NREL
NATIONAL RENEWABLE ENERGY LABORATORY

National Plug-In Electric Vehicle Infrastructure Analysis

Eric Wood, Clement Rames, Matteo Muratori, Sesha Raghavan, Marc Melaina

January 8, 2018

NREL/PR-5400-70779

PEV Charging Analysis – NREL Objective

Inform regional/national stakeholders on plug-in electric vehicle (PEV) charging infrastructure, focusing on non-residential applications to:

- Reduce range anxiety as a barrier to increased PEV sales
- Enhance charging options to maximize eVMT and enable greater PEV adoption
- Ensure effective use of private/public infrastructure investments

Some key questions related to investment in PEV charging stations…

How many?

What kind?

Where?

Recent Studies

California (2014)
Seattle, WA (2015)
Massachusetts (2017)
Colorado (2017)
Columbus, OH (forthcoming)
National PEV Infrastructure Analysis (2017)

National PEV Infrastructure Analysis Report (2017)

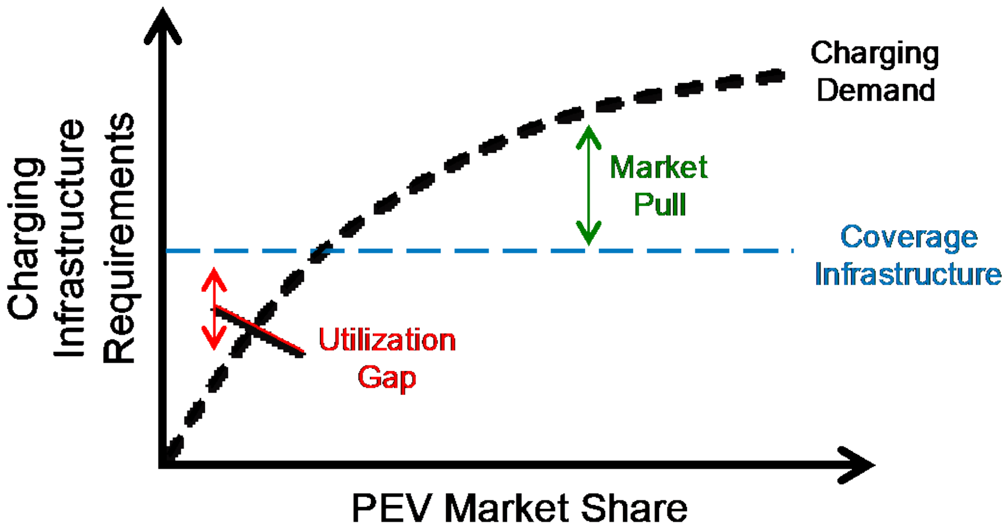
- NREL analysis was published in September 2017 as a Department of Energy **EERE Report**.
- This study was supported by the U.S. Department of Energy's **Vehicle Technologies Office**.
- The authors would specifically like to thank Michael Berube, Sarah Olexsak, Jacob Ward, Rachael Nealer, and David Gohlke for their guidance and support.

Wood, E., Rames, C., Muratori, M., Srinivasa Raghavan, S. and Melaina, M. *National Plug-In Electric Vehicle Infrastructure Analysis*, 2017. https://www.nrel.gov/docs/fy17osti/69031.pdf

Conceptual Representation of PEV Charging Requirements

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"

