**
- Charging behavior

**MM**
- Freight demand

**CAV**
- Infrastructure location
- National fuel mix by year

**MDS and MM**
- Infrastructure location

CAV: connected and automated vehicle, MDS: mobility decision science, MM: multi-modal
<table>
<thead>
<tr>
<th>Year</th>
<th>Q</th>
<th>Quarterly Milestone</th>
<th>Progress</th>
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</thead>
<tbody>
<tr>
<td>FY17</td>
<td>Q1</td>
<td>Identify geographic areas for study and external partners.</td>
<td>Completed</td>
</tr>
<tr>
<td></td>
<td>Q2</td>
<td>Complete design of revenue/cost model framework for infrastructure deployment planning.</td>
<td>Completed</td>
</tr>
<tr>
<td></td>
<td>Q4</td>
<td>For selected regions, complete near-term infrastructure planning analysis supporting inter-city travel of privately-owned light duty vehicles and intra-city car/ride-sharing fleets.</td>
<td>In Progress</td>
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</table>
Overall Approach

- Identify short-term market potential of shared mobility
  - Types of shared mobility
  - # of shared vehicles vs. population density
- Analyze travel survey data and model EVSE demand
  - Types of trips could be shared
  - Maximum eVMT with infrastructure support
- Model EVSE Return of Investment (ROI)
- Extrapolate from regional to national

Regional

VMT
%eVMT

Summarize by population density, trip type, vehicle type, class

By vehicle class, powertrain type, fuel type,

National Energy

VMT
%eVMT
Market Adoption
Survival
Fuel efficiency

BaSce Assumptions

BaSce: Prospective Benefits Assessments of Vehicle Technologies, Argonne
Approach for Analyzing Infrastructure Impacts on Electric Vehicle Market Share and Energy Use

Charging Infrastructure Scenarios
- Locations of Charging Stations
- Number of chargers per station

Charging Opportunity
- Probability of finding a charging station at a stop
- Recharging at charging stations can extend electric vehicles’ range

Extended Electric Vehicle Range
- Sale & Fleet Size: SI/Ci/HEV/PHEV/BEV

Vehicle Market Share
- Energy use by fuel type
- GHG
- VMT and eVMT

EVI-Pro Model

Charging opportunity Model

MA3T Model

VISION Model

EVI-Pro Schematic

Stop-based Charging Opportunity

Fuel and Electricity Use

Social Impact (energy, environ, econ)

input
output
feedback

Auto Industry

Energy Prices

Policy Maker

Driving Behavior

Component Attributes

Fuel and Electricity Use

Experience

Stock

Social Impact (energy, environ, econ)

MA3T Model

VISION Model

Approach/Strategy
Demand/Cost Modeling Framework for Regional Infrastructure Planning

Installation cost = f(X1 \ldots X5)

- X1: Electrical service upgrades required or not
- X2: Aboveground or underground service
- X3: Surface condition
- X4: Size of trenching or boring required
- X5: Distance from the power source

Revenue scenarios
- $ per session
- $ per kWh
- $ per hour
- Alternative revenue sources (ads, concessions, etc.)

Iterate to develop fueling infrastructure network siting plan that serves driver demand and is financially sustainable
Summary of Technical Accomplishments

Developed approach for 1) analyzing infrastructure impacts on electric vehicle market share and energy use, and 2) modeling demand/cost framework

**Task 1**
- Identified three types of sharing: car-sharing, ride-hailing, ride-sharing, each one has different impacts on VMT, vehicle ownership and fleet turnover
- Work/home trips have greater VMT reduction potential if shared, however, such potential varies by population density
- MA3T: Bridged the gap between infrastructure deployment and charging opportunity information

**Task 2**
- Identified cost drivers of DC fast charger installation
- Identified inputs to charge rate structure of a utility company to various customers
- Developed framework for synthesizing shared mobility data from GPS trajectories
Three Types Of Sharing Has Different Impacts On Energy Consumption

