Modeling Framework and Results to Inform Charging Infrastructure Investments

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June 21, 2018

DOE Vehicle Technologies Office
2018 Annual Merit Review and Peer Evaluation Meeting
Washington, D.C.

Project ID VAN026

NREL/PR-5400-71488

Overview

Timeline

- Project start date: October 2015
- Project end date: September 2019
- Percent complete: 70% complete

Budget

- Total project funding
  - DOE share: $1,075k
    - Includes $200k to INL for DCFC analysis
  - Contractor share: NA
- Funding for FY 2017: $800k
- Funding for FY 2018: $125k

Barriers

- Availability of alternative fuels and electric charging station infrastructure
- Consumer reluctance to purchase new technologies
- Maintenance of local coalition effectiveness

Partners

- Idaho National Laboratory (INL)
- California Energy Commission
- Electric Power Research Institute
- U.S. Department of Transportation
- U.S. Environmental Protection Agency
- U.S. DOE SMART Mobility Consortium
- Others listed by project in slides

Significant Public/Private Investments Being Made in EV Charging Infrastructure

Relevance

Disparate group of stakeholders* requires consistent approach for intelligently informing infrastructure investments to grow the PEV market and improve domestic energy security

*Automotive manufacturers, electric utilities, charging networks, transportation network companies, state/local governments

Volkswagen Plans to 'Electrify America' with $2 Billion Investment in the Largest U.S. EV Charging Network

Maryland's utilities propose spending $104 million on statewide electric-vehicle charging network

PG&E Launches Country's Largest Utility-Sponsored EV Charging Program

The pilot program will introduce 7,500 electric car chargers in California. More utility electrification initiatives to come.

EMMA FOEHRINGER MERCHANT | JANUARY 17, 2018

Senator Skinner Introduces "E-CAr" (SB 1014) to Shift Ride-Hailing to Zero-Emission Vehicles

State to Spend $14M on Electric Car Charging Stations

Virginia is looking for a developer to build a statewide charging network for electric vehicles.

California aims to have 5 million electric cars on the road and 250k charging stations by 2030

Fred Lambert - Jan. 29th 2018 10:40 am ET @FredericLambert

BP becomes latest oil giant to invest in electric vehicle charging

Fred Lambert - Jan. 30th 2018 8:02 am ET @FredericLambert

Washington state to spend $1M on electric-vehicle charging stations

Originally published September 7, 2017 at 10:19 am | *Updated September 7, 2017 at 2:21 pm*

Volkswagen, Walmart partner to bring EV charging to more than 100 Walmart stores in 34 states

Western governors set sights on electric vehicle charging network spanning seven states

Deal signed to ease EV range anxiety with fast-charge network along 11 Interstate highways

Via: Electrek, Greentech Media, Baltimore Sun, Future Car, US News and World Report, Seattle Times, Denver Post, CNET, CA-Senate, NY Daily News

Six Analysis Projects Contribute to the Overall Research Goal

Milestones

Massachusetts EVSE Case Study — **Complete**
Estimating electric vehicle supply equipment (EVSE) requirements for future plug-in electric vehicle (PEVs)

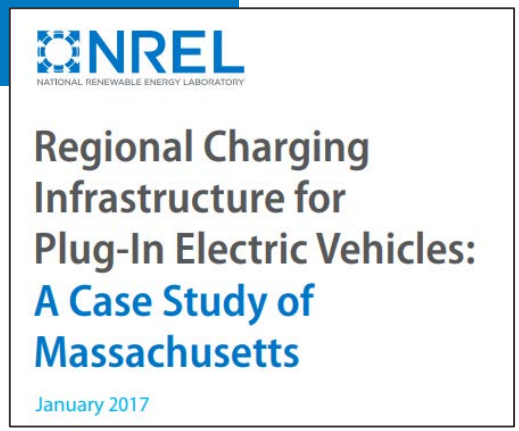
Columbus EV Charging Scenario Analysis — **Complete**
Collaborative scenarios developed with input from multiple local and industry stakeholders

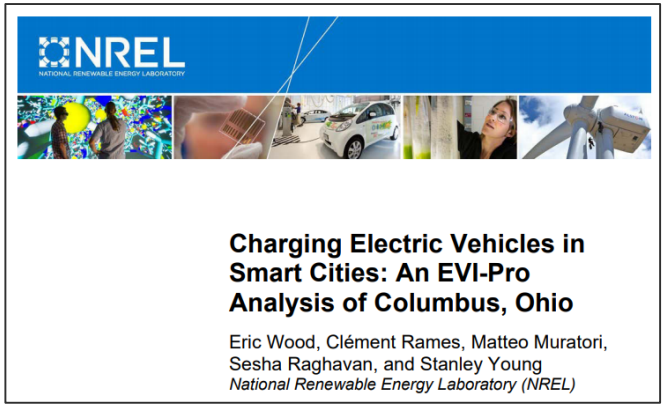
National Corridor/Community EVSE Analysis — **Complete**
Scaling insights from regional studies to national level.

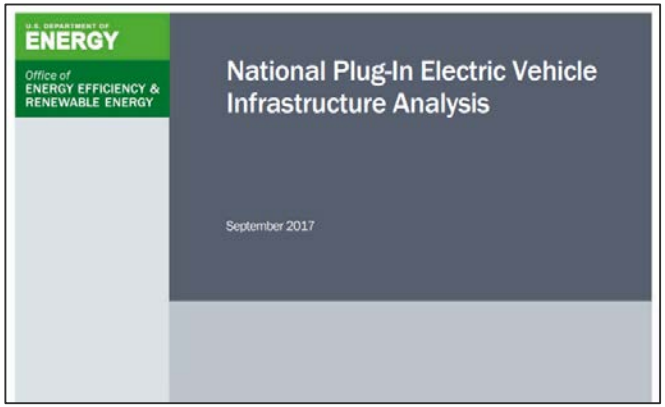
PEV Infrastructure Tool (EVI-Pro Lite) — **Complete**
Simple tool designed to be used by various stakeholders.

Cost of Direct Current (DC) Fast Charging (w/INL) — **Complete**
How do utility demand charges impact cost of fast charging and what technologies can be used to mitigate.

PEV Charging at Multi-Unit Dwellings — **On-going**
Estimate access to residential charging for US population and evaluate alternatives.







Each project draws upon similar core analytic methods & data

Conceptual Representation of PEV Charging Requirements

Approach 1

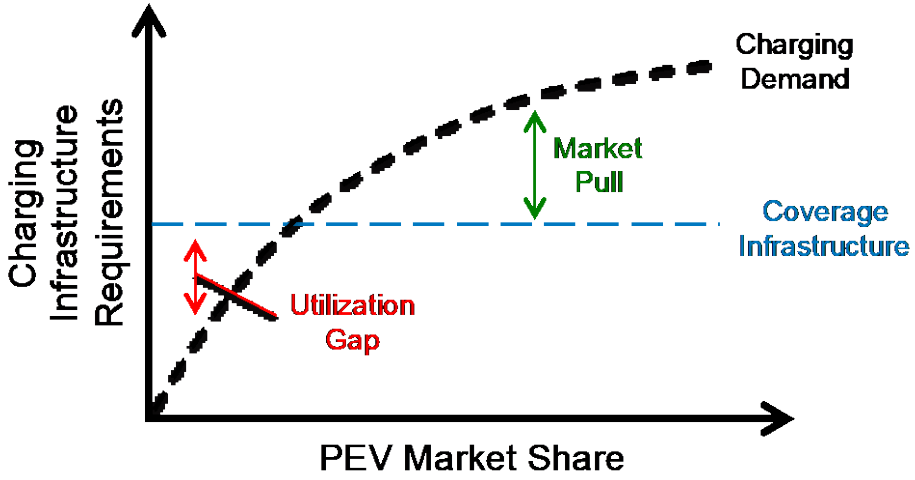
Consumer demand for PEV charging is coverage-based
"Need access to charging anywhere their travels lead them"

