NREL
NATIONAL RENEWABLE ENERGY LABORATORY

# Charging Electric Vehicles in Smart Cities:

## An EVI-Pro Analysis of Columbus, Ohio

Eric Wood, Clément Rames, Matteo Muratori, Sesha Raghavan, and Stanley Young

June 13, 2018

Electric Power Research Institute
Infrastructure Working Council

# $40 MILLION

**78 APPLIED • COLUMBUS WON**

SMART CITY CHALLENGE

THE CITY OF COLUMBUS
ANDREW J. GINTHER, MAYOR

SMART COLUMBUS

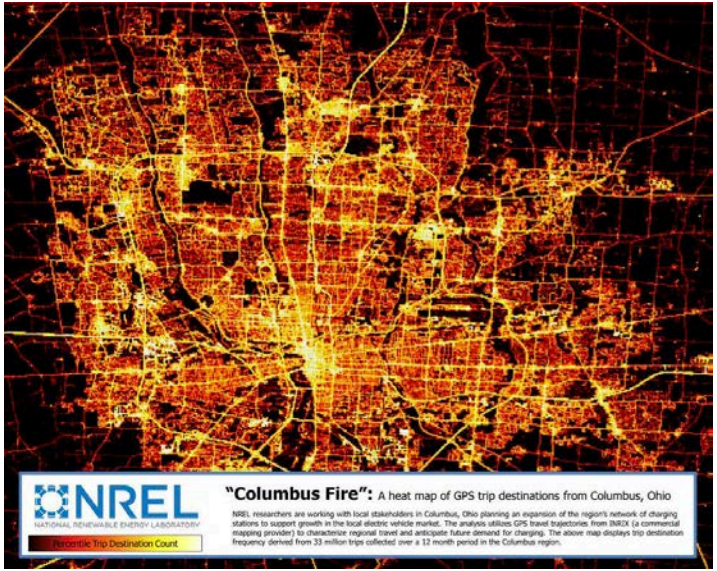
U.S. Department of Transportation

# NREL's Infrastructure Analysis

NREL analyzed **charging behavior and infrastructure requirements to support plug-in electric vehicle (PEV) adoption in Columbus, OH**, including estimating PEV supply equipment counts, location, use, and resulting hourly load profiles


**Charging Electric Vehicles in Smart Cities: An EVI-Pro Analysis of Columbus, Ohio**

Eric Wood, Clément Rames, Matteo Muratori, Sesha Raghavan, and Stanley Young
*National Renewable Energy Laboratory (NREL)*



# Smart Columbus: Goals

As part of the Smart Columbus Initiative, **the city has set specific goals** for annual PEV sales:

| Year | PEV Sales Goal |
|---|---|
| 2017 | 0.6% |
| 2018 | 1.1% |
| 2019 | 1.8% |

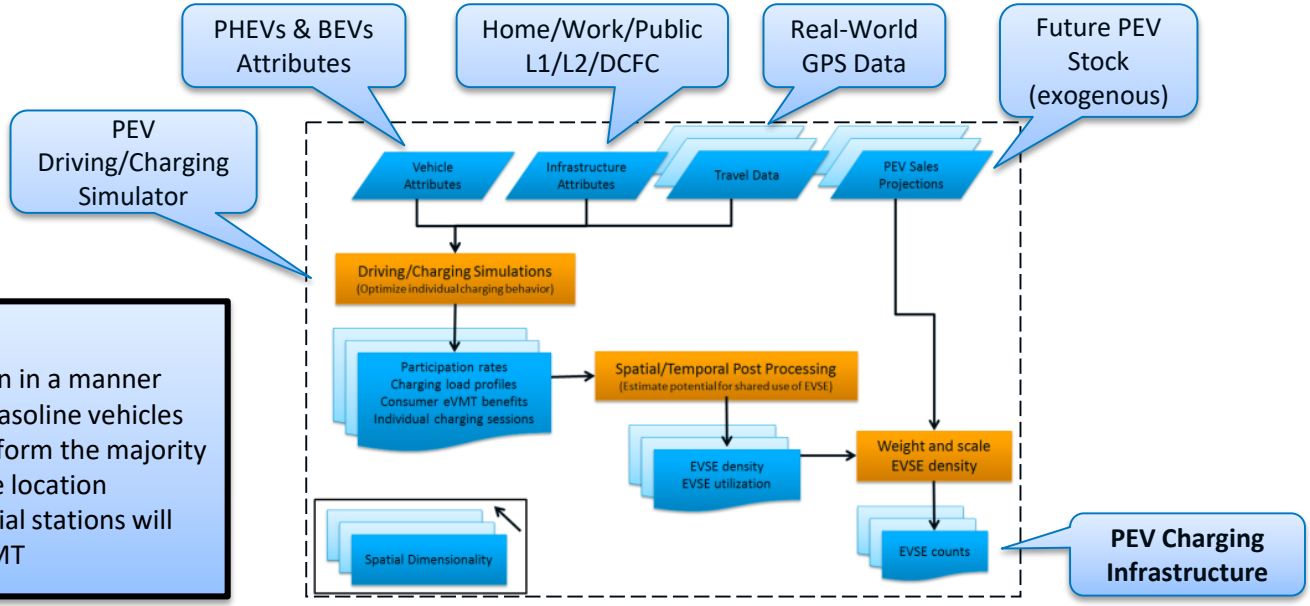
- Approximately **91,500 light-duty vehicles (LDVs) are sold per year in Columbus**
- The Columbus goal translates to **3,200 new PEVs** registered in Columbus over three years, bringing the **2019 Columbus PEV fleet to 5,300 vehicles**

# Analysis Approach

- Use NREL's **Electric Vehicle Infrastructure Projection (EVI- Pro)** model to:
  - Generate **scenarios of regional charging infrastructure** based on regional travel to support PEV adoption in line with Smart Columbus
  - Anticipate future **demand for PEV charging** to better inform the impact of PEV adoption on the electric load
- **GPS travel data**
- Assess **current PEV market**
- **Results**: electric vehicle supply equipment (EVSE) requirements
- **Sensitivity** analysis
- Promising **locations for public EVSE**

# EVI-Pro

The Electric Vehicle Infrastructure Projection (EVI-Pro) tool estimates PEV charging requirements and charging load profiles