Energy consumption are affected by ownership, mileage, fleet turnover rate

- **CAR-SHARING**: short-term rental, involves use of a vehicle that may be fleet-owned or privately owned. E.g. Car2Go, Zipcar

- **RIDE-SHARING**: also known as carpooling and often happen peer-to-peer, involves two or more people utilizing shared transportation to reduce costs, emissions and fuel use. E.g. WazeRider/Carpool

- **RIDE-HAILING**: encompasses traditional taxi services and non-licensed services. E.g. Uber, Lyft

<table>
<thead>
<tr>
<th>Mobility Type</th>
<th>Transaction Type (charge per)</th>
<th>Trip Type</th>
<th>Impacts on Ownership</th>
<th>Impacts on VMT (fixed demand)</th>
<th>Impacts on Fleet Turnover</th>
</tr>
</thead>
<tbody>
<tr>
<td>Car Sharing</td>
<td>minute or hours</td>
<td>unscheduled</td>
<td>down</td>
<td>not much</td>
<td>not much</td>
</tr>
<tr>
<td>Ride Sharing</td>
<td>mile</td>
<td>Fixed, regular</td>
<td>not much</td>
<td>down</td>
<td>not much</td>
</tr>
<tr>
<td>Ride Hailing</td>
<td>mile</td>
<td>unscheduled regular trips</td>
<td>down</td>
<td>down</td>
<td>up</td>
</tr>
</tbody>
</table>

Accomplishments
Car Sharing Services Heavily Focus On Downtown > Universities > Airport
Chicago: Zipcar and Enterprise CarShare

Most of the cars are in garage, where it’s relatively easier to install EVSE
Some of them are on the streets

Chicago:
850+ vehicles
Zipcar

About 200 vehicles
Enterprise CarShare
Infrastructure Electrifying Home and Work Related Miles Have Greater Potential Energy Reduction With Sharing

Home and work trips have lower occupancy rate than other trip types

VMT Percentage by Trip Purposes

- Home: 33.7%
- Work: 21.4%
- Social/Recreational: 13.8%
- Shopping/Errands: 12.4%
- Transport someone: 6.0%
- Meals: 4.5%
- Family personal business/Obligations: 2.7%
- School/Daycare/Religious activity: 1.7%
- Medical/Dental services: 0.5%
- Other reason: 1.7%

2009 National Household Travel Survey
Infrastructure Electrifying Home and Work Related Miles Have Greater Potential Energy Reduction With Sharing

Home and work trips have lower occupancy rate than other trip types

2009 National Household Travel Survey
Work Related VMT Could Be Reduced By 4-8% In Weekdays
Estimates based on National Household Travel Survey

If we increase occupancy rate by 20% - 90% based on population density

However, dense areas have much less work VMT on private vehicles

Weekday Work VMT (%) by Population Density

% represents reduction of the total VMT of each population and vehicle type group (e.g. 6% total reduction of all weekday car travel by drivers in 0-99 density group)
Developed Framework For Rescheduling Movements Of Personally Owned And Operated Vehicles To Emulate Shared Mobility Services

- Modeling advanced fueling infrastructure requires spatially-resolved knowledge of vehicle activity patterns

- Developing algorithms to synthesize shared mobility vehicle trajectories from personal vehicle GPS trajectories to simulate EVSE charger demand and locations