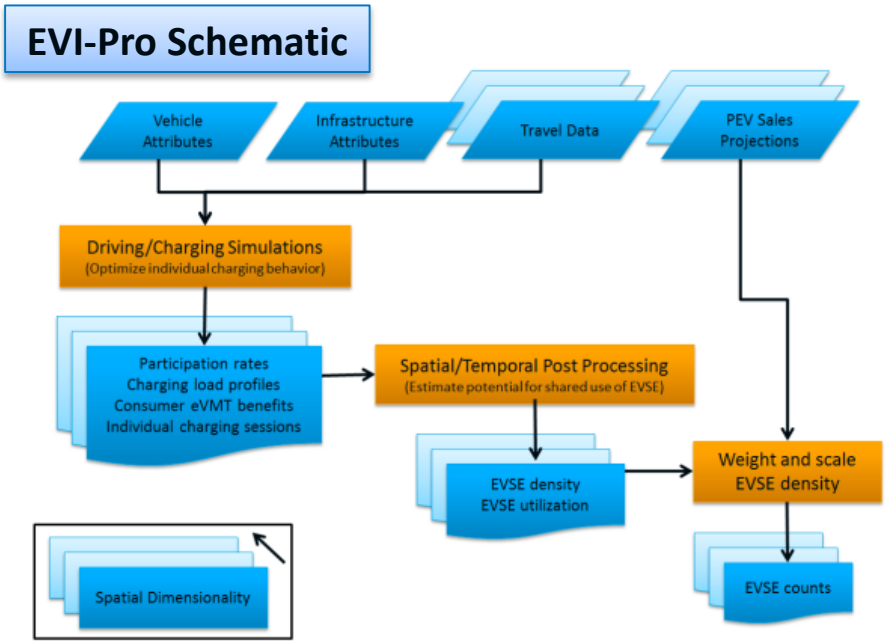
Infrastructure providers make capacity-driven investments
"Increase supply of stations proportional to utilization"

While calculating coverage requirements is fundamentally a geographic problem, estimating **consumer demand for charging infrastructure** requires a more sophisticated approach.

NREL has developed the **Electric Vehicle Infrastructure Projection (EVI-Pro) Tool** in collaboration with the California Energy Commission to estimate consumer demand for charging infrastructure.

EVI-Pro is a bottom-up PEV driving/charging simulator that leverages real-world travel profiles and assumes economically efficient charging behavior with the majority of charging occurring at residential locations (subject to user input).

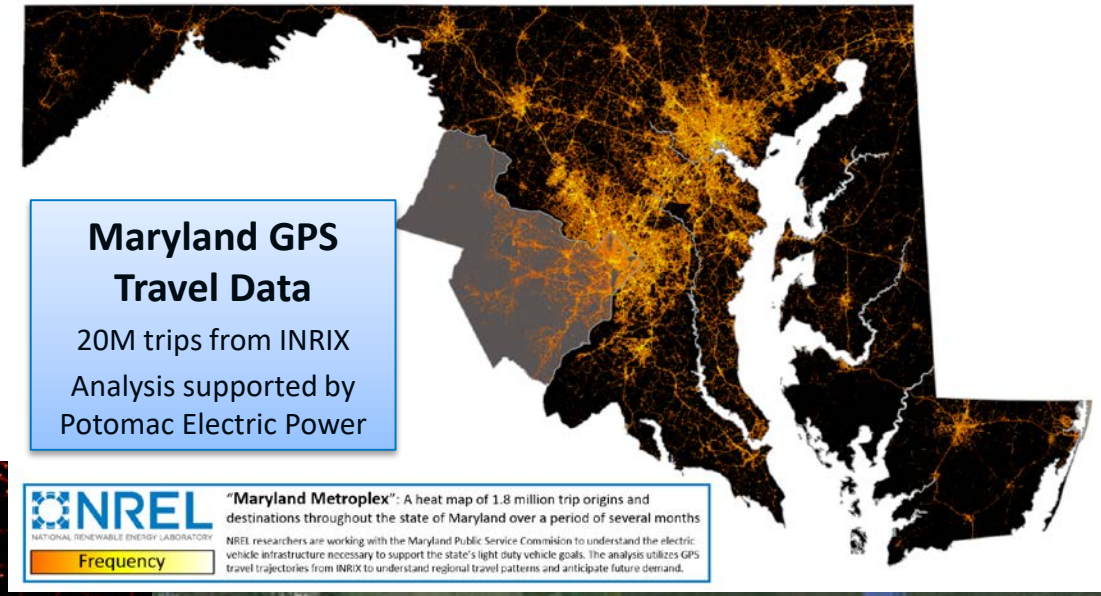




Consumer Travel Data

One of the fundamental inputs to EVI-Pro is geographically resolved, real-world travel data from the area of interest.

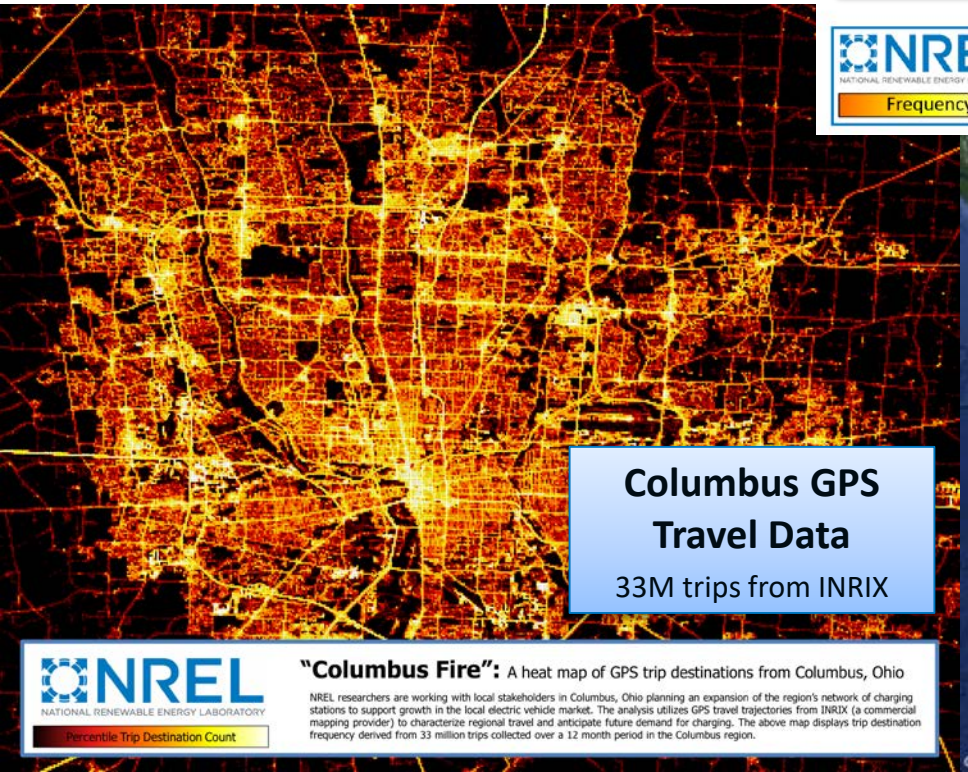
NREL has acquired numerous travel data sets for use in simulating consumer charging requirements by power level, location, and time of day.