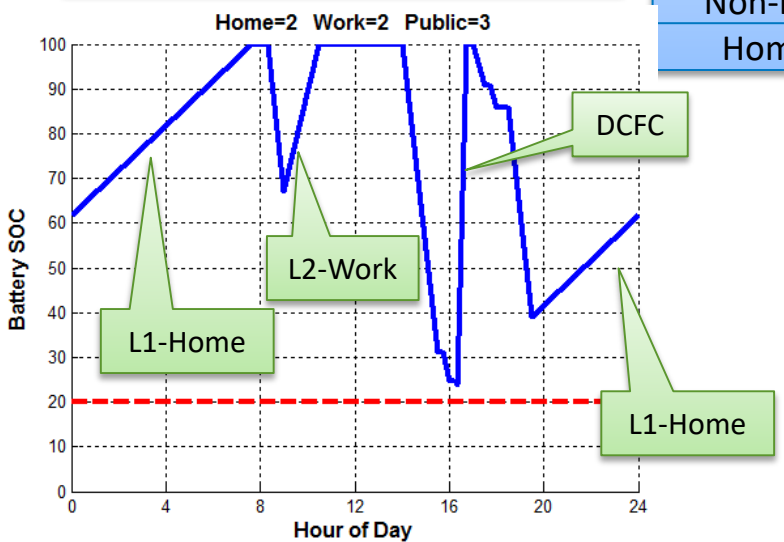

**Foundational Assumptions**

- Future PEVs will be driven in a manner consistent with today's gasoline vehicles
- Consumers prefer to perform the majority of charging at their home location
- Charging at non-residential stations will be used to maximize eVMT

# EVI-Pro

Simulated charging behavior for a BEV100 under an example travel day

| Destination | Departure | Arrival | Drive Miles | Dwell Hours | Simulated Charging |
|---|---|---|---|---|---|
| Work | 8:20 AM | 9:00 AM | 32.8 | 5.00 | L2 |
| Non-Res | 2:00 PM | 3:30 PM | 68.9 | 0.25 | --- |
| Non-Res | 3:45 PM | 4:00 PM | 6.3 | 0.25 | --- |
| Non-Res | 4:15 PM | 4:20 PM | 0.9 | 0.67 | DCFC |
| Non-Res | 5:00 PM | 5:30 PM | 9.2 | 0.25 | --- |
| Non-Res | 5:45 PM | 6:00 PM | 5.0 | 0.50 | --- |
| Home | 6:30 PM | 7:30 PM | 46.8 | 12.83 | L1 |



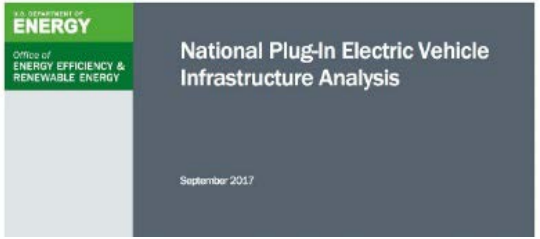

**Bottom-up simulations** based on travel behavior are used to produce a variety of charging scenarios

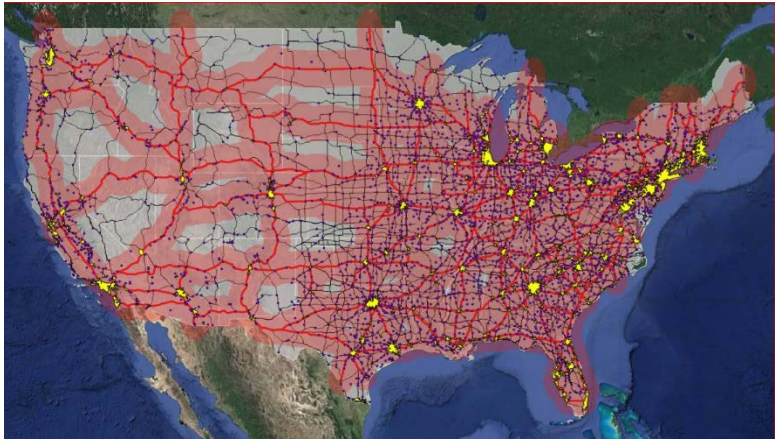
**Optimal charging behavior** is assumed to investigate spatial and temporal charging demand and to estimate:

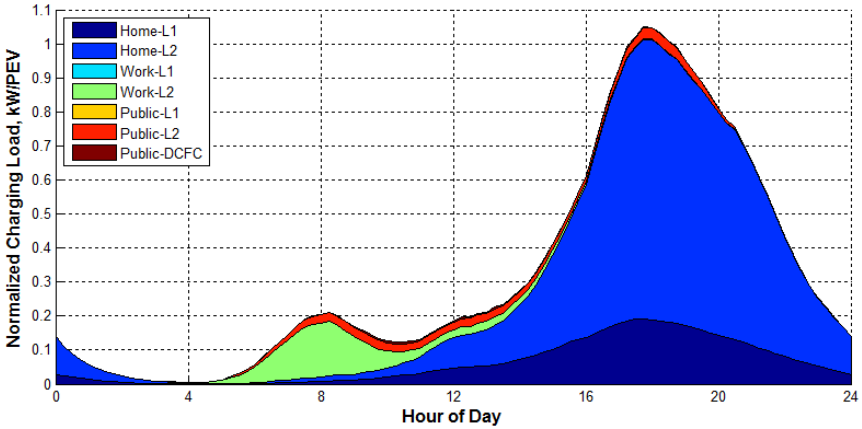
- Non-residential infrastructure requirements
- Aggregate load profiles

# National Infrastructure Analysis

NREL analyzed national charging behavior and infrastructure requirements to support PEV adoption, including interstate corridors





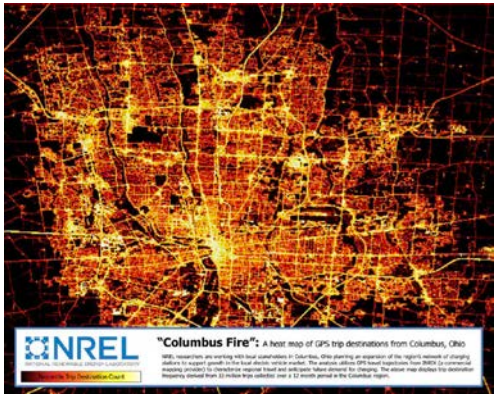

Source: Wood et al. 2017. Model: NREL's EVI-Pro

# GPS Travel Data

To properly model PEV charging infrastructure requirements in Columbus, **NREL acquired individual GPS travel trajectories from INRIX**

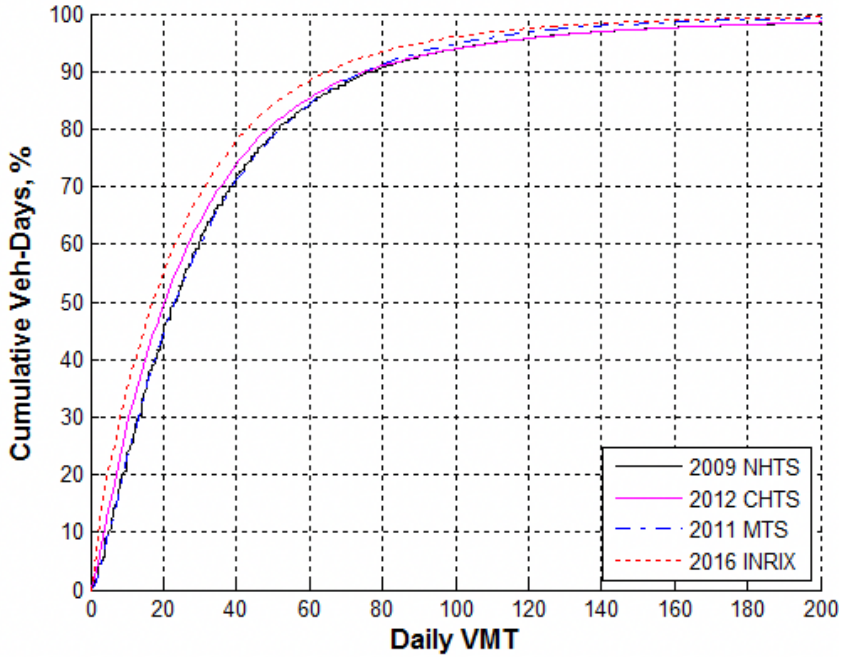
Each travel trajectory features **trip-level data** such as start and end times and GPS coordinates (including origin, destination, and intermediate waypoints)

