Project ID: elt258

Grid-Enhanced, Mobility-Integrated Network Infrastructures for Extreme Fast Charging (GEMINI-XFC)

Andrew Meintz (PI and Presenter)

Tim Lipman, Bryan Palmintier, Matteo Muratori (Co-PIs)

N. Panossian, P. Jadun, H. Laarabi, R. Waraich, R. Desai, A. Von Meier, K. Moffat C. Sheppard

June 23, 2021
DOE Vehicle Technologies Office (VTO) Annual Merit Review

Overview

TIMELINE

- Project start date: December 2019
- Project end date: September 2022
- Percent complete: 50%

BUDGET

- Total project funding: $3.0M
  - DOE share: $3.0M
  - Contractor share: $0
- Funding for FY 2020: $1M
- Funding for FY 2021: $1M

PARTNERS

- National Renewable Energy Laboratory (NREL)
- Lawrence Berkeley National Laboratory (LBNL)

BARRIERS ADDRESSED

- Develop technologies that minimize the impacts of electric vehicle (EV) charging on the nation's electric grid and support vehicle electrification
- Develop controls and integration to enable extreme fast charging (XFC) to support EVs at scale

Relevance

Increasing **vehicle electrification will require extensive use of extreme fast charging (XFC)**, especially for larger vehicles. Uncoordinated XFC can create grid challenges, particularly at the distribution level. Two strategies can support widespread XFC:

× Extensive grid upgrades (i.e., upgrade all systems to enable worst-case, fully coincident loads) or

✓ Integrated planning to co-design a smart system based on advanced controls that leverage load flexibility and distributed energy resources.

With the right design and control, XFC can simultaneously **support both mobility and grid operations**.

Fully realizing the potential of XFC will require **unprecedented coordination among the charging infrastructure, grid, and vehicles.**

Objectives:

- Identify how XFC will support transportation with evolving mobility patterns and very high EV adoption levels
- Assess the impact of widespread uncoordinated XFC of passenger vehicles on distribution networks
- Design effective control strategies to integrated XFC in distribution systems

Milestones

	Milestone Name/Description	End Date	Type
✓	Document progress towards definition of future mobility/power scenarios requirements and format	12/30/2019	Quarterly Progress
✓	Document progress on forecasts XFC electricity demand	6/30/2020	Quarterly Progress
✓	Document progress on coordination scheme and analysis	9/30/2020	Annual Milestone
✓ 1.	Full scenario definition	12/30/2020	Quarterly Progress
✓ 2.	Proof-of-concept integrated simulation with GEMINI framework	3/30/2021	Go / No-Go
3.	Document progress on finalizing coordination scheme and analysis	6/30/2021	Quarterly Progress
4.	Assess impact of widespread uncoordinated XFC on distribution networks (first key question)	9/30/2021	Go / No-Go Annual Milestone
	Assess strategies to mitigate the negative impact on distribution networks from widespread XFC of light-duty and commercial vehicles (second key question)	3/30/2022	Quarterly Progress
	Assess communication requirements to enable coordinated XFC of light-duty and commercial vehicles (third key question)	6/30/2022	Quarterly Progress
	Project completion. Model and result/insights documentation	9/30/2022	Annual Milestone

Year 2 Activities

1. TEMPO scenario development for EV and technology adoption
2. Develop a grid and transportation systems co-simulation using the HELICS framework
3. Refinement of control and coordination strategies
4. Evaluation of uncoordinated XFC impacts on the grid