Maryland GPS Travel Data

20M trips from INRIX

Analysis supported by Potomac Electric Power



Columbus GPS Travel Data

33M trips from INRIX

National Long Distance Travel Data

9M unique origin-destination (O/D) pairs from FHWA Traveler Analysis Framework

Electricity Rates for Fast Charging & Fast Charging Station Power Profiles

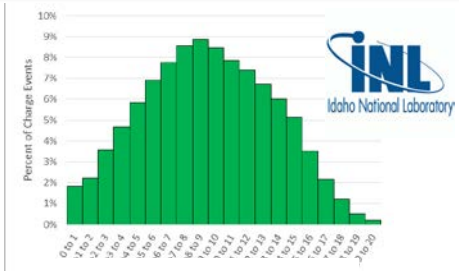
Approach 3

Direct current fast charging (DCFC) stations offer **rapid recharging opportunities** to electric vehicles (EVs), extending their effective range beyond that of a single charge.

Demand charges have been identified as a critical rate component for DCFC.

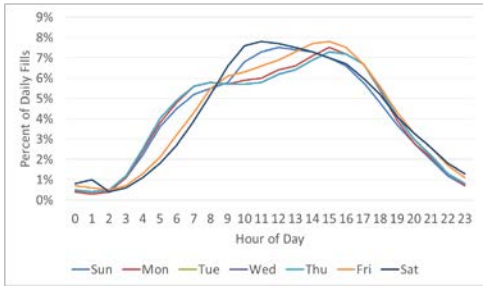
Estimate power profiles of potential future charging sites using various real-world data sources (e.g., current DCFC usage, historical gas station usage, gas fueling event data)

Current DCFC Usage*



*Data provided by EVgo

Historical Gas Station Usage



Determine for a year's worth of charges:

- When each charge starts
- How much energy each driver will need
- Power profile of each individual charge
- Total power profile of the site

Informed by a convening of experts, assess the **cost of electricity** for different scenarios of DCFC station size and use, based on **over 7,500 commercial electricity rates** from NREL's Utility Rate DB.

Utility Rate DATABASE

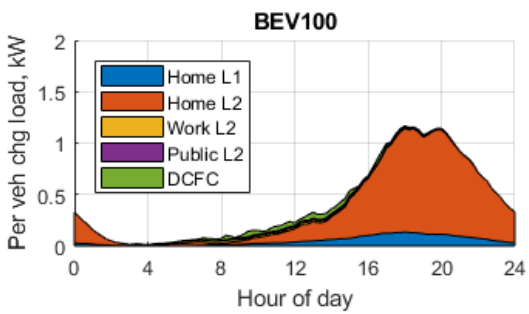
REopt

NREL's REopt model is then used to identify technology solutions that can help reduce the electricity cost for DCFC (e.g., solar generation, storage, co-location with existing load).

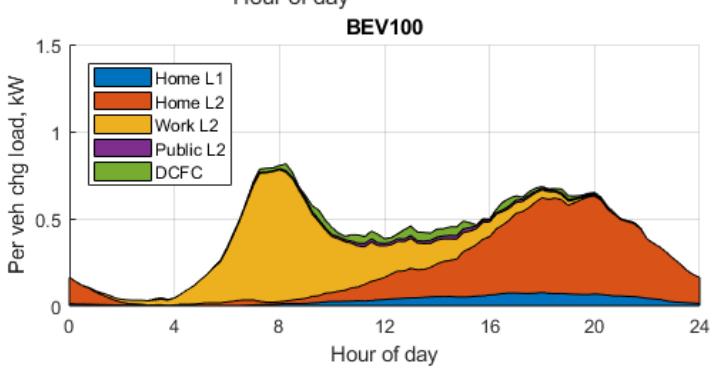
EVSE Siting and Load Flexibility: Columbus Scenario Analysis

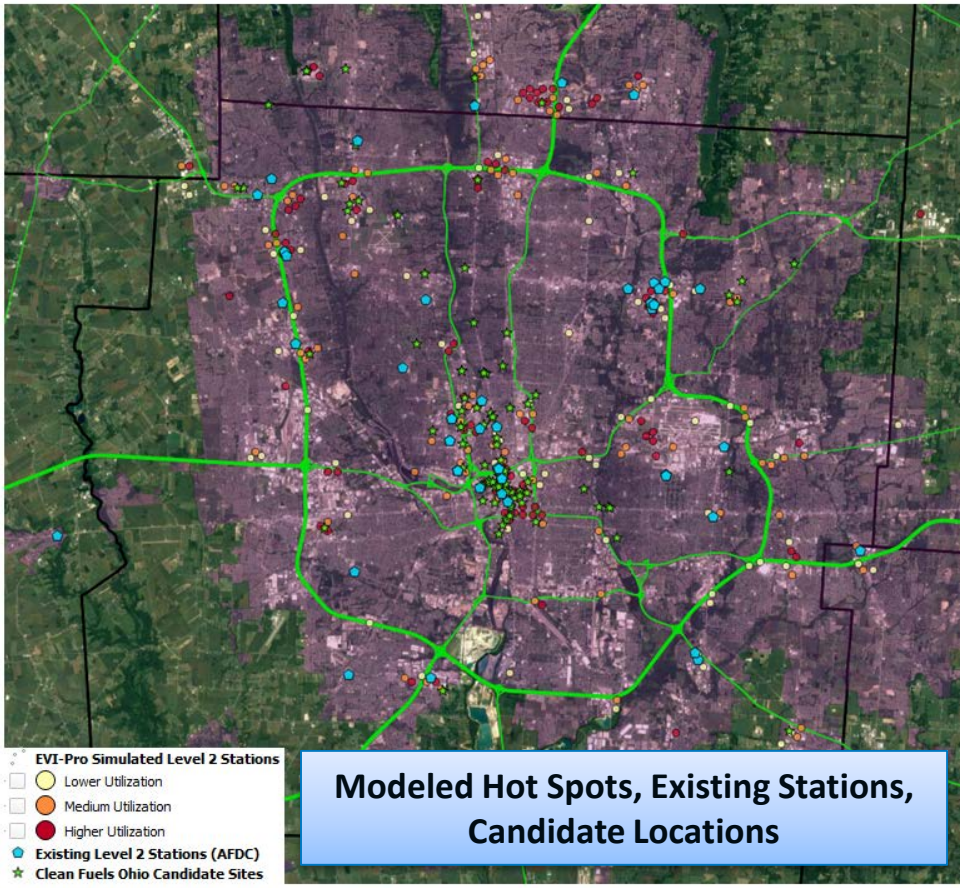
Objective: Support DOT Smart City (Columbus, OH) plan for an expanded EVSE network to reduce range anxiety as a barrier to PEV adoption and ensure effective use of public/ private investments.

Approach: Simulate consumer PEV driving/ charging behavior to identify locations with high estimated future demand for EVSE.



Load flexibility
Top: Without workplace charging
Bottom: With workplace charging





Modeled Hot Spots, Existing Stations, Candidate Locations

Significance & Impact

- City of Columbus is using results to assist in identifying site hosts for new EVSE installations.
- Report serving as a template for planning PEV charging stations in Columbus and other Smart Cities.