- 7.82 million unique device identifiers
- **32.9 million trips**
- **1.04 billion miles of driving**
- 2.58 billion GPS waypoints



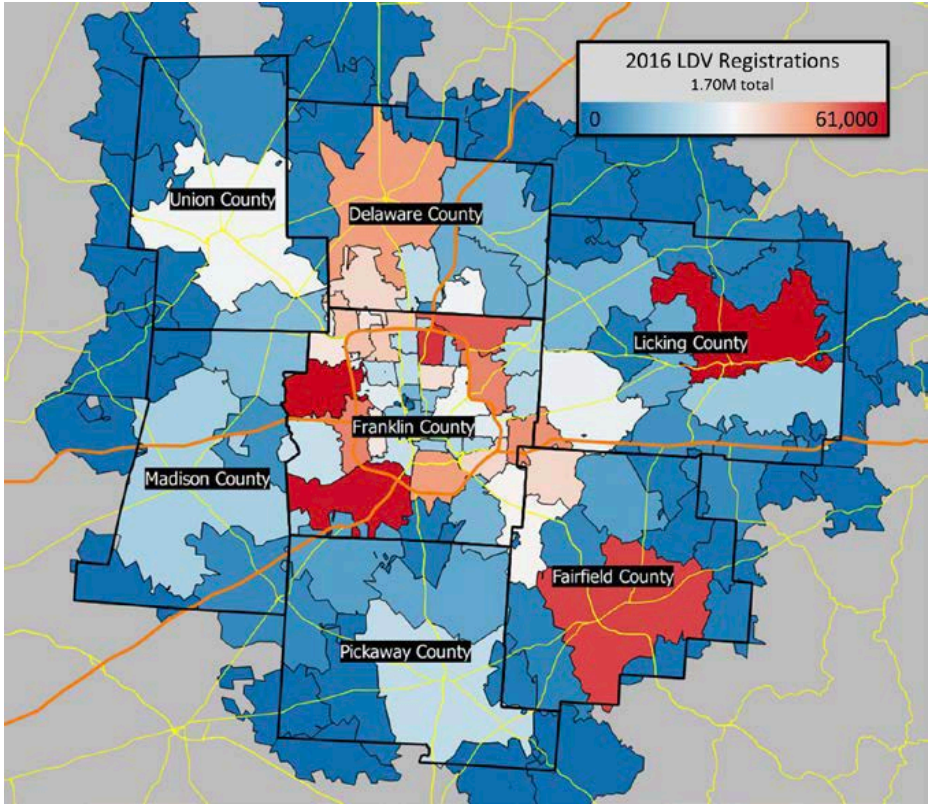
# GPS Travel Data

INRIX travel data for Columbus are **compared to traditional travel surveys** to check for consistency and compare trends




As additional validation, the INRIX data are compared to estimated trip counts by traffic analysis zone (TAZ) from the Mid-Ohio Regional Planning Commission's (**MORPC**) 2015 travel demand model showing **good agreement**

# Current LDV Market

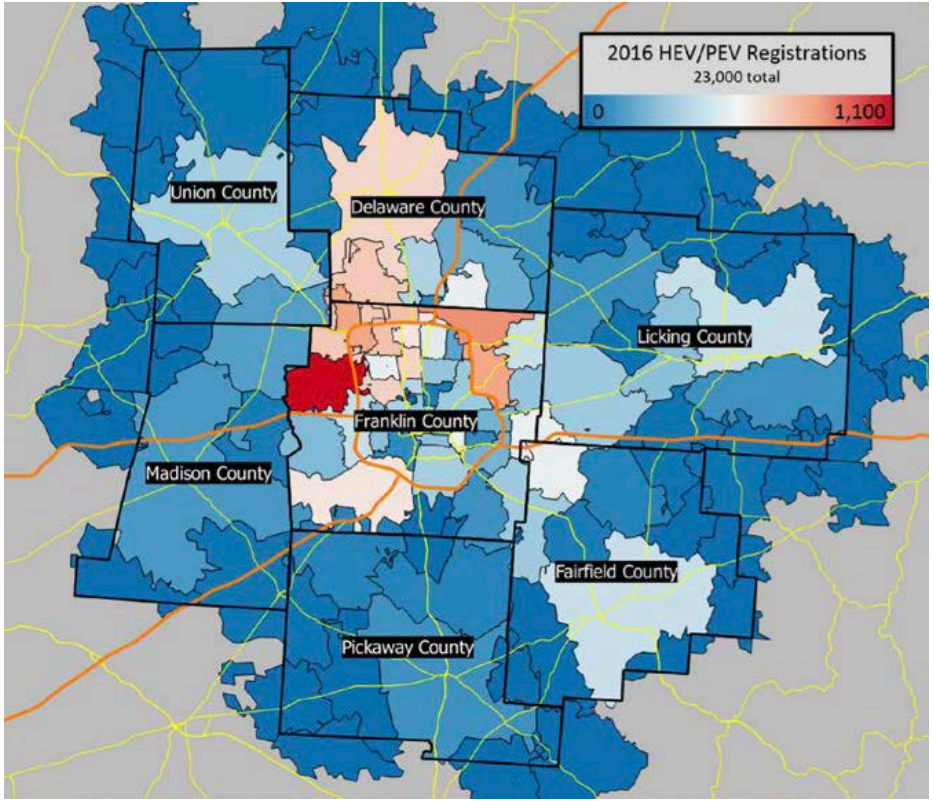



The **Columbus region** is defined as the seven-county area surrounding the City of Columbus

**LDV in Columbus:**

- **~ 1.70 million vehicles**
- **~91,500 sales per year**
- Currently dominated by **ICE vehicles (98%)** with spatial distribution roughly **mirroring population**

# Current PEV Market




- Only **2,100 PEVs** in Columbus
- Columbus PEV preference **consistent with Ohio**
- Relatively **PHEV dominant** (2/3 of PEVs compared to ~1/2 at the national level)
- **Clustering effects** in PEV adoption assumed in line with historical HEV adoption

# Baseline Scenario

Baseline assumptions:

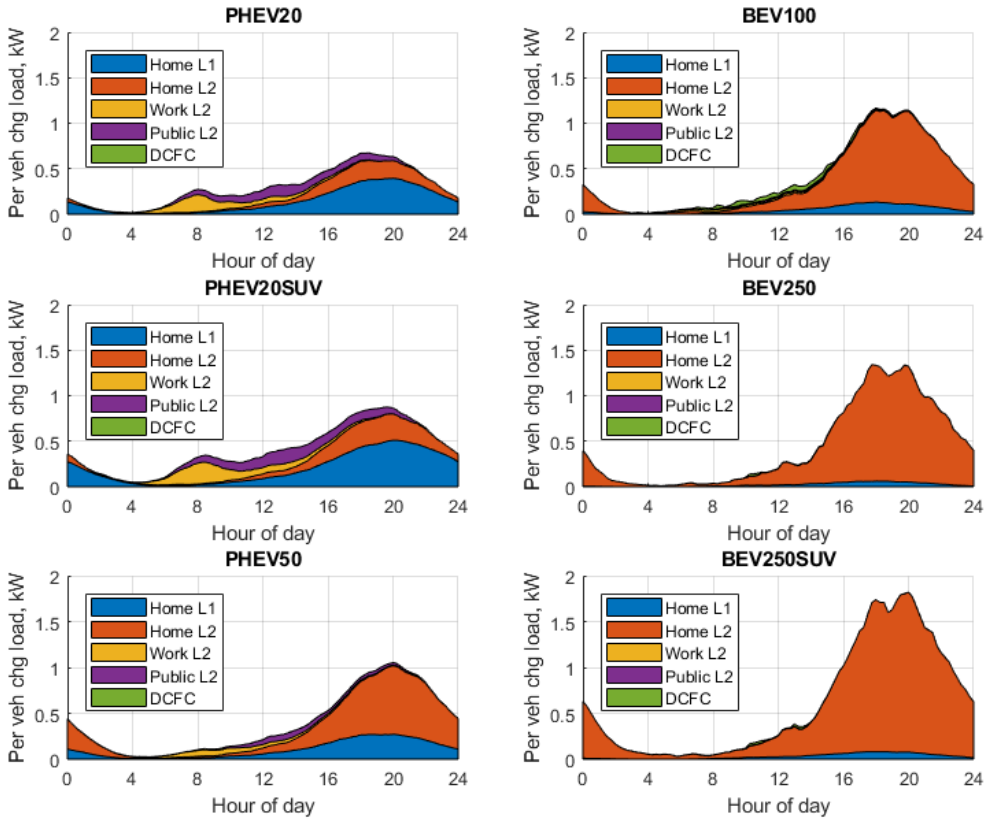
- **5,300 PEVs on the road** by the end of 2019
- **54:46 PHEV/BEV** split (national average), evenly split between short- and long-range
- **Spatial PEV adoption in line with existing HEVs**
- Full **support for PHEV** charging
- **Mild ambient temperature** (typical of May in Columbus)
- Consumers in both single-unit dwellings (SUDs) and multi-unit dwellings (MUDs) have access to home charging and prefer to do the **majority of charging at home**
  - SUD: one plug per PEV, split evenly between L1 and L2
  - MUD: one L2 plug per PEV

# Results: Plug Counts

Estimated plug counts for Columbus by the end of 2019:

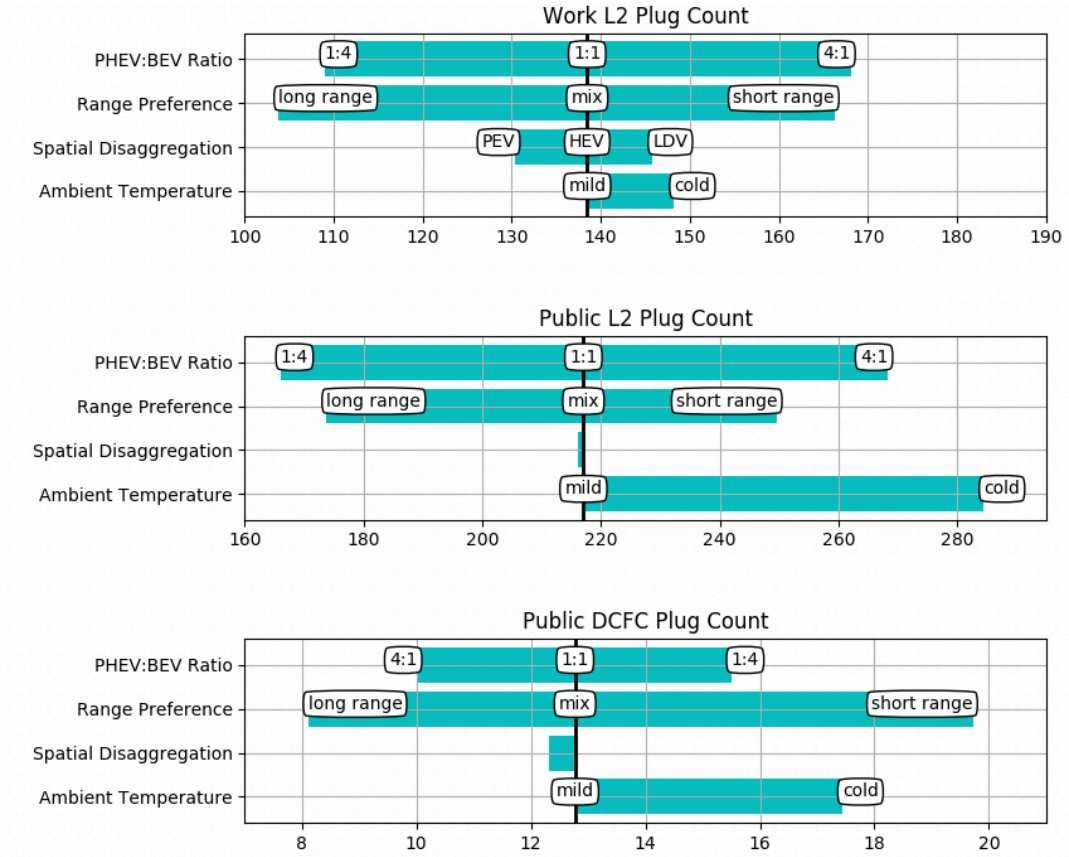
| | Delaware | Fairfield | Franklin | Licking | Madison | Pickaway | Union | Total |
|---|---|---|---|---|---|---|---|---|
| **SUD L1** | 319 | 152 | 1,622 | 182 | 36 | 39 | 74 | **2,424** |
| **SUD L2** | 313 | 147 | 1,448 | 164 | 32 | 44 | 75 | **2,222** |
| **MUD L2** | 27 | 15 | 327 | 18 | 4 | 5 | 8 | **404** |
| **Work L2** | 29 | 12 | 70 | 13 | 3 | 8 | 3 | **138** |
| **Public L2** | 31 | 13 | 146 | 13 | 2 | 4 | 7 | **217** |
| **DCFC** | 4 | 1 | 7 | 0 | 0 | 0 | 1 | **13** |