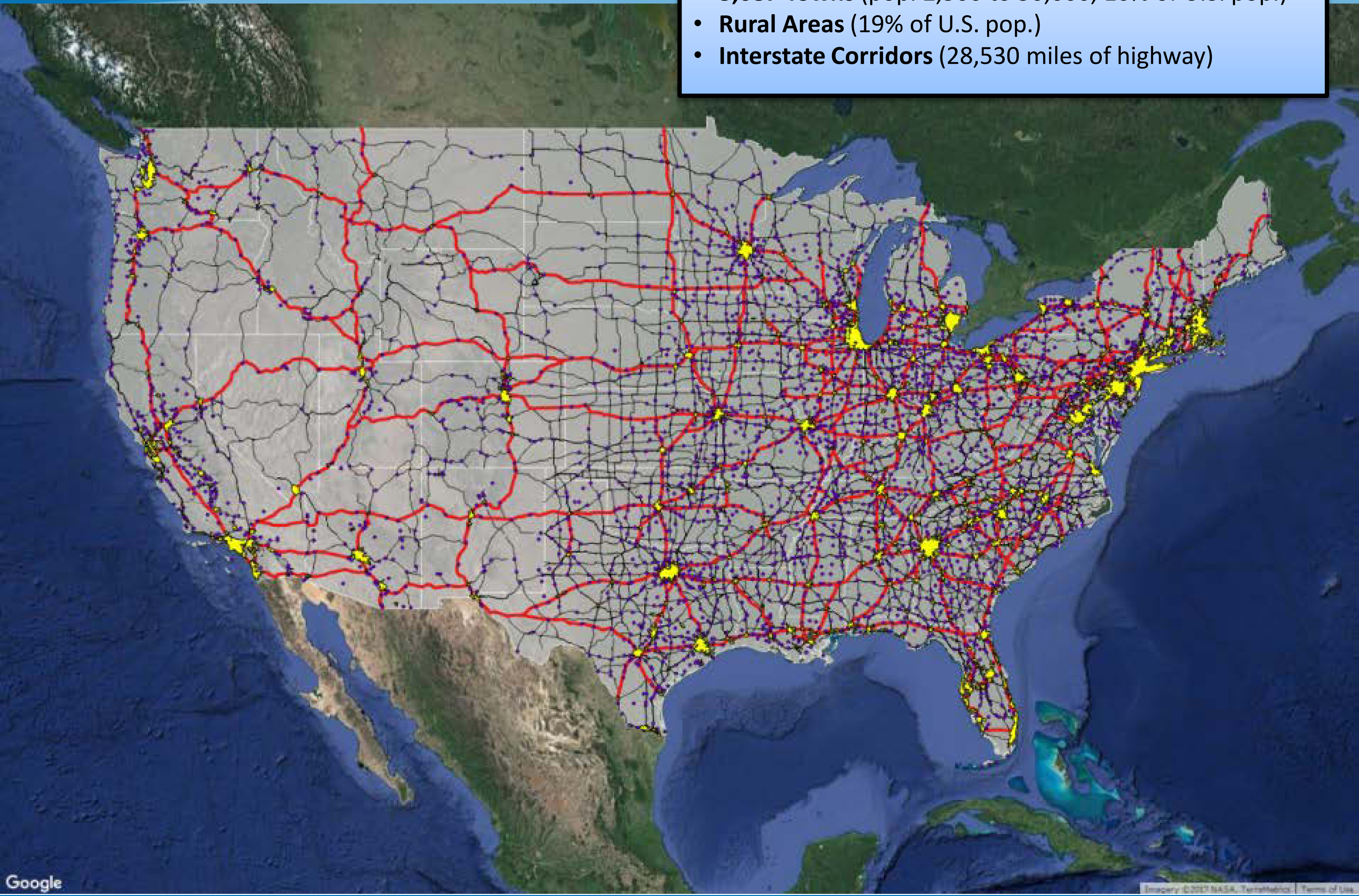


A "utilization gap" persists in a low vehicle density environment making it difficult to justify investment in new stations when existing stations are poorly utilized (aka: chicken & egg)