Statewide Assessments in Massachusetts, Maryland, California, Colorado

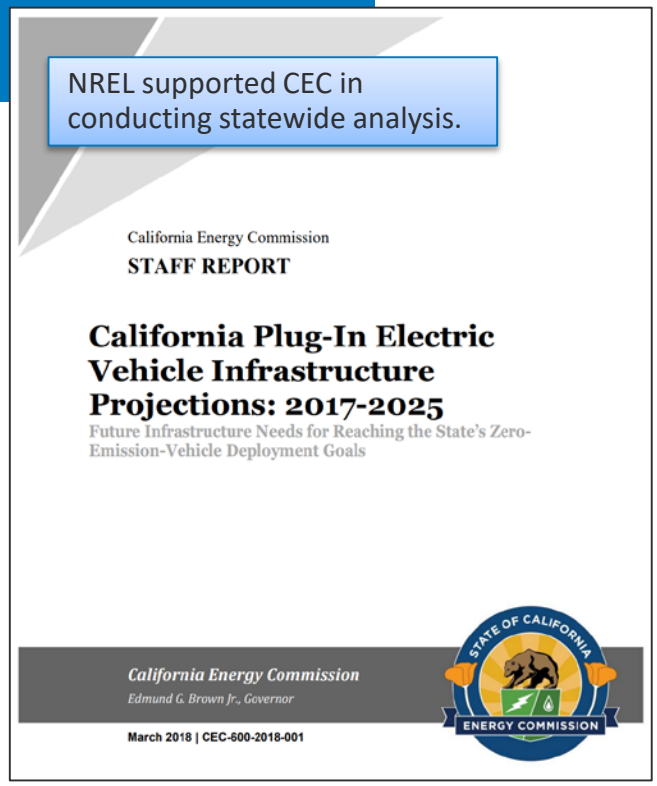
Objective: To provide guidance on PEV charging infrastructure requirements to regional stakeholders.

Approach: Superimpose existing regional driving data with simulated PEVs and identify work/public EVSE requirements that meet anticipated consumer demand.

Significance & Impact

- State agencies in MA, MD, CA, and CO are using demand projections from EVI-Pro to assist in planning statewide EVSE growth supporting PEVs.
- Related organizations have inquired on the potential to run similar analysis in additional states.

NREL supported CEC in conducting statewide analysis.


California Energy Commission
STAFF REPORT

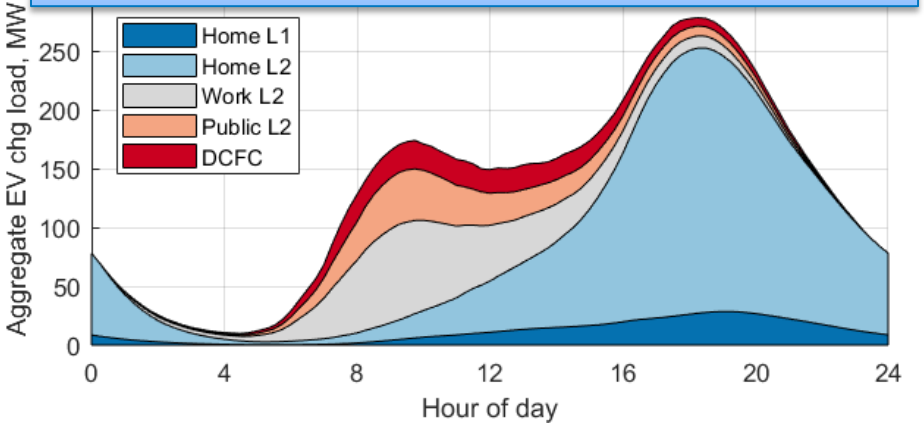
California Plug-In Electric Vehicle Infrastructure Projections: 2017-2025

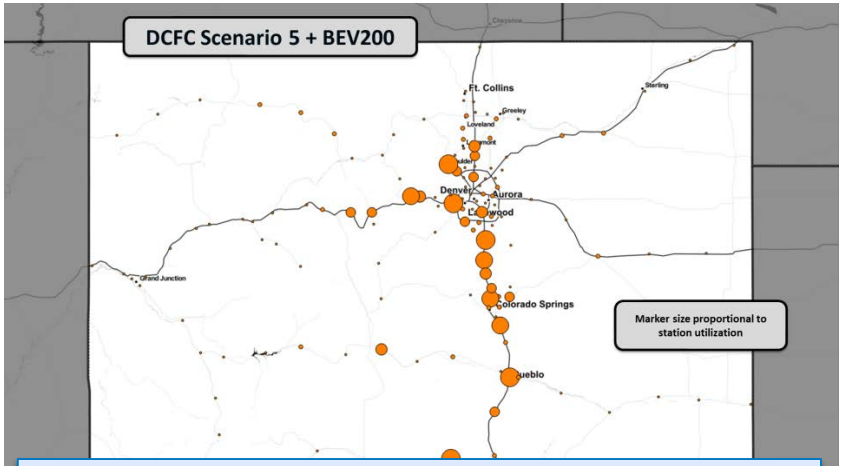
Future Infrastructure Needs for Reaching the State's Zero-Emission-Vehicle Deployment Goals

California Energy Commission
Edmund G. Brown Jr., Governor

March 2018 | CEC-600-2018-001

Potomac Electric and Maryland Public Service Commission supporting NREL analysis of EVSE requirements to meet ZEV goal.





Colorado Department of Transportation and Regional Air Quality Council supported NREL analysis of DCFC in CO.

National PEV Charging Analysis

Objective: Develop objective estimates of corridor and community charging stations necessary to support national PEV adoption.

Approach: Build upon existing EVI-Pro assessments to develop framework for making national estimations with city-, state-, and corridor-level resolution.

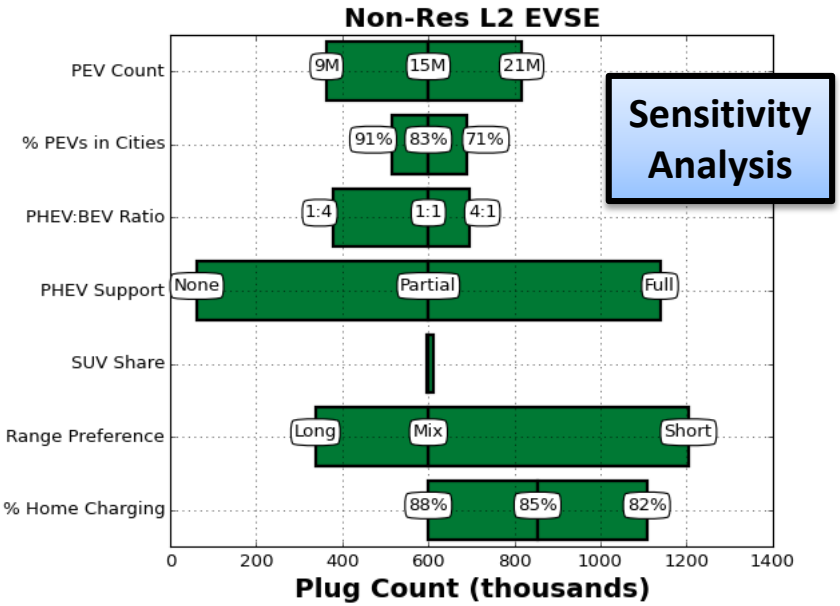
Central Scenario Results

		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

Significance & Impact

- First of its kind national analysis with infrastructure estimates incorporating routine daily travel patterns and infrequent long distance trips.
- Report is serving as the de facto starting point for conversations between automakers, electric utilities, charging networks, and government agencies regarding investments in EVSE buildout at a variety of geographic scales.