# Results: Charging Profiles



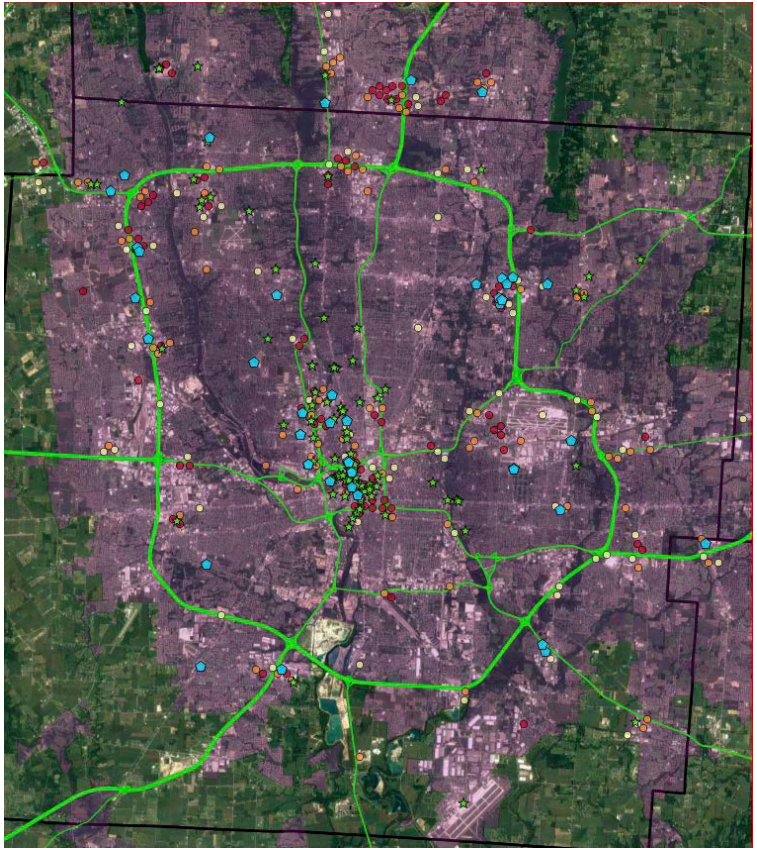

- Majority of charging between **4 p.m. and 12 a.m. at home**
- **Workplace charging peaks around 8 a.m.** for the PHEV20
- **Longer range vehicles do not require workplace** charging
- **Public L2** charging is used consistently **throughout the day by PHEVs** (maximizing eVMT)
- **DCFC demand is modest** for the BEV100 and almost nonexistent for longer-range BEVs, since we focus on local travel

# Sensitivity Analysis



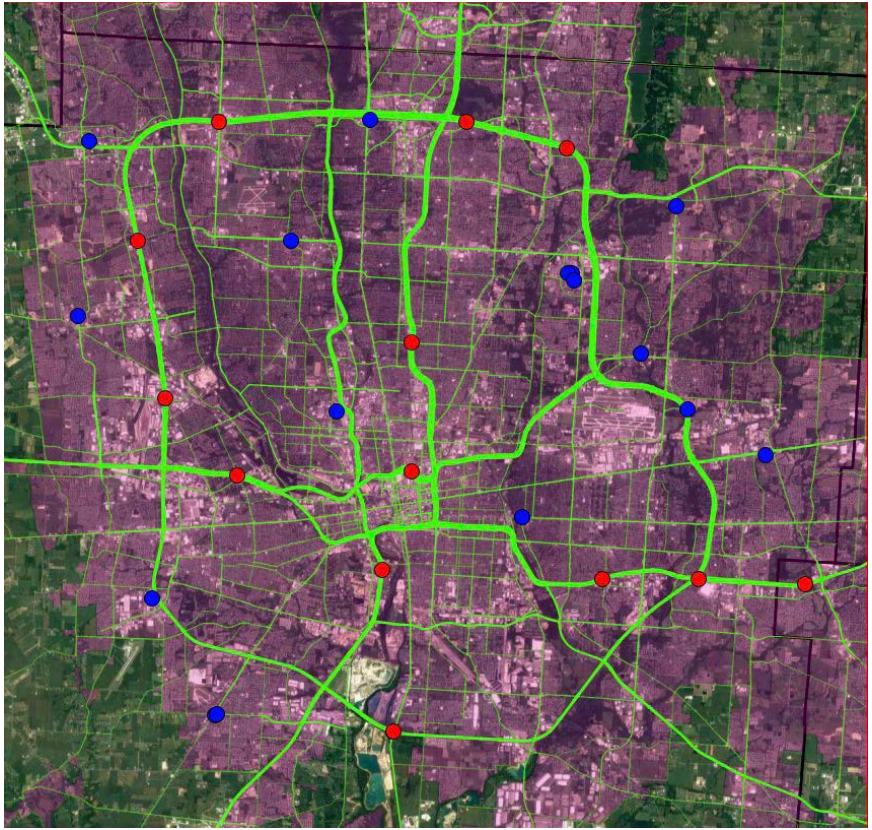

- **Consumer preferences** (PHEV vs. BEV, range) have the largest influence on infrastructure requirements
- **Spatial disaggregation** of PEV adoption will largely affect the **EVSE geographical distribution**
- **Ambient temperature** is known to drastically affect the energy consumption of PEVs. Winter conditions are harsher in Columbus

# Promising Locations for Public L2



- **Purple outline**: Columbus area
- **Blue pentagons**: existing L2 EVSE
- **Green stars**: future sites under consideration by local planners
- **Dots:** simulated PEV charging **"hot spots" for L2 public charging** (0.3-mi diameter) color coded by tier (1st tier = red, 2nd tier = orange, 3rd tier = yellow)