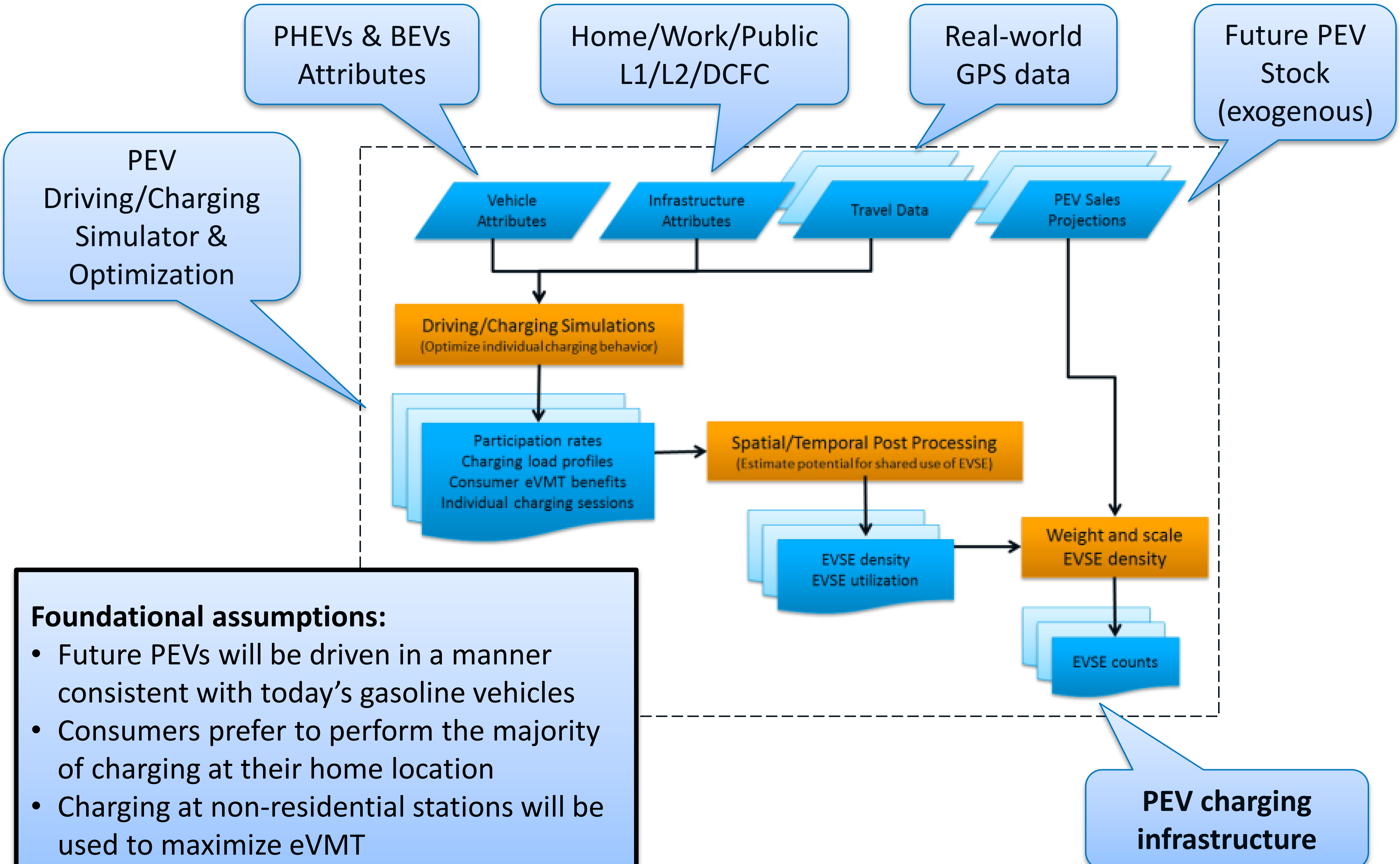
This work **quantifies non-residential PEV charging requirements** necessary to meet consumer coverage expectations (independent of PEV adoption level) and capacity necessary to meet consumer demand in high PEV adoption scenarios

Geographic Segmentation

- **486 Cities** (pop. greater than 50,000, 71% of U.S. pop.)
- **3,087 Towns** (pop. 2,500 to 50,000, 10% of U.S. pop.)
- **Rural Areas** (19% of U.S. pop.)
- **Interstate Corridors** (28,530 miles of highway)



Electric Vehicle Infrastructure Projection Tool (EVI-Pro)



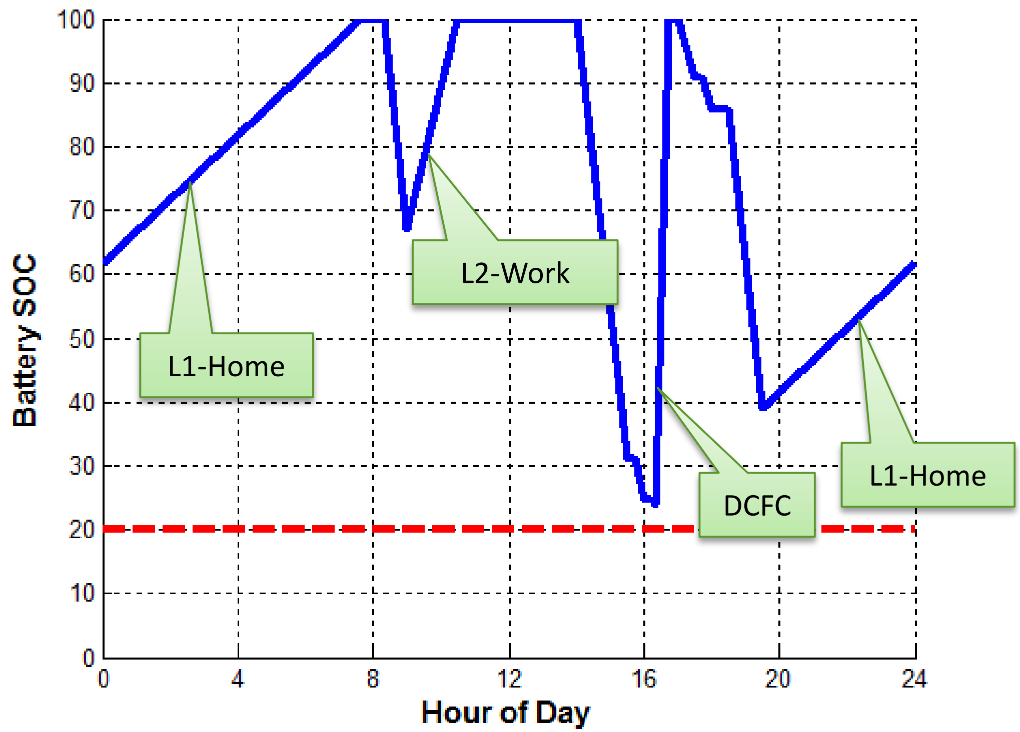
Foundational assumptions:

- 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

Driving/Charging Simulations

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

Simulated charging behavior for a BEV100 under an example travel day

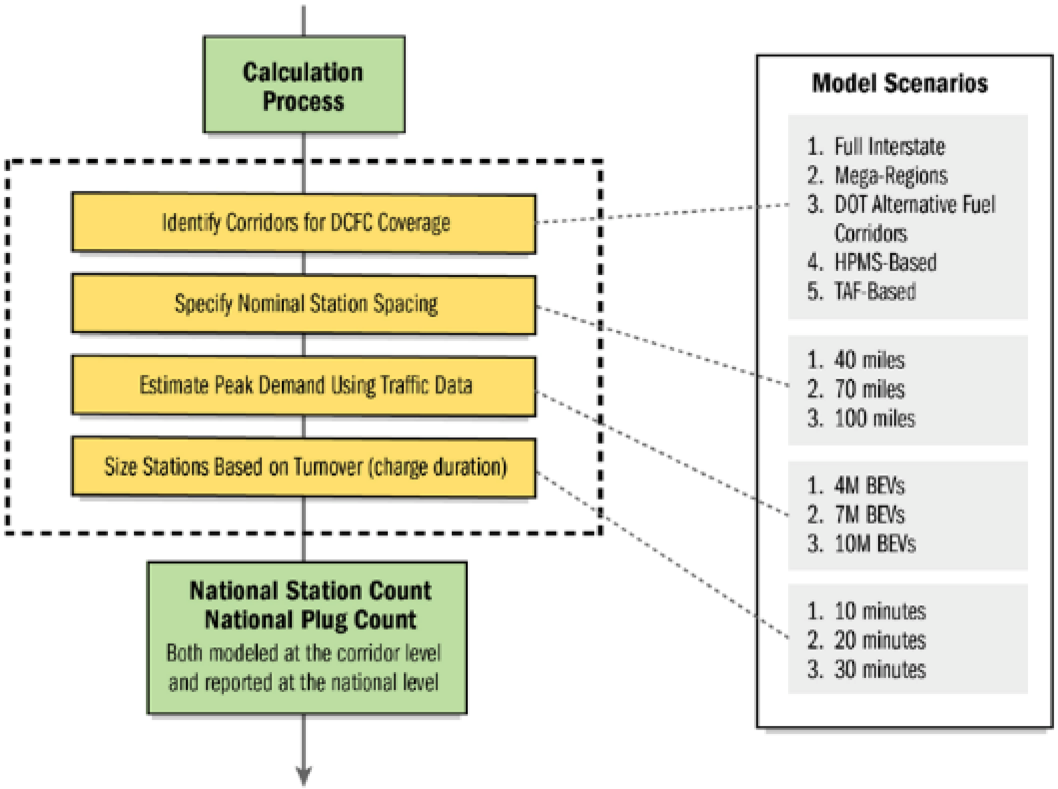


Bottom-up simulations based on travel behavior are used to produce a variety of charging scenarios. **Optimal charging behavior** is assumed to investigate spatial and temporal charging demand and to estimate:

- non-residential infrastructure requirements
- aggregate load profiles

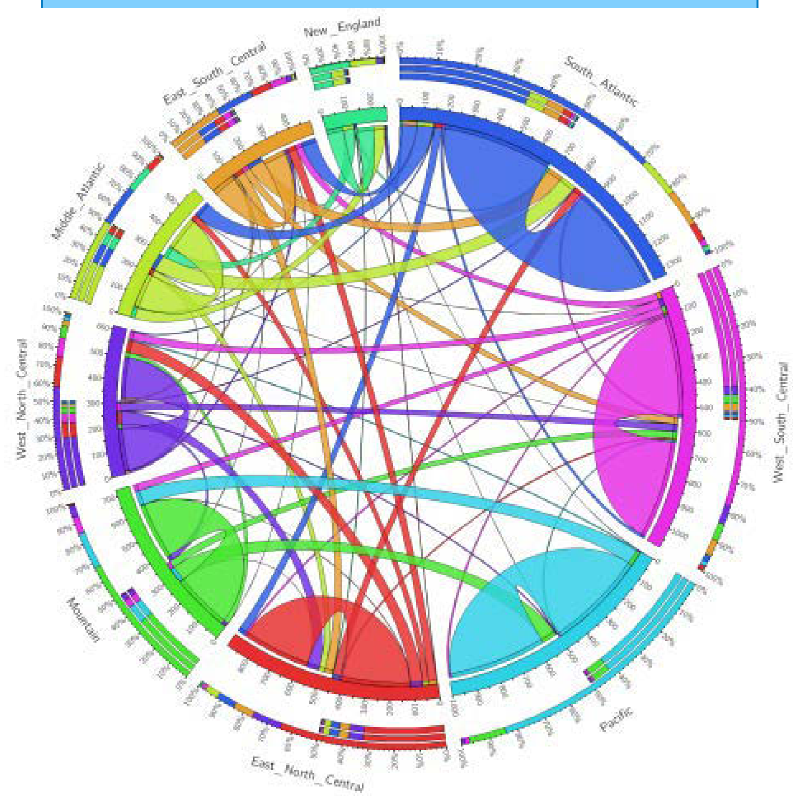
Interstate Corridors

While most travels can be completed on a single-charge, access to an extensive and convenient network of DCFC stations along corridors that enable reliable long-distance intercity travel is required to support long-distance travel



TAF Auto Trips by Census Division

Implies that the majority of **long distance auto travel is mostly regional**



Central Scenario and Sensitivity Analysis

15M PEVs Nationally

Preference for long range PEVs

Equal shares of PHEV & BEV

Majority of charging at home locations

Full corridor coverage

Variable	Central Scenario	Sensitivity
PEV Total	15M (linear growth to 20% of LDV sales in 2030)	9M (growth to 10% of 2030 sales) 21M (growth to 30% of 2030 sales)
PEV Mix (range preference)	Mix PHEV20 10% PHEV50 35% BEV100 15% BEV250 30% PHEV20-SUV 5% BEV250-SUV 5%	Long / Short PHEV20 0% / 40% PHEV50 50% / 0% BEV100 0% / 50% BEV250 40% / 0% PHEV20-SUV 0% / 10% BEV250-SUV 10% / 0%
Share of PEVs in Cities (pop. > 50k)	83% (based on existing HEVs)	71% (based on existing LDVs) 91% (based on existing PEVs)
PHEV:BEV Ratio	1:1	4:1 to 1:4
PHEV Support	Half of full support	No PHEV support to full support
SUV Share	10%	5% to 50%
% Home Charging	88%	88%, 85%, and 82%
Interstate Coverage	Full Interstate	Mega-regions to Full Interstate
Corridor DCFC Spacing	70 miles	40 to 100 miles
DCFC Charge Time	20 minutes (150 kW)	10 to 30 minutes (400 to 100 kW)