- Project EVSE demand and location considering sharing and cost

Real-world travel profiles

Preliminary Results

**Car-sharing preliminary results: scenario 1.i)**

1.i) Free floating scenario w/o relocation and unlimited size fleet

<table>
<thead>
<tr>
<th></th>
<th>Personal car synthetic data</th>
<th>Shared Car synthetic data y=0.1 miles</th>
<th>Shared Car synthetic data y=0.25 miles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Vehicle Count</td>
<td>231</td>
<td>296</td>
<td>333</td>
</tr>
<tr>
<td>Trip Count</td>
<td>1363 (constant in all cases): avg. trips per person 5.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Avg VMT per person</td>
<td>22.27 (constant in all cases)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>% car-sharing trips</td>
<td>0</td>
<td>43.8%</td>
<td>53.41%</td>
</tr>
<tr>
<td>Car sharing vehicles</td>
<td>0</td>
<td>153</td>
<td>212</td>
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<tr>
<td>Users of car share</td>
<td>n.a.</td>
<td>88</td>
<td>110</td>
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<tr>
<td>Avg # users/shared car/per day</td>
<td>n.a.</td>
<td>1.32</td>
<td>1.31</td>
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<tr>
<td>Avg VMT/shared car/day</td>
<td>n.a.</td>
<td>12.93</td>
<td>11.39</td>
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<tr>
<td>Avg VMT/personal car/day</td>
<td>22.27</td>
<td>22.71</td>
<td>22.84</td>
</tr>
<tr>
<td>Avg shared car VMT/trip</td>
<td>n.a.</td>
<td>3.49</td>
<td>3.39</td>
</tr>
<tr>
<td>Avg personal car VMT/trip</td>
<td>3.78</td>
<td>4.00</td>
<td>4.20</td>
</tr>
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</table>

Collaboration

- DOE’s SMART Mobility Laboratory Consortium: ANL, INL, ORNL and NREL
- Engaging shared mobility and AFV fueling infrastructure service providers to develop industry partnerships (e.g. ReachNow, ChargePoint)
- Purchased INRIX GPS travel data
- Leveraged work:
  - NREL Columbus infrastructure assessment
  - INL charging site cost work
  - Argonne BaSce analysis assumptions
Remaining Challenges and Barriers

- Data availability and quality: challenges for all models and analysis
  - Travel demand with shared mobility
  - EVSE usage data of shared vehicles
  - Infrastructure installation cost data

- Modeling methodologies
  - Modification of public charging opportunity definition (DCFC only, previously defined as a mix of L1, L2, and DCFC) for BEVs in MA3T
  - Potential data transfer inconsistency between EVI-Pro, MA3T, and VISION
  - Fundamental EVI-Pro assumption: Consumers prefer to maximize eVMT and minimize operating cost (real vs. perceived)
  - EVI-Pro home dominant charging preference for simulated consumers with economically efficient behavior
Planned/Proposed Future Work

FY17

- Convert regional charging infrastructure demand to charging availability/opportunity used in MA3T and analyze market adoptions
- EVSE demand modeling with EVI-Pro application to synthetic car/ride-sharing trip datasets
- Design cost efficient EVSE network for the three identified regions
- Estimate national energy and emissions impacts based on regional results

FY18/19

- Design fueling infrastructure for energy efficient shared-automated fleets using various fuels
- Estimate market penetration of shared-automated vehicles using different fuels, based on cost/benefit analysis of vehicle and infrastructure technologies for shared-automated fleet applications

Any proposed future work is subject to change based on funding levels
Objective of this project is to design fueling infrastructure for energy efficient shared-automated fleets using various fuels and assess the national energy and economic impacts, with FY17 focus on charging infrastructure supporting intra-city shared mobility.

The main product of this project is regional infrastructure network design for three selected regions and estimated national impacts.

The project utilizes national labs’ sophisticated tools (VISION, EVI-Pro, MA3T, etc), database (Transportation Secure Data Center, EV Project), and expertise to identify solutions that overcome barriers to future sustainable transportation.