Online PEV Infrastructure Tool: EVI-Pro Lite

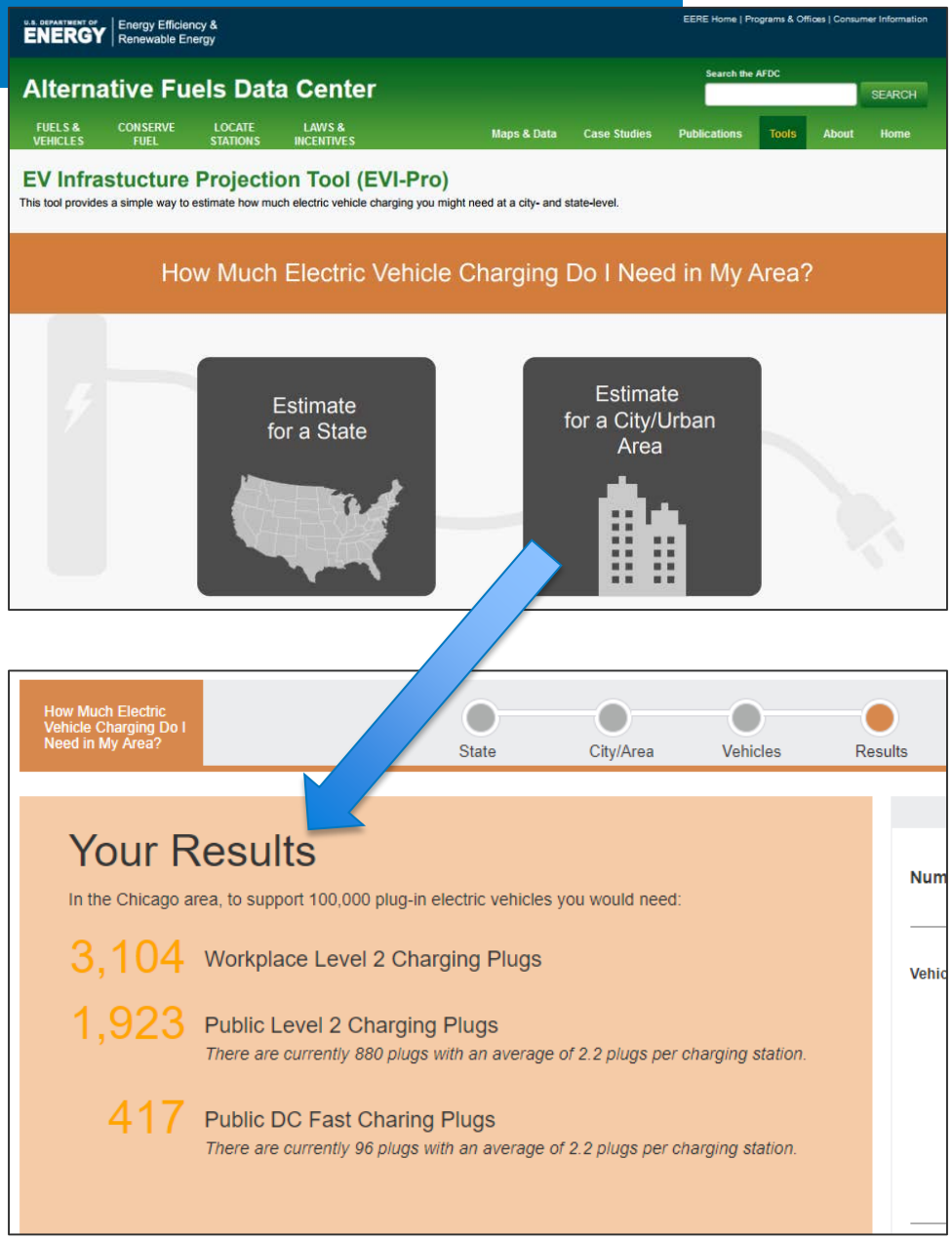
Objective: Make analytic capabilities of EVI-Pro model accessible to broad group of stakeholders for EVSE investment decisions.

Approach: Develop a simplified, web-based interface for EVI-Pro that gives users access to a limited number of critical input variables.

Significance & Impact

- EVI-Pro "unlocks" an unlimited number of scenarios for planners to explore regarding EV charging infrastructure requirements.
- Ability to rapidly develop scenarios and explore sensitivities will help users understand the key drivers for investment.

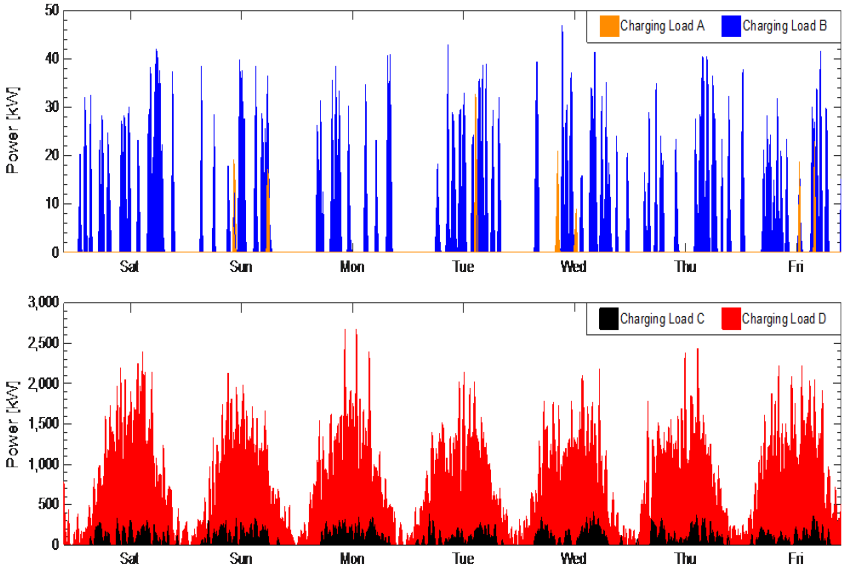
The simple tool allows rapid estimates of EVSE needs based on multiple input variables.



DCFC Power Profiles and Cost of Electricity

Charge profiles were developed to represent usage of current and potential future DCFC sites

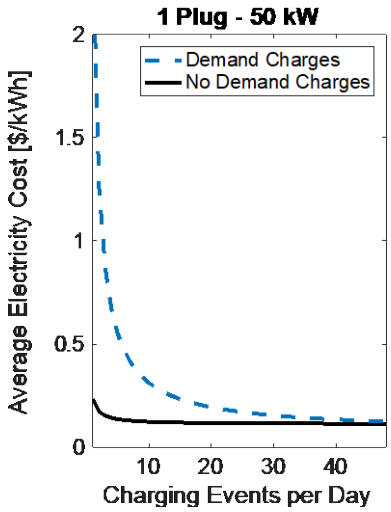
- Single 50-kW DCFC (Loads A and B)
- 4 co-located 150-kW DCFC (Load C)
- 20 co-located 400-kW DCFC (Load D)



Cost of electricity was assessed for different scenarios of DCFC station size and use, informed by a convening of experts, based on **over 7,500 commercial electricity rates**.

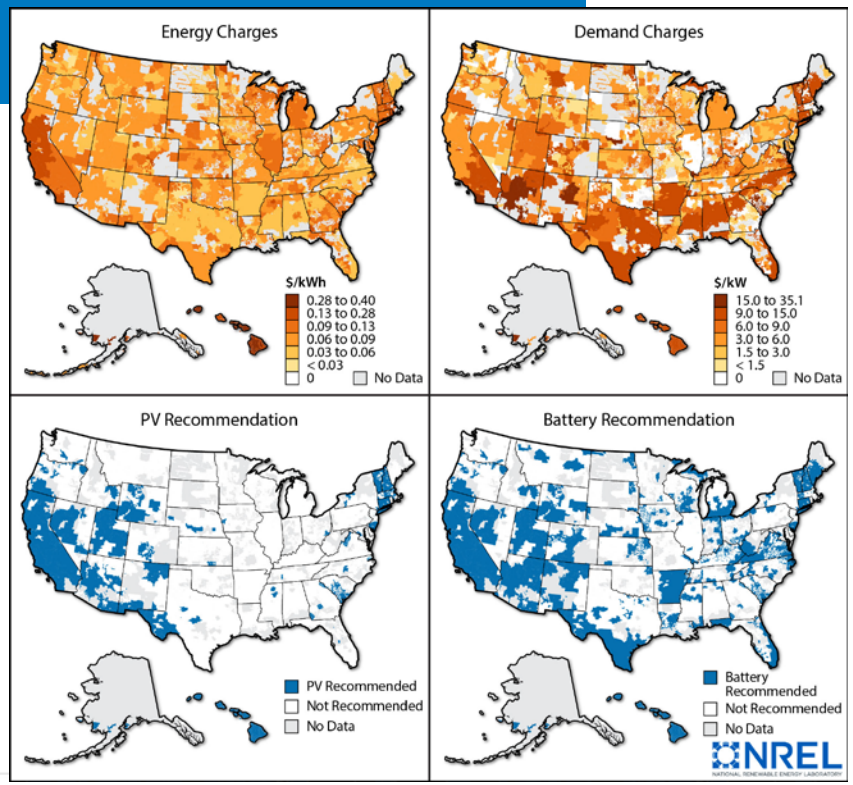
Cost of electricity for DCFC varies dramatically, from less than $0.10 to over $2 per kilowatt-hour.