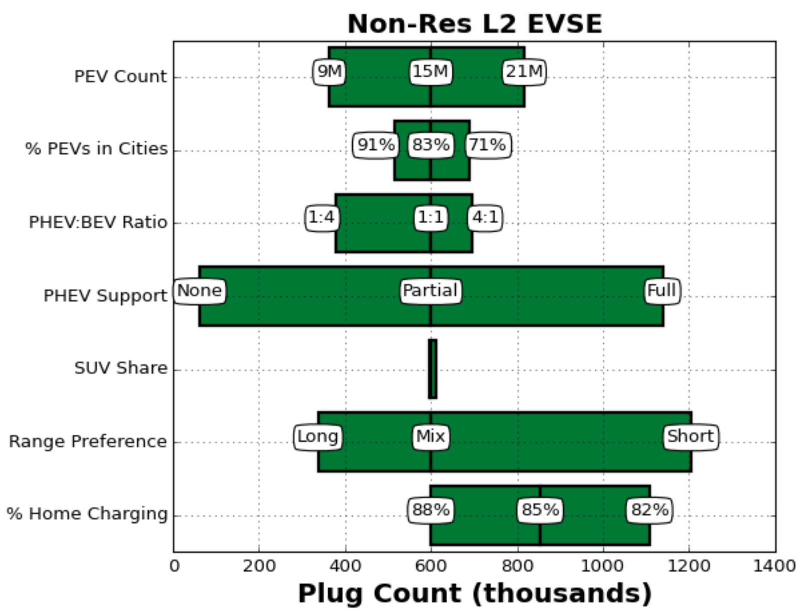
Results – Central Scenario & Sensitivity Analysis

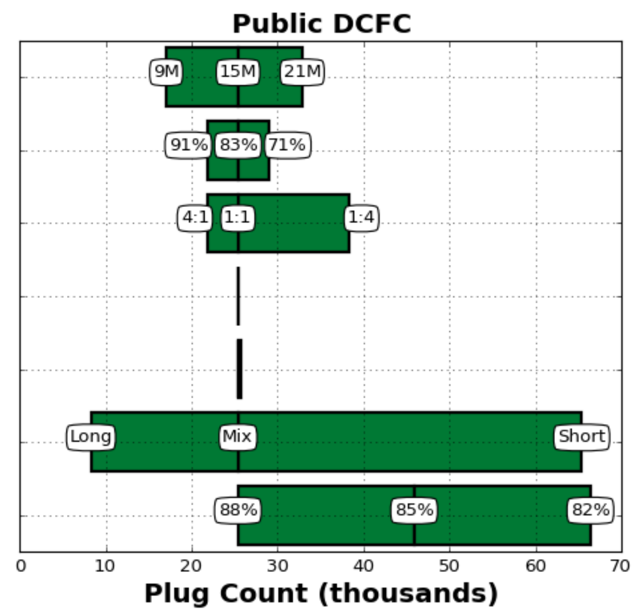
Central Scenario

		Cities	Towns	Rural Areas	Interstate Corridors
PEVs		12,411,000	1,848,000	642,000	---
DCFC	Stations (to provide coverage)	4,900	3,200	---	400
	Plugs (to meet demand)	19,000	4,000	2,000	2,500
	Plugs per station	3.9	1.3	---	6.3
	Plugs per 1,000 PEVs	1.5	2.2	3.1	---
Non-Res L2	Plugs (to meet demand)	451,000	99,000	51,000	---
	Plugs per 1,000 PEVs	36	54	79	---

Estimated requirements for PEV charging infrastructure are heavily dependent on:
1) evolution of the PEV market, 2) consumer preferences, and 3) technology development

Sensitivity Analysis





Insights and conclusions

- **Communities** are expected to have significantly larger charging infrastructure requirements (coverage) than **Interstate corridors**:
  - About 8,100 DCFC stations required to provide a minimum level of nationwide coverage in the communities where 81% of people live.
  - Approximately 400 DCFC stations required to enable long-distance BEV travel along Interstate highways.
- Demand for non-residential plugs for a **15-million PEV market**:
  - 25,000 DCFC plugs in communities (approximately 3.4 plugs per 1,000 BEVs)
  - 600,000 L2 plugs (approximately 40 plugs per 1,000 PEVs)
- Sensitivity analysis indicates a **strong relationship between the evolution of the PEV and EVSE markets**
- Understanding **driving patterns**, **PEV characteristics** (range, charging power), and **charging behavior** and then prioritizing corridors and setting station spacing accordingly could help **optimize the utility and economics of charging stations**