# Promising Locations for Public DCFC



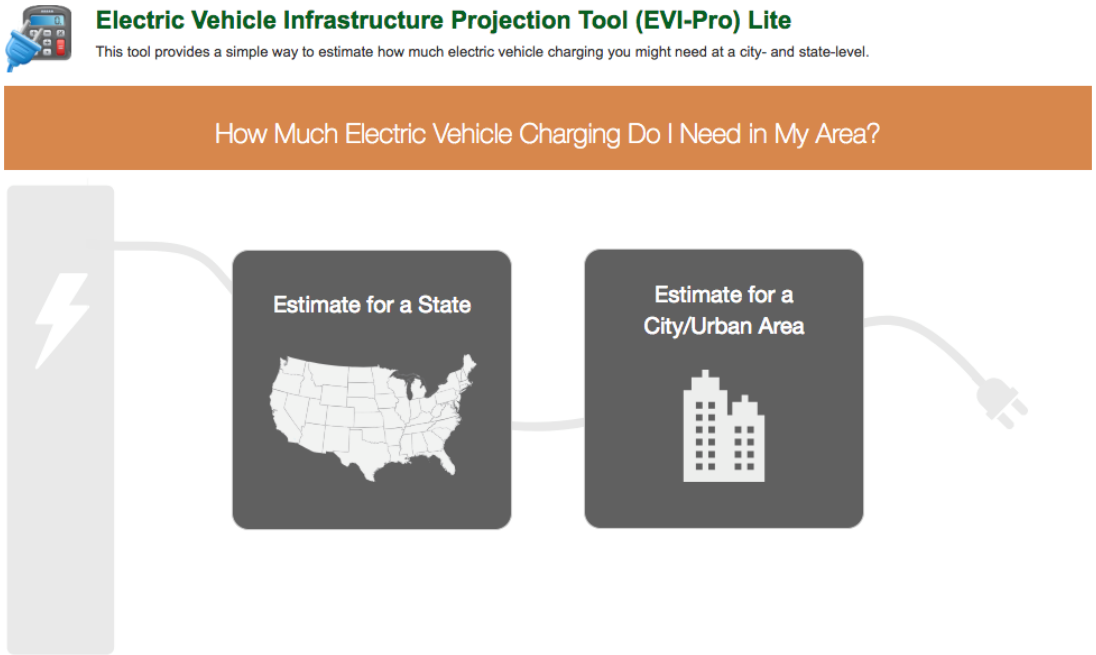
- **Purple outline**: Columbus area.
- **Blue dots**: Sixteen existing DCFC station locations in Columbus as of August 2017
- **Red dots**: 13 hypothetical future locations to improve DCFC coverage to support 5,300 PEVs in 2019

# Conclusions

- Guide **PEV charging infrastructure deployment to reduce range anxiety** and ensure the effective use of private/public investments
- Assuming **ubiquitous residential charging** (including multi-unit dwellings) approximately **400 MUD Level 2** plugs, **350 non-residential Level 2** plugs, and **13 DCFC** plugs are required to support Columbus' primary PEV goal of 5,300 PEVs on the road by the end of 2019
- While consumer **demand for fast charging is expected to remain low** (due to modest anticipated adoption of short-range battery electric vehicles and ubiquitous residential charging), a minimum level of **fast charging coverage is required to ease consumer range anxiety**

# EVI-Pro Lite

NREL released [EVI-Pro Lite] to provide a simple way to estimate how much electric vehicle charging might be needed need at a city and state level



# Ongoing Research and Collaboration Opportunities

**Research** at NREL:

- Assess opportunities to **leverage PEV charging flexibility** to support grid operation and facilitate renewable integration (demand response)
- Assess the **impact of non-residential PEV charging** on the power system, especially DC fast charging
- Better capture the **infrastructure implications of transportation electrification**, including:
  - The "**PEV adoption–EVSE availability**" nexus for light-duty vehicles
  - Electrification strategies for different **medium- and heavy-duty vocations**
  - Impact of **automated vehicles**, future mobility options, and transportation network companies (TNCs)

# Acknowledgements

This study was supported by the **U.S. Department of Energy's Vehicle Technologies Office**. The authors would specifically like to thank Michael Berube, Robert Graham, Jacob Ward, Rachael Nealer, David Gohlke, and Kelly Fleming for their guidance and support. Additional thanks to members of the **Smart Columbus working group on EV charging infrastructure**. Their feedback was invaluable in tailoring this analysis to the mid-Ohio region.

Please **cite as:** Wood, Eric, Clément Rames, Matteo Muratori, Sesha Raghavan, and Stanley Young. 2018. "Charging Electric Vehicles in Smart Cities: An EVI-Pro Analysis of Columbus, Ohio." Golden, CO: National Renewable Energy Laboratory. NREL/PR-5400-71776. URL: https://www.nrel.gov/docs/fy19osti/71776.pdf.

**References:**

- Wood, E., C. Rames, M. Muratori, S. Raghavan, and S. Young. 2018. *Charging Electric Vehicles in Smart Cities: An EVI-Pro Analysis of Columbus, Ohio*. https://www.nrel.gov/docs/fy18osti/70367.pdf
- Wood, E., C. Rames, M. Muratori, S. Srinivasa Raghavan, and M. Melaina. 2017. *National Plug-In Electric Vehicle Infrastructure Analysis*. https://www.nrel.gov/docs/fy17osti/69031.pdf
- Electric Vehicle Infrastructure Projection Tool (EVI-Pro) Lite
- Matteo Muratori.2018. "Electrification Opportunities in the Transportation Sector and Impact of Residential Charging." https://www.nrel.gov/docs/fy18osti/71102.pdf

# Thank you

Matteo.Muratori@NREL.gov

**www.nrel.gov**

NREL/PR-5400-71776

This work was authored by the National Renewable Energy Laboratory, operated by the Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Vehicle Technologies Office. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.

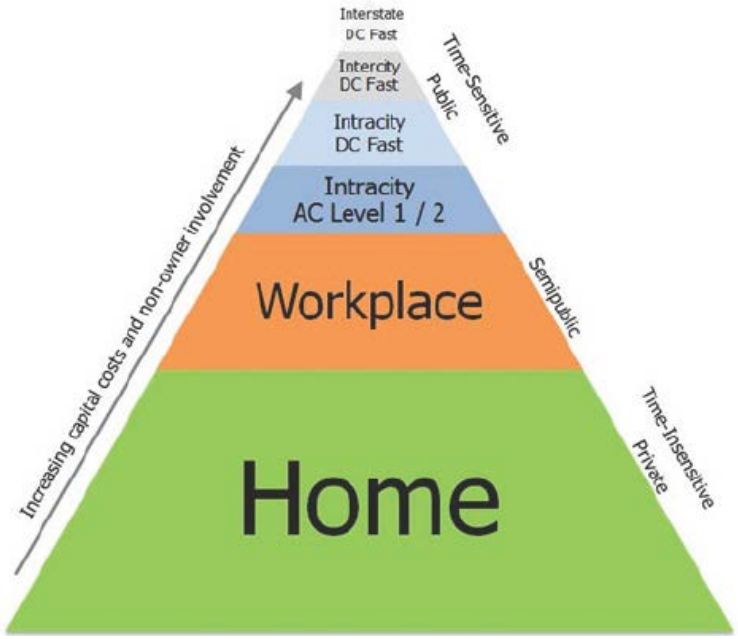
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

# Charging Requirements

While the majority of PEV charging is expected to come from residential plugs, a network of **non-residential chargers** is still required to:

- Support adopters that cannot reliably charge at home
- Enable long-distance travel
- Cope with range anxiety (safety net)

**Infrastructure plays a big role in enabling and supporting PEV adoption** (dynamic charging or battery swapping also have big infrastructure components)




Source: National Research Council. *Overcoming barriers to deployment of plug-in electric vehicles*. National Academies Press, 2015.