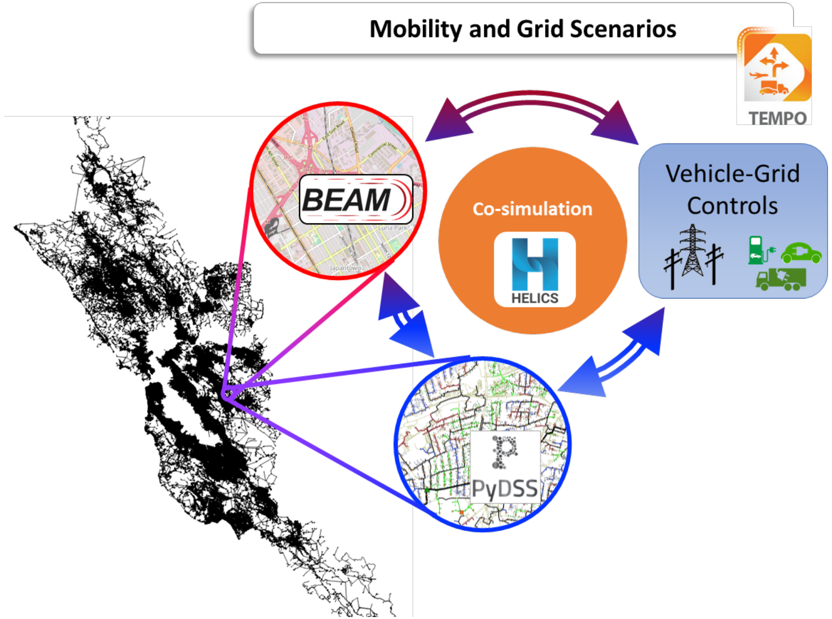
XFC – Extreme Fast Charging
HPC – High Performance Computing
TEMPO – Transportation Energy & Mobility Pathway Options
HELICS – Hierarchical Engine for Large-scale Infrastructure Co-Simulation

Approach

GEMINI-XFC will use **first-of-a-kind integrated high-fidelity grid and transport modeling to identify effective pathways for widespread electrification**, to design and evaluate integrated vehicle-grid control schemes, and to optimize electric vehicle integration at a **full regional scale with individual customer resolution.**

Control variables will include:

- **Charging station design** and planning (where and what kind of charging stations)
- **EV route scheduling** considering grid ”status”
- **Dispatch of behind-the-meter energy storage** and legacy voltage control actuators (on-load tap changes, voltage regulators, capacitors).



Focus on **XFC** (single plug at 250 kW or multiple plugs for a total of 1+ MW)

Approach (Scope)

GEMINI-XFC will focus on **on-road passenger mobility in the entire San Francisco Bay Area** looking at transportation options and grid systems in a **long-term future** (~2040) characterized by significant changes compared to today's systems.

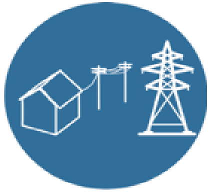
Leverage existing capabilities through co-simulation and workflow automation:

- **Customer-resolved** mobility meso-modeling, charging requirements, and power flow
- Mapping **EV charging and synthetic grid data** for rapid and open analysis.

Geographic extent:
Large metro regions (e.g., San Francisco, Denver, etc)

Disruptive technologies:
Consideration of impact of wide-spread electrification, connectivity, automation, new business models

Electrical grid:
Full electric grid from customer connections, through feeders, and up to bulk system



Temporal resolution:
Minutes for driving dynamics, traffic, charging profiles, grid services, tariffs, solar/wind/load dynamics, grid dispatch and control equipment

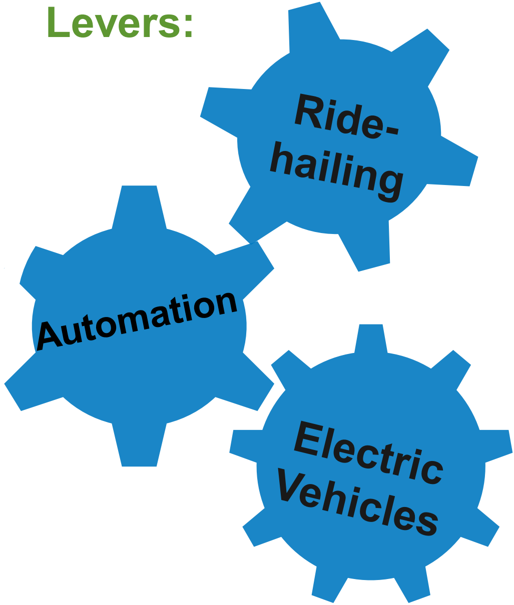
Technical Accomplishments and Progress: Transportation Scenarios Approach