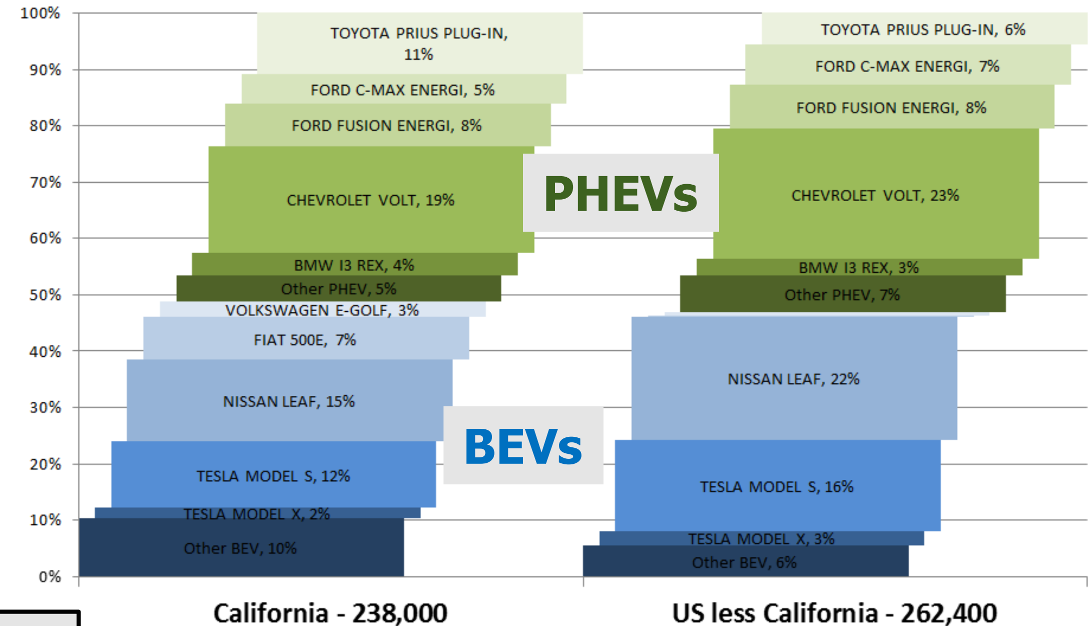
Thanks! Questions?

Eric.Wood@NREL.gov
Matteo.Muratori@NREL.gov

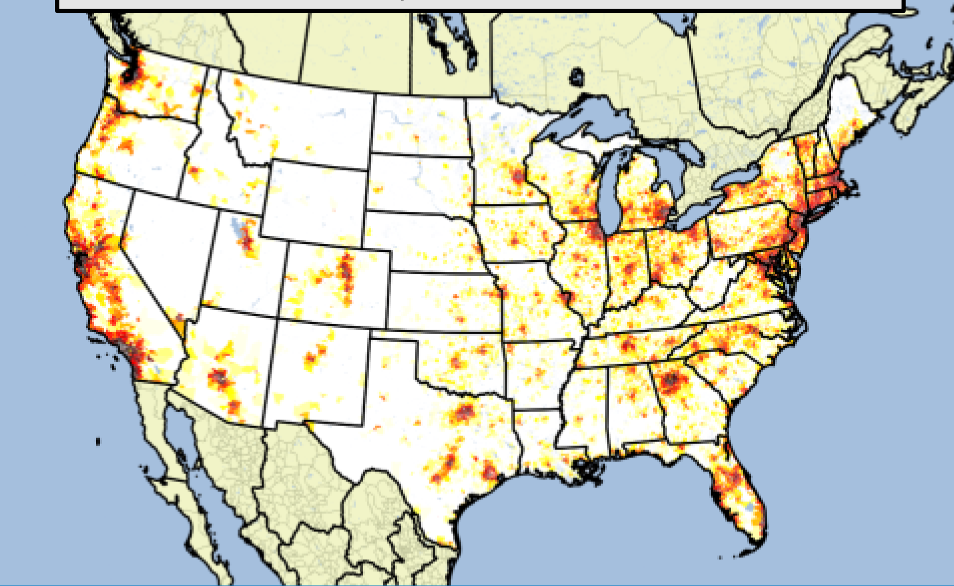
This work was funded by the US Department of Energy Vehicle Technologies Office.

Existing PEV Market – Data from IHS Automotive

NREL analysis leverages IHS Automotive data including registration records for over 250 million light-duty vehicles in the US



~500,000 Registered PEVs in U.S. (through 2016)
Per NREL analysis of IHS Automotive Data