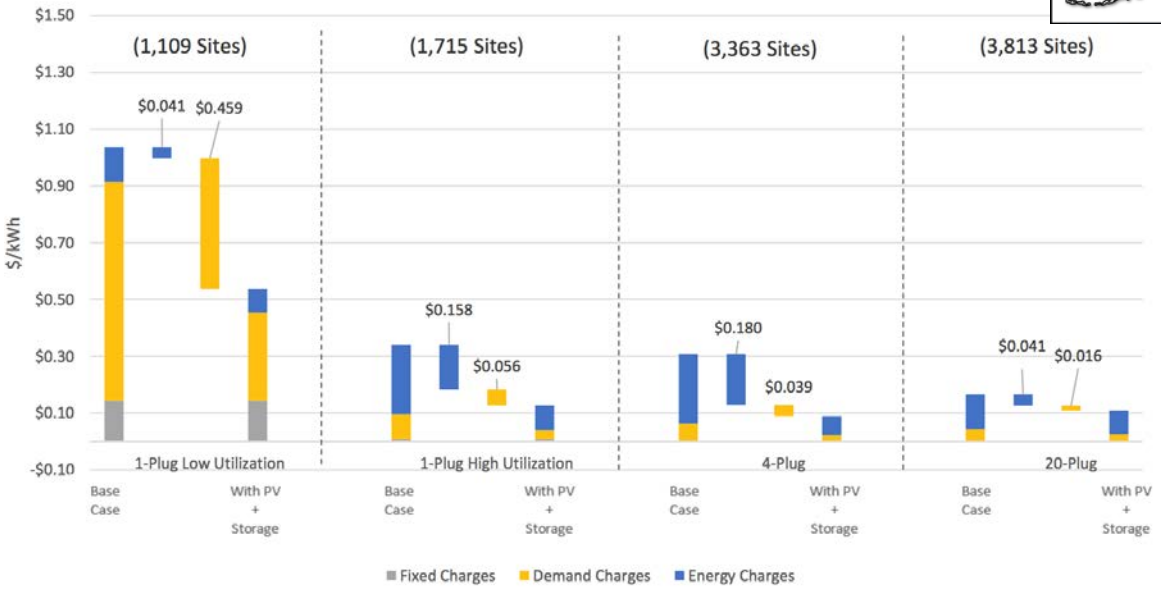
Cost of electricity decreases rapidly as DCFC station use increases



Technology Solutions to Reduce Cost of DCFC

- Analysis examines **over 7,500 electricity rates** to understand DCFC costs and mitigation opportunities.
- **Demand charges** are significant cost for low-utilization stations and become much less important as utilization increases
- Energy storage (battery) can mitigate high **demand charges**
- Photovoltaic (PV) energy can mitigate high **energy charges**, even in areas with lower solar irradiance (e.g., Vermont)





Technology solutions are **effective at reducing electricity cost** for DCFC:

- Co-location helps small stations (high fixed charges)
- PV and batteries can support locations with high energy and/or demand charges

Responses to Previous Year Reviewers' Comments

Comment Response

- Coordination with U.S. DOT, OEMs, and Universities
  - Reviewers commented in FY17 that this effort should seek greater levels of coordination with the U.S. DOT Alternative Fuel Corridor Initiative and to solicit input from automotive manufacturers and universities.
  - NREL has responded by hosting officials from U.S. DOT at meetings in Colorado for the purpose of reviewing NREL EVSE modeling/analysis. U.S. DOT is aware of DOE-supported efforts in this space and is working directly with NREL on the second round of Alternative Fuel Corridor designations.
  - U.S. DOT and automotive manufacturers were well represented during an October 2017 convening as part of the INL/NREL fast charging analysis (see slide 16).
  - Additionally, NREL has solicited feedback from automotive manufacturers (e.g., Ford, GM, Honda, Tesla) and universities (e.g., University of California (UC) - Davis, University of Washington, Ohio State University) during the past fiscal year. Additional collaborators are shown on slides 15 and 16.

- Emphasis on Large PEV Markets
  - FY17 reviewers requested that greater emphasis be placed on tailoring analysis to large PEV markets.
  - NREL has responded by expanding the geographies covered with detailed EVI-Pro models to include the following urban areas: San Francisco/San Jose, Los Angeles, San Diego, Boston, Baltimore, and Washington D.C.
  - FY18 analysis has also been expanded to consider factors unique to PEV ownership in urban areas, such as charging solutions for residents of multi-unit dwellings (MUDs). Case studies of Los Angeles, Chicago, New York City, and Washington, D.C. are being considered.

Collaboration and Coordination with Other Institutions

Collaboration 1

The following stakeholder groups contributed to each project listed below.

California Energy Commission – Collaborative development of EVI-Pro

Massachusetts EVSE Case Study

- Massachusetts Executive Office of Energy and Environmental Affairs, California Energy Commission, EPRI

Columbus PEV Infrastructure Scenario Analysis

- City of Columbus, Ohio State University, U.S. Department of Transportation, MORPC, Clean Fuels Ohio, Ohio EPA, AEP, Honda, ChargePoint, GDP Group, HNTB

National Corridor/Community EVSE Analysis

- U.S. Department of Transportation, U.S. Environmental Protection Agency, ElectrifyAmerica, Ford, GM, Tesla, EPRI, Sacramento Municipal Utility District (SMUD), Atlas Public Policy, California Energy Commission, City and County of Denver, Georgetown Climate Center, UC Davis, University of Washington, ICCT, Northeast States for Coordinated Air Use Management (NESCAUM)

PEV Infrastructure Tool (EVI-Pro Lite)

- ChargePoint, City and County of Denver, North Central Regional Clean Cities Coordinators, Clean Cities West Virginia, Colorado Electric Vehicle Coalition, Edison Electric Institute (EEI), Electrification Coalition, GM, Maryland Public Service Commission, Massachusetts Office of Energy & Environmental Affairs, MJ Bradley, New York Power Authority, Sierra Club, Southern Company, Tesla, U.S. Environmental Protection Agency

Collaboration and Coordination with Other Institutions

Collaboration 2

Cost of DC Fast Charging and Demand Charges

- AeroVironment
- Ameren Missouri
- American Public Power Association (APPA)
- Atlas Public Policy
- ChargePoint
- Colorado Energy Office
- EEI
- Electric Drive Transportation Association
- EPRI
- Electrify America
- Energetics Incorporated
- EVgo
- Exelon
- Ford Motor Company
- Georgia Power
- Georgia Public Service Commission
- Greenlots
- Missouri Public Service Commission
- National Association of Regulatory Utility Commissioners (NARUC)
- National Association of State Energy Officials (NASEO)
- National Rural Electric Cooperative Association (NRECA)
- National Rural Utilities Cooperative Finance Corporation
- Nissan North America
- NESCAUM
- NV Energy
- PacifiCorp
- Portland General Electric
- Rappahannock Electric Cooperative
- SMUD
- SemaConnect Inc.
- U.S. Department of Energy (VTO & OP)
- U.S. Department of Transportation
- U.S. Environmental Protection Agency
- Washington State Department of Commerce

Remaining Challenges and Barriers

- **Future PEV Market Uncertainty**: Uncertainty regarding PEV sales, vehicle attributes, infrastructure attributes (e.g. extreme fast charging), and consumer charging behavior makes projecting infrastructure requirements more challenging. This is challenge is addressed in each study using sensitivity analysis to quantify impacts of input parameters that are inherently uncertain.