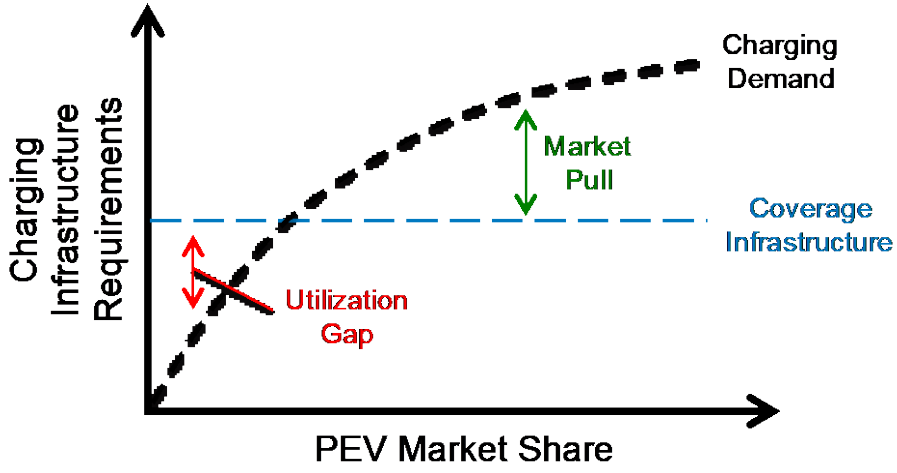
# EVI-Pro: Conceptual

**Consumers' demand for PEV charging is coverage-based:**

"Need access to charging anywhere their travels lead them"

**Infrastructure providers make capacity-driven investments:**

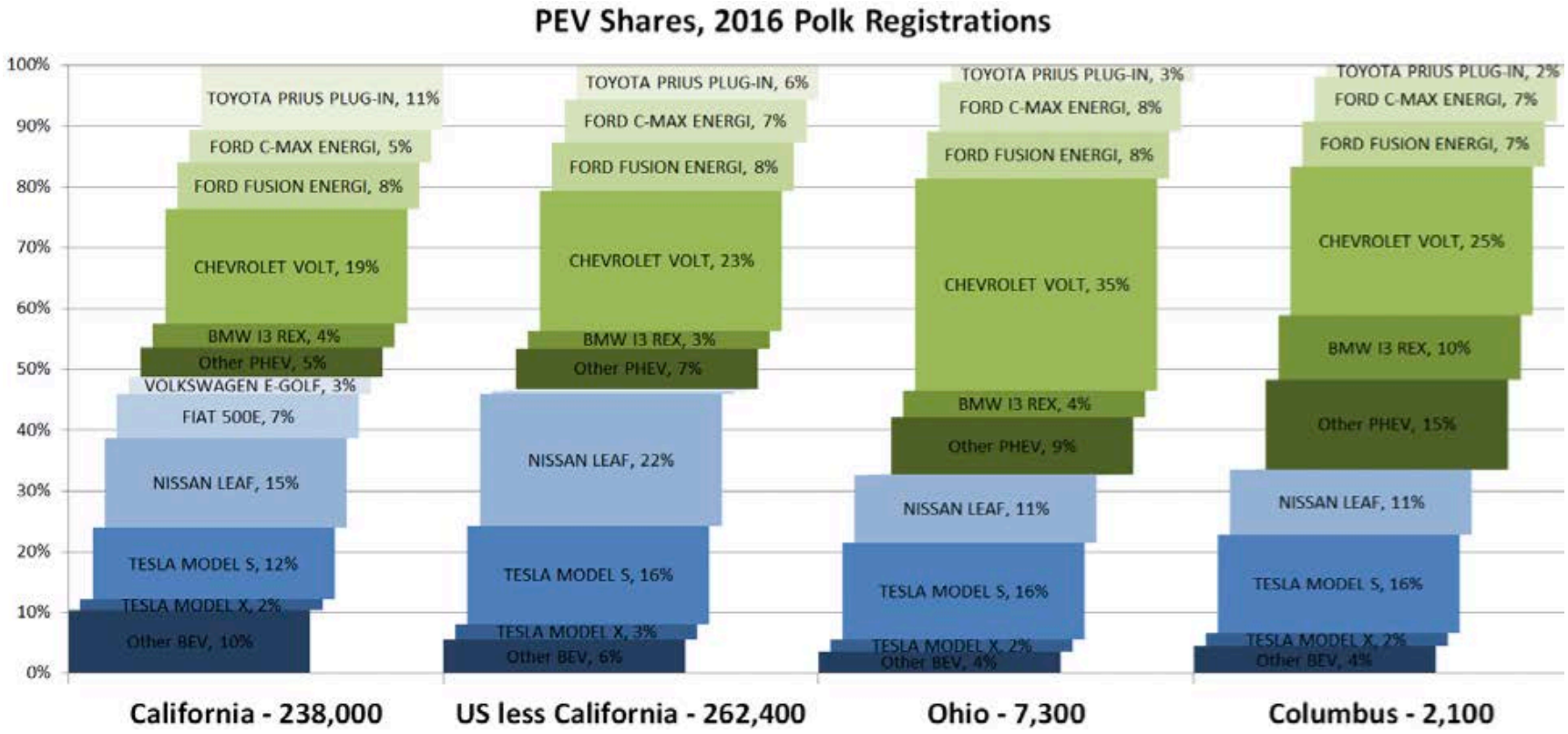
"Increase supply of stations proportional to utilization"



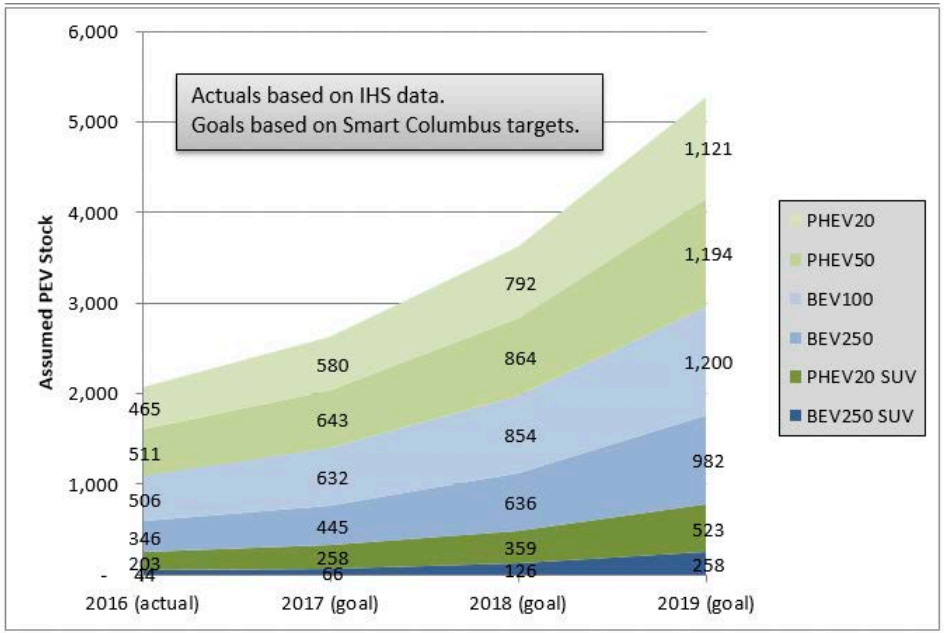

A "utilization gap" persists in a low vehicle density environment making it difficult to justify investment in new stations when existing stations are poorly utilized (aka: chicken and egg)