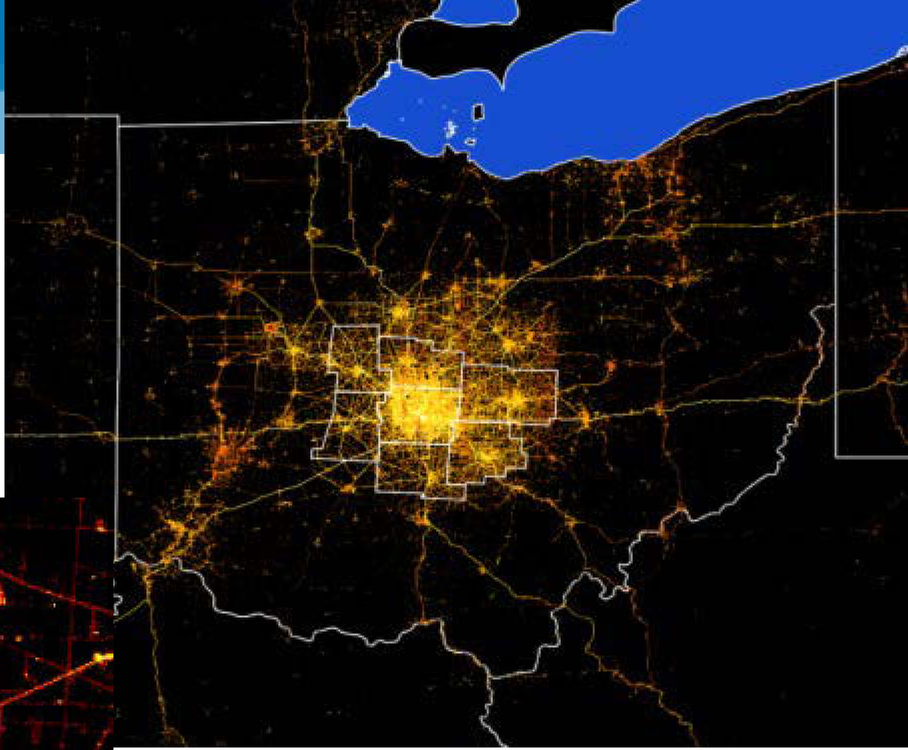


- PEV market has been dominated by PHEVs (*e.g.,* Chevy Volt) and short-range BEVs (*e.g.,* Nissan Leaf), with the notable exception of Tesla
- Introduction of new "mass market" BEVs with 200+ mi range is on the horizon:
  - Chevy Bolt
  - Tesla Model 3

GPS Travel Data

Commercial GPS dataset (developed by INRIX) from Columbus, OH used to characterize daily travel patterns

Complemented public travel data from California and Massachusetts



<u>By the numbers:</u>

12 months of trips (all of 2016)
All trips intersecting Columbus region
Driving mode imputed by INRIX trip engine

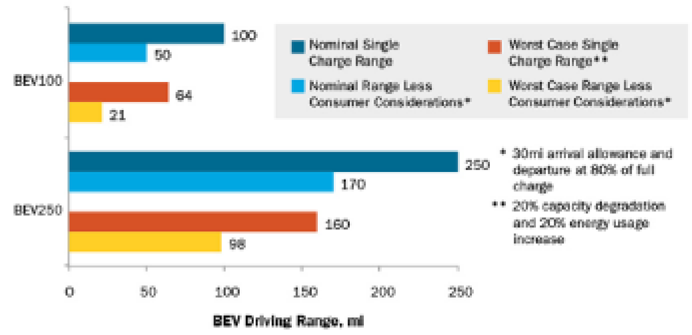
7.82M device ids
32.9M trips
1.04B miles
2.58B waypoints

Corridor DCFC Station Spacing

BEV Single-Charge Driving Range & DCFC Spacing Considerations

Rated driving range is intended to represent the distance a fully charged BEV can cover until fully depleted under typical conditions. However, it is well documented that real-world range can be significantly different depending on driving speed and aggression, use of cabin climate control, and long-term battery degradation. Thus, rated single-charge driving range is a poor yardstick for designing a robust DCFC network that empowers consumers to drive BEVs on long distance trips in a variety of traffic and weather conditions (as they currently do with conventional vehicles). This study proposes a set of consumer considerations (i.e., arrival allowance and early departure penalty) that can be taken in concert with variability of single-charge driving range to estimate station spacing for a reliable DCFC network.

DCFC Station Spacing Considerations



Arrival Allowance

Assume consumers will prefer to stop at DCFC stations well before fully depleting their BEV range. This project assumes a typical arrival allowance of 30 miles.

Early Departure Penalty

Due to battery limitations, BEVs typically experience reduced DCFC rates near top of charge. Consequently, consumers are likely to depart DCFC stations prior to receiving a full charge. This project assumes consumers will typically depart DCFC stations with 80% of a full charge.