- **Charging at MUDs**: Relatively little is currently known regarding the number of PEVs that are owned by consumers with inconsistent access to residential charging and how this segment may evolve over time.

- **Electrification of Transportation Network Companies (TNCs)**: Recent trends in personal mobility have resulted in the rapid growth of TNCs providing on-demand ride-hailing. The opportunity space to electrify this vocation is poorly understood due to a lack of TNC operational data.

Proposed Future Work

- **Future PEV Market Uncertainty**: This challenge is being addressed through analysis supported by the California Energy Commission towards:
  - Integrating EVSE availability into NREL's consumer choice model (ADOPT) with calibrations based on IHS Polk Registration data and the AFDC Station Locator. Collaborating with University of Tennessee.
  - Tracking consumer charging behavior through historical data collection from charging network companies in California.

- **Charging at MUDs**: This market segment is being investigated by the ongoing MUD-specific analysis (DOE funded).
  - Estimates for the share of PEVs that may be exclusively reliant on non-residential EVSE networks are being developed.
  - Impact of charging behaviors for this market segment will be quantified using EVI-Pro with various levels of restriction on access to residential charging.

- **Electrification of TNCs**: This challenge is being addressed through research projects within the DOE Systems and Modeling for Accelerated Research in Transportation (SMART) Mobility Consortium under the Energy Efficiency Mobility Systems (EEMS) program.
  - Collection of TNC activity data is being pursued as well as development of city-scale mobility models (e.g., BEAM, Polaris) for simulating TNC activity patterns

Any proposed future work is subject to change based on funding levels

Summary

Relevance

- Significant investments are currently being made in PEV charging infrastructure
- Stakeholders require consistent approach for informing investments to grow the PEV market and improve domestic energy security

Approach

- Six distinct projects contribute to the overall research goal
- EVI-Pro estimates EVSE requirements based upon multiple inputs
- NREL/INL have developed rigorous methods to calculate cost of electricity for DCFC

Technical Accomplishments and Progress

- EVI-Pro analyses have been published for Columbus, OH; CA; CO; MA; and MD
- The National PEV Infrastructure Analysis extrapolates results from regional studies to national level and is being leveraged by numerous stakeholders
- Insights from EVI-Pro are being made available through a web app: EVI-Pro Lite
- NREL/INL demonstrated technological solutions for decreasing cost of fast charging

Collaboration

- Multiple stakeholder groups have contributed to each of the different projects

Proposed Future Research

- Improve understanding of relationship between EVSE availability and PEV sales, quantify potential size of MUD-PEV market, and estimate requirements for electrification of TNCs

Thank You

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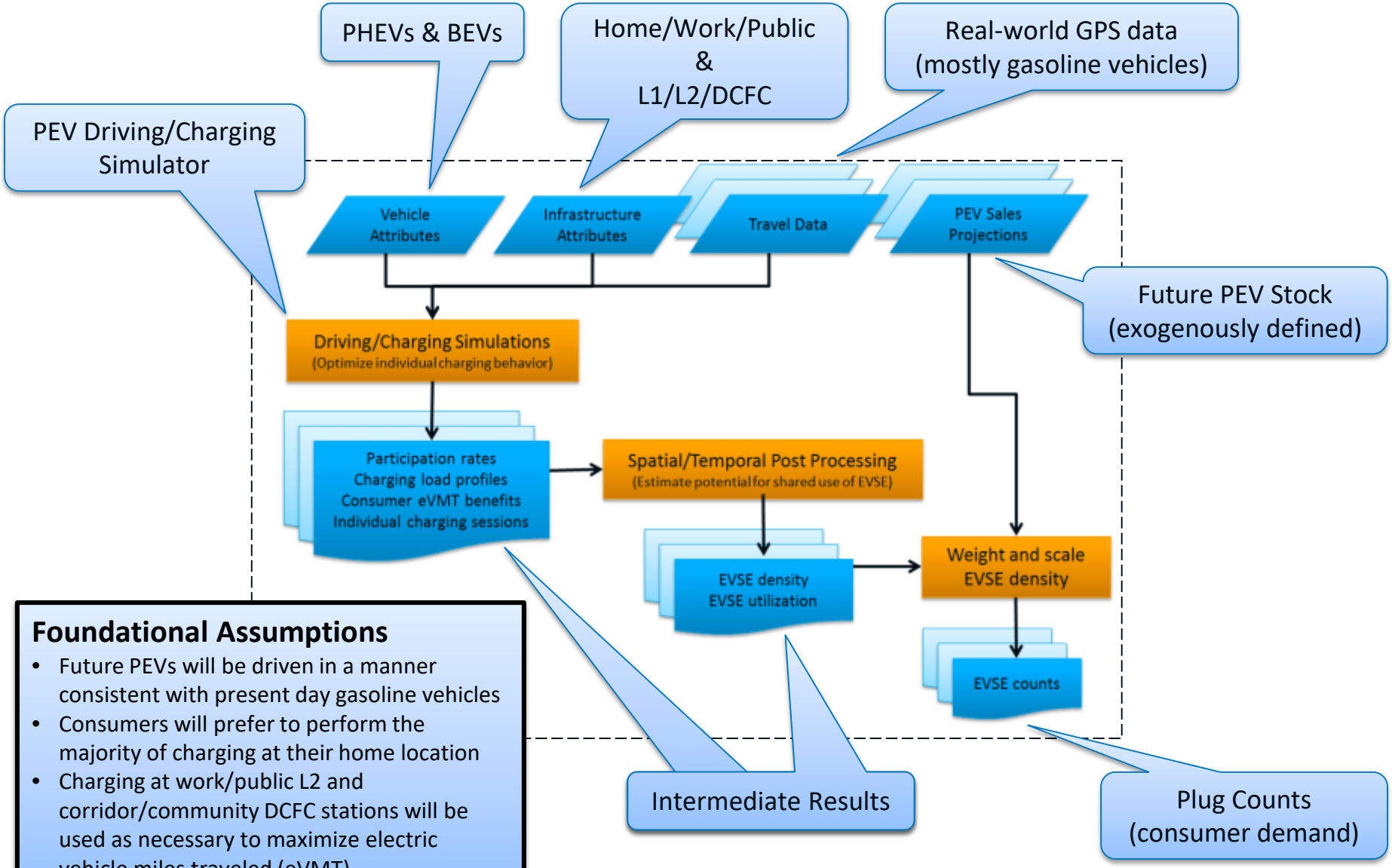
Technical Back-Up Slides

Electric Vehicle Infrastructure Projection Tool (EVI-Pro)



Foundational Assumptions

- Future PEVs will be driven in a manner consistent with present day gasoline vehicles
- Consumers will prefer to perform the majority of charging at their home location
- Charging at work/public L2 and corridor/community DCFC stations will be used as necessary to maximize electric vehicle miles traveled (eVMT)