We **quantify non-residential PEV charging requirements** necessary to meet consumer coverage expectations (independent of PEV adoption level) and capacity necessary to meet consumer demand in high PEV adoption scenarios

# PEV Sales Distribution



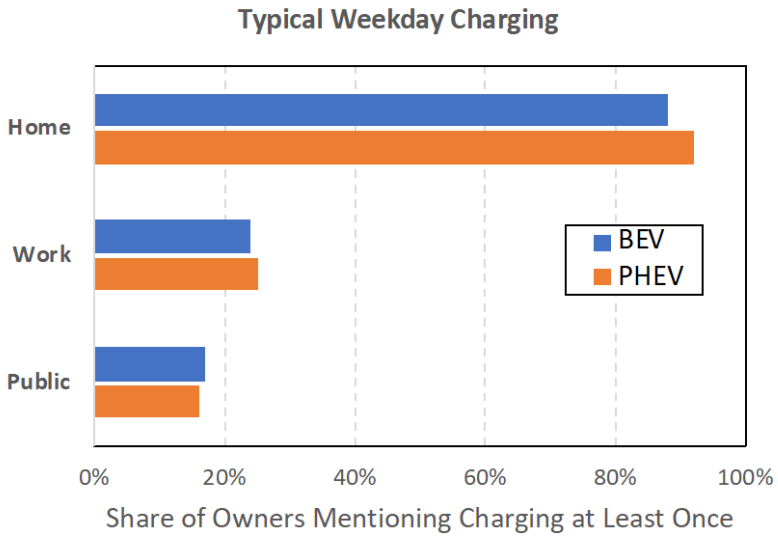
# PEV Sales Distribution

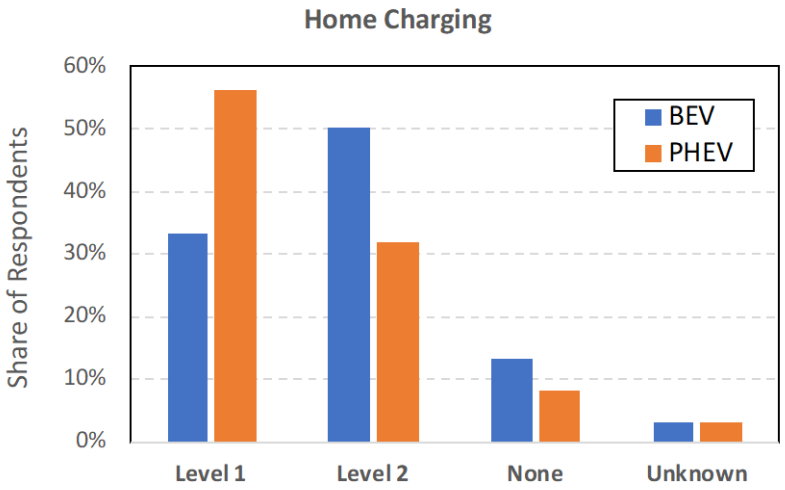



# L1 Vs. L2 Charging

With 12% of the population of the United States, California has 24% of the public PEV charging stations and 30% of the outlets for charging PEVs .

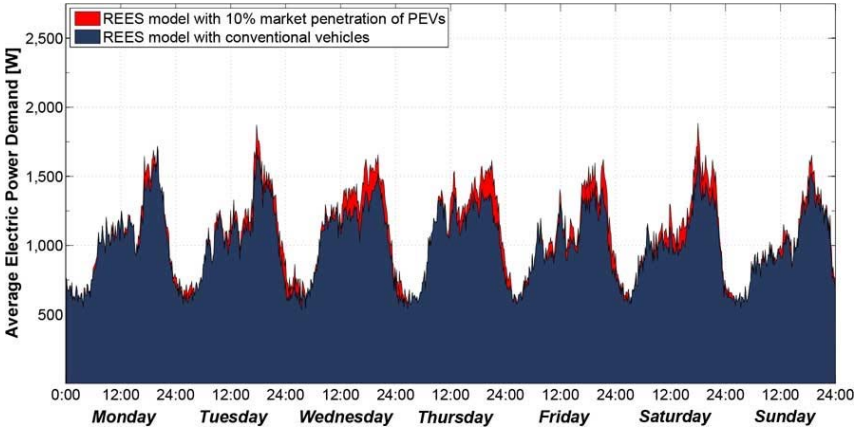
159 BEV owners and 156 PHEV owners responded to questions in the [2016 California Vehicle Survey] about where and when they charged their vehicles on a typical weekday

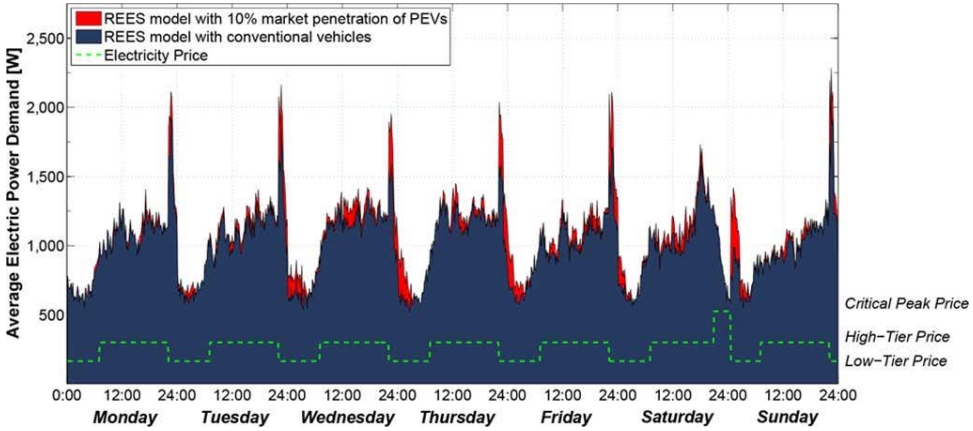


# Rebound Peaks

Widespread participation (automated energy management systems) in demand response programs using time-varying electricity pricing (e.g., TOU) might create pronounced rebound peaks.




M. Muratori and G. Rizzoni. 2016. "Residential demand response: dynamic energy management and time-varying electricity pricing." *IEEE Trans. on Power Systems*, Vol. 31 (2). 10.1109/TPWRS.2015.2414880

# Key Capabilities and Tools

## Data

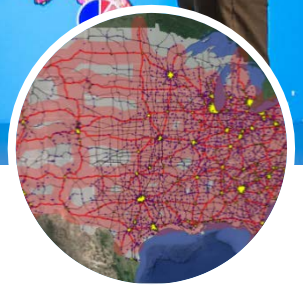
Transportation Secure Data Center & Alternative Fuels Data Center


## ADOPT

Vehicle Adoption Modeling

## FASTSim

Vehicle Powertrain Modeling



## EVI-PRO

Plug-in Electric Vehicle Charging Infrastructure

## SERA

Alternative Fuel Infrastructure Supply and Infrastructure