TEMPO

Scenarios designed to capture range of possible futures and impact on XFC operation

Scenario	Questions to Answer	Description
Base	What is the baseline state for comparison?	Business as usual (aligned with EIA AEO Reference), with proposed CA policy
Mid-Term High EV Adoption	Impacts of XFC under high electrification? Can smart controls mitigate these impacts?	High EV adoption (driven by advanced technology and CA policy), business-as-usual mobility options, and consumer behavior (limited ride-hailing, sharing, automation)
Mid-Term Advanced Mobility	What are the impacts of disruptive mobility changes? Are different controls needed?	High EV adoption with disruptive mobility changes: widespread ride-hailing, reduced vehicle ownership, automation
Long-Term Advanced Mobility	What are the incremental impacts of XFC and how do capabilities of control change under extreme levels of electrification?	Almost full EV adoption with disruptive mobility changes

Key Scenario Levers:

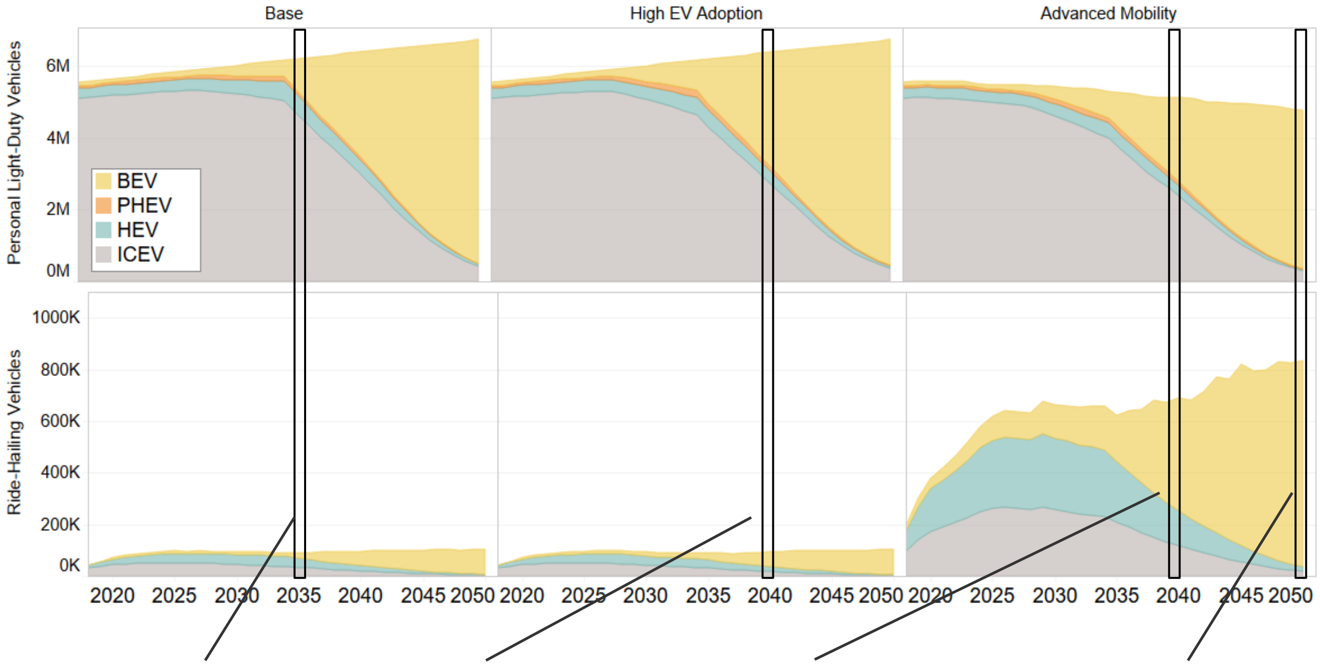


EIA – Energy Information Administration
AEO – Annual Energy Outlook

Technical Accomplishments and Progress: Transportation Scenario Inputs

TEMPO

- Vehicle stock for personal and ride-hailing light-duty vehicles estimated using TEMPO model (results shown for San Francisco Bay Area)
- TEMPO stock results will be used as input for the vehicle stock in BEAM