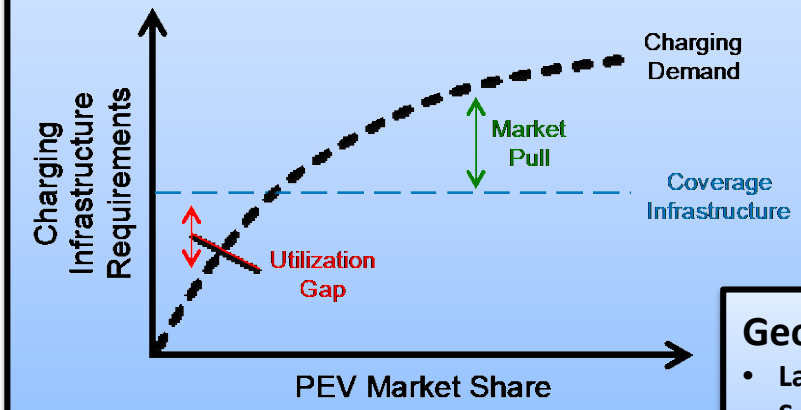
National PEV Infrastructure Analysis: Approach

Foundational Assumptions

- Future PEVs will be driven in a manner consistent with present day gasoline vehicles
- Consumers will prefer to perform the majority of charging at their home location
- Charging at work/public L2 and corridor/community DCFC stations will be used as necessary to maximize eVMT

Coverage vs Demand

Roadmap estimates **charging coverage** needed to enable national travel in PEVs and infrastructure necessary to meet **charging demand** in large PEV market



Summary of Scenarios

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 (w/ 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)

Geographic Segmentation

- **Large Cities** (486 Census Urban Areas, pop. greater than 50,000, 71% of U.S. pop.)
- **Small Towns** (3,087 Census Urban Clusters, pop. 2,500 to 50,000, 10% of U.S. pop.)
- **Rural Areas** (regions not covered by Census Urban Areas/Clusters, 19% of U.S.)
- **Interstate Corridors** (28,530 miles of highway coverage connecting Urban Areas)

National PEV Infrastructure Analysis: Key Insights

Community Charging

- About 8,000 DCFC stations (strategically located) would be required to provide a minimum level of coverage nationwide in large cities and small towns
- For a potential future market with 15M PEVs, the majority of infrastructure requirements would exist in large cities, but are very sensitive to PEV mix and consumer behavior

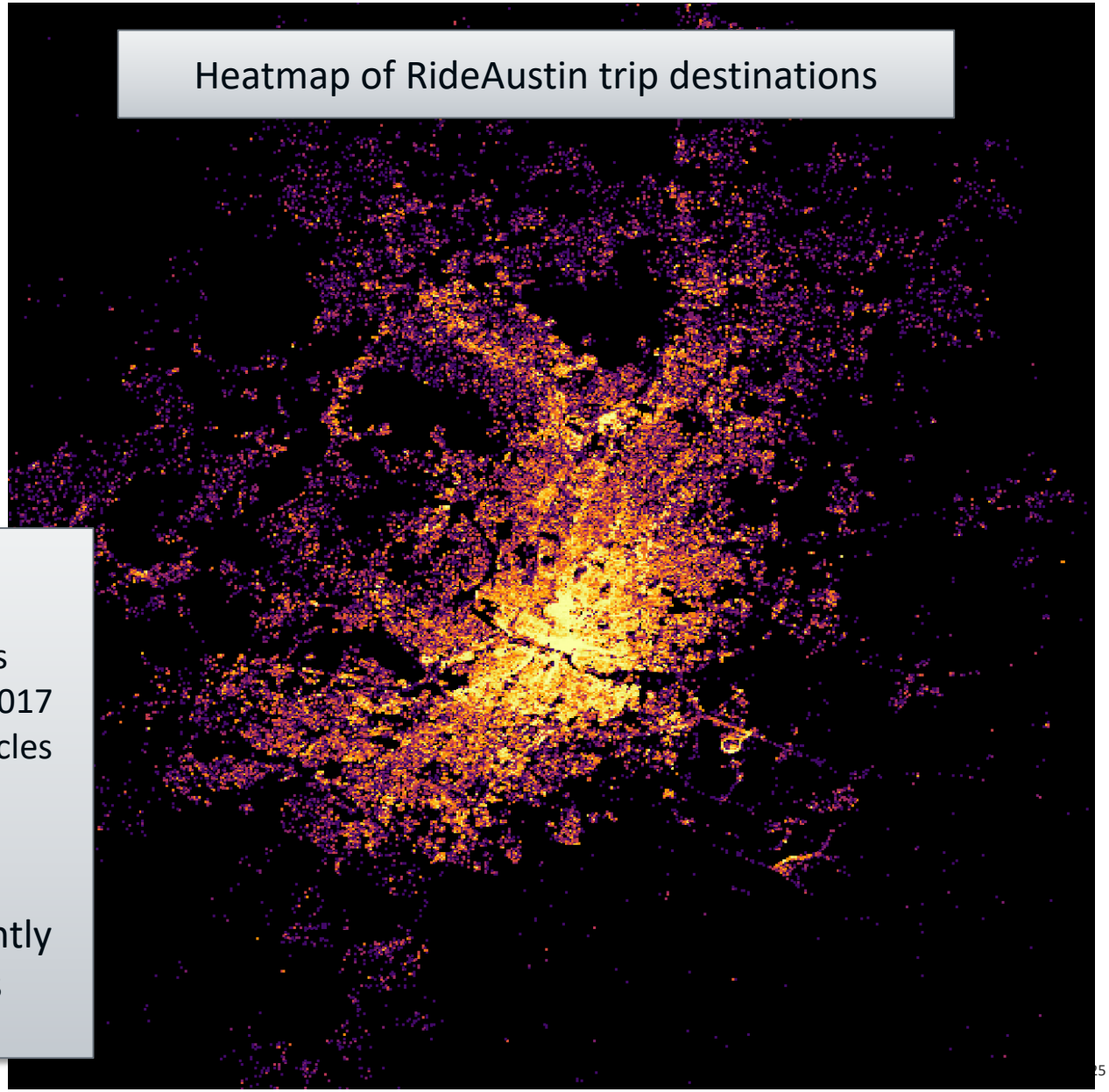
Corridor Charging

- A relatively modest number of corridor DCFC stations (250-400) are necessary at the national level to enable long-distance interstate travel between U.S. cities (where vehicles are concentrated)
- The majority of consumer long-distance automobile travel is regional (not national), emphasizing the importance of multi-state DCFC corridor planning
- Minimizing distance between stations along corridors would provide consumers with a robust network that is resilient to adverse conditions and dissipate demand across a larger network
- Establishing financial viability of these stations could be difficult in situations with low initial utilization and high capital/operating costs

Recommendations for Regional/Local Planners

- Pay close attention to consumer preferences with respect to electric range (particularly long range battery EVs)
- Focus efforts on providing consumers with adequate charging coverage (particularly DCFC supporting adoption of battery EVs) with the expectation to monitor station utilization and grow charging capacity (both in terms of rated power and number of plugs) as the PEV market continues to grow over time

Electrification of TNCs: A Case Study of RideAustin



By the numbers

- Sample duration: 10 months
- Period: June 2016 to April 2017
- 4,961 unique drivers & vehicles
- 261,000 unique riders
- 1.49 million trips

Largest TNC dataset currently available to researchers

Electrification of TNCs: Preliminary Results

- Approximately 90% of driving shifts are less than 150 mi
- Approximately 50% of drivers have no shifts above 200 mi
  - All shift totals include dead-heading and commuting
- Simulated driving/charging in EVI-Pro revealed potentially high-utilization of DCFC (depending on access to home charging) and unique load profile for residential charging