Key factor for project success is the continuing interactions with DOE sponsors, partner laboratories within Smart Mobility Consortium, and industry partners.
THANK YOU!
QUESTIONS?
Approach and Interaction

Task 1: Estimating National Impacts
- Personal Travel Data w/o O-D
- Travel Survey Analysis
- VISION
- MA3T
- Estimating impact of infrastructure on sales
- VMT, efficiency, survival, vehicle markets
- Energy, Emissions, Employment

Task 2: Regional ROI Analysis
- Personal Travel Data w/ O-D
- Mobility Service Model
- EVI-Pro
- Estimating infrastructure w/ and w/o mobility service
- Feedback loop for vehicle sales & infrastructure
- Capital, operating, revenue model for ROI
- Infrastructure Network Design

Estimating market ceilings and VMT impacts
Emulating mobility services using personal vehicle travel

VMT, efficiency, survival, vehicle markets

Financial Model

Estimating impact of infrastructure on sales

Capital, operating, revenue model for ROI
**Approach of Electric Vehicle Infrastructure Projection Tool (EVI-Pro)**

- PEV driving/charging simulator + Real-world travel profiles
- Economically efficient consumer charging behavior
  - Home dominant (default scenario)
- Estimates EVSE requirements for
  - Shared mobility environments
  - PHEV and BEV powertrains
  - Single- and multi-unit dwellings
  - Weekday and weekend travel

**EVI-Pro Schematic**

- Vehicle Attributes
- Infrastructure Attributes
- Travel Data
- PEV Sales Projections

- Driving/Charging Simulations (Optimize individual charging behavior)

- Spatial/Temporal Post Processing (Estimate potential for shared use of EVSE)

- EVSE density
- EVSE utilization

- Weight and scale EVSE density
- EVSE counts

**Columbus GPS Travel Data**
EVI-Pro Vehicle/Infrastructure Attributes For EVSE Demand Modeling

- Travel profiles are simulated using six vehicle models.
- A matrix of charging options are made available to each combination of travel profile and vehicle type.
- Optimization algorithm selects charging behavior at the individual level to maximize eVMT and minimize charging cost.
- Simulated consumers have an assumed preference for charging type and location (based on electricity price) which is home dominant by default.

<table>
<thead>
<tr>
<th>EVSE Type / Location</th>
<th>Home-SUD</th>
<th>Home-MUD</th>
<th>Non-Residential</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 1</td>
<td>Available</td>
<td>Excluded</td>
<td>Excluded</td>
</tr>
<tr>
<td>Level 2</td>
<td>Available</td>
<td>Available</td>
<td>Available</td>
</tr>
<tr>
<td>DC Fast</td>
<td>Excluded</td>
<td>Excluded</td>
<td>Available</td>
</tr>
</tbody>
</table>

Vehicle Types

- PHEV20
- PHEV40
- PHEV60
- BEV100
- BEV200
- BEV300
Approach of VISION: Fleet Impact Modeling

Major Inputs (User defined)
- Market share
- Fuel efficiency
- Travel volume
- Economic factors

Internal Calculations
- Vehicle stock
- VMT per vehicle
- VMT per technology
- Emission and energy rate

Energy use and GHG emissions by vehicle tech, vehicle type and fuel type

Major Outputs

Vehicles
- Cars
- Light Trucks
- Class 7-8 Single Unit Trucks
- Class 7-8 Combination Trucks

Technology & Fuel
- 4 ICEVs (gasoline, diesel, E85, CNG)
- 3 HEVs (gasoline, diesel, E85)
- 3 PHEVs (2 gasoline types, diesel)
- 2 EVs
- 1 FCEV

Fuel Pathways
- Crude oil to gasoline and diesel
- Natural gas
  - To CNG, LNG, F-T diesel
- Soybeans to biodiesel
- Corn, sugarcane, Switchgrass, etc. to ethanol
- Coal, nuclear, Renewables, etc. to electricity
- NG, coal, Biomass, etc. to H2
Approach of PEV Infra Cost Model

Estimates infrastructure installation costs based on:
1. Electrical service upgrade
2. Materials
3. Ground surface conditions

Estimates infrastructure operational costs based on:
1. Mainly focus on electricity cost
2. Electricity rate determined by operators’ business type defined by the utility company
3. Operators’ current and future electricity consumption and demand capacity information

Locate sites of low installation/operation costs for required EVSE