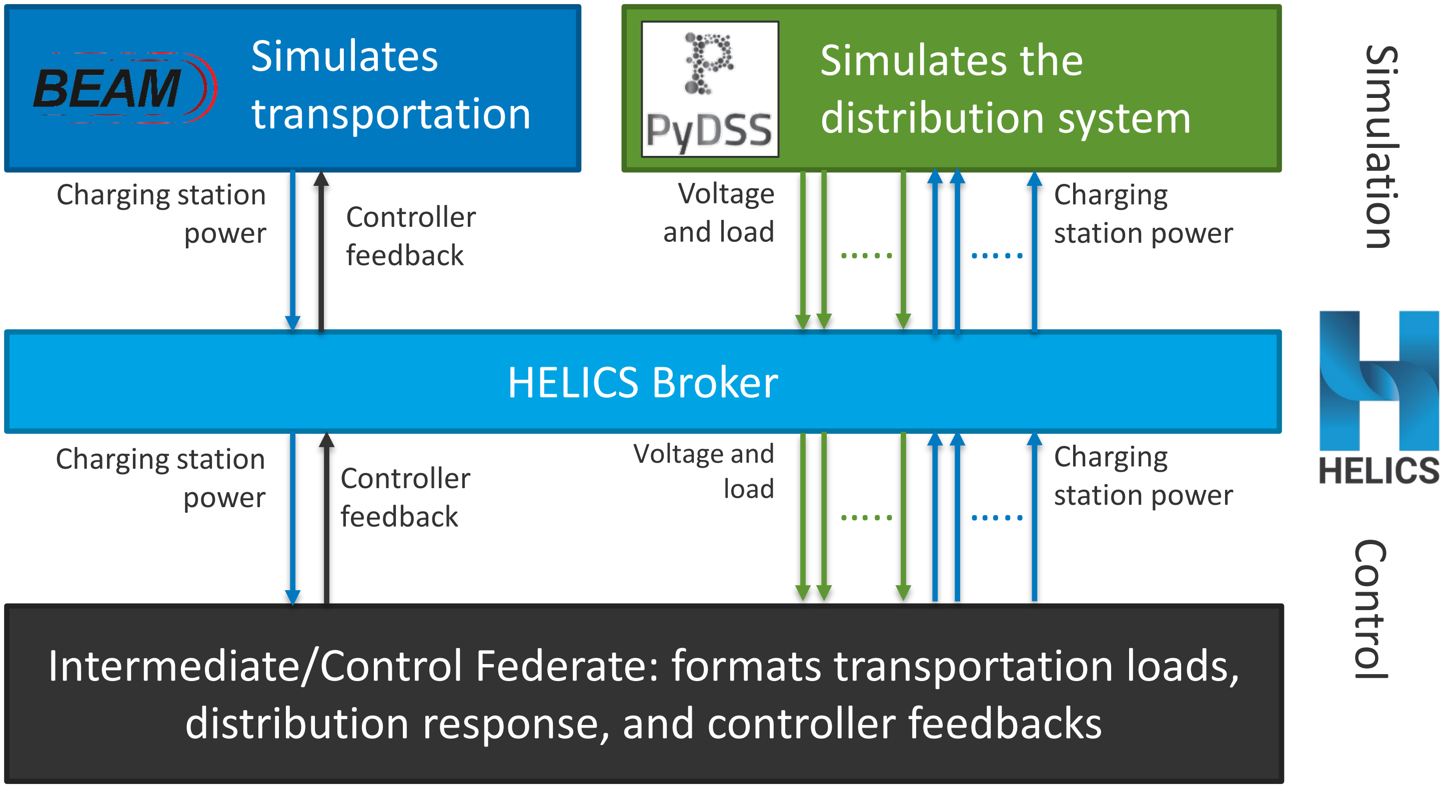
Base:
16% EV adoption

Mid-Term
High EV Adoption:
51% EV adoption

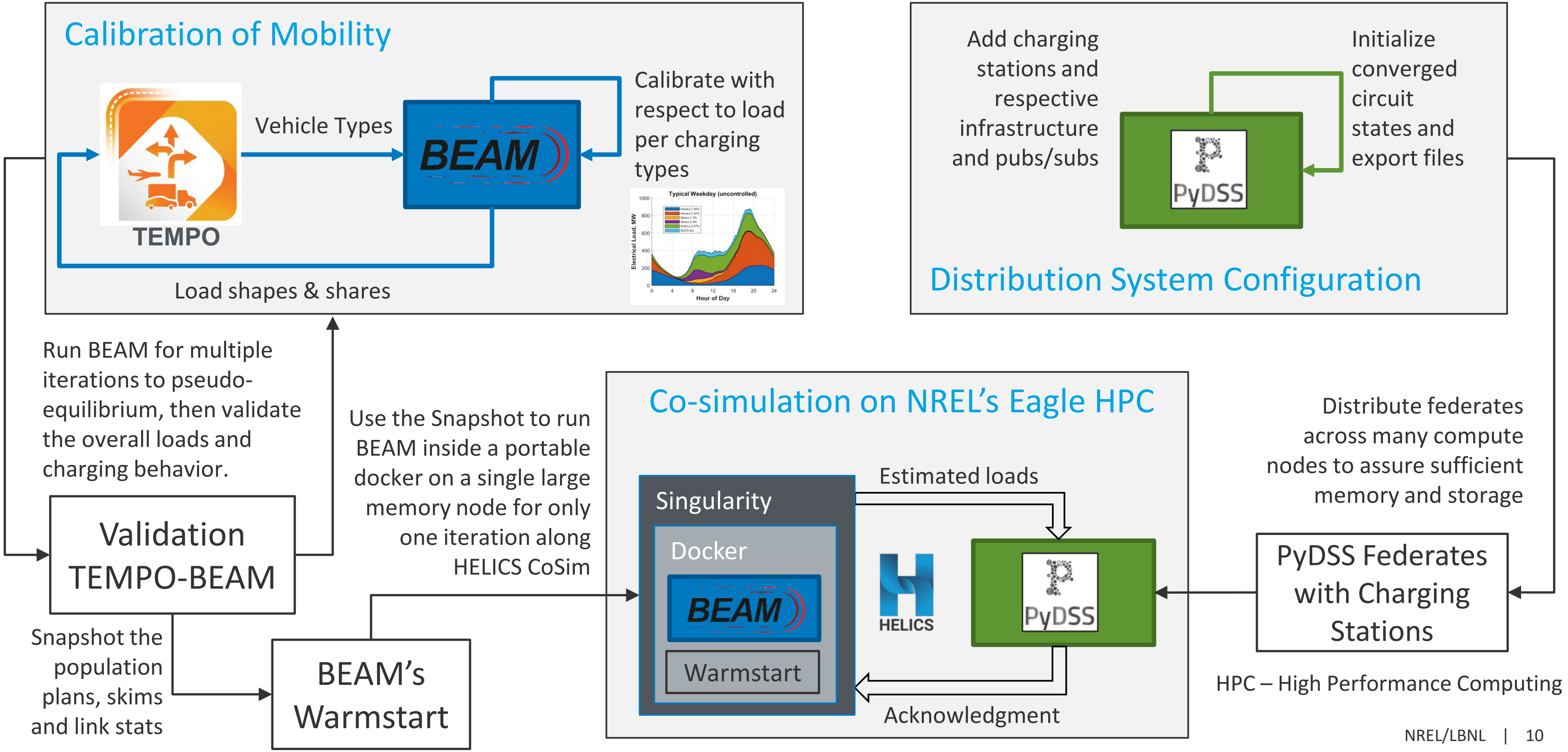
Mid-Term
Advanced Mobility:
49% EV adoption

Long-Term
Advanced Mobility:
93% EV adoption

Technical Accomplishments and Progress: Co-Simulation Setup



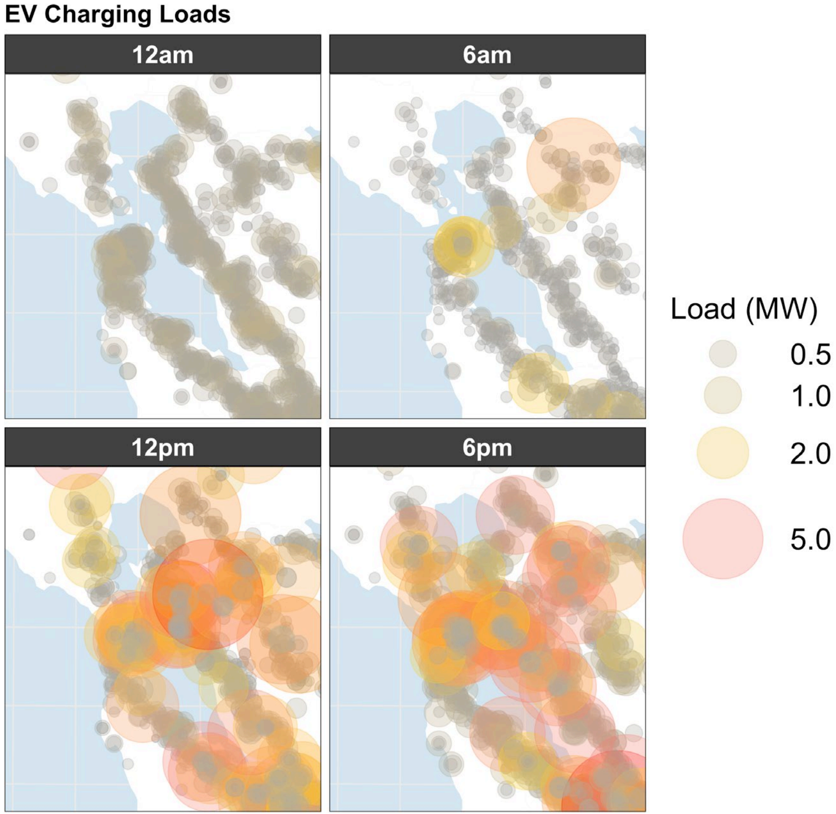
Technical Accomplishments and Progress: Uncontrolled Co-Simulation Pipeline



Technical Accomplishments and Progress: XFC Requirements

The results show for the Base Scenario, with uncontrolled charging, illustrates the **spatiotemporal representation of XFC events** (>1 MW, or single plug >250 kW) possible using BEAM.

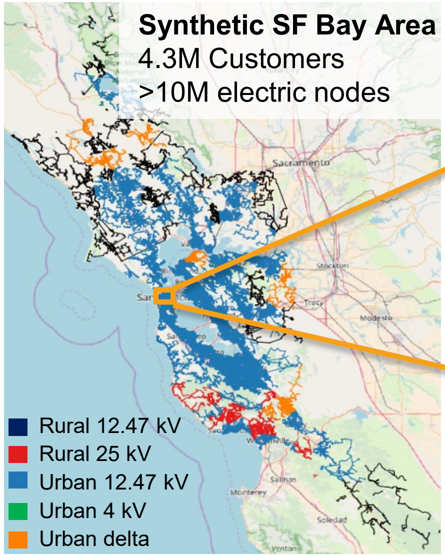
- Charging for electrification of **1M vehicles** (16 % of the fleet)
- Limited transition from privately owned vehicles to ride-hailing (6% of EVs are for commercial ride-hailing use)
- 29% of the total charging power demand is served by XFC (7% of charging energy goes to commercial ride-hailing use).



Technical Accomplishments and Progress: Grid Scenarios

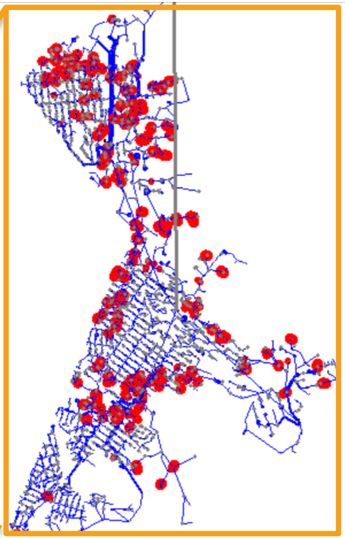
Identified full customer-resolution distribution data (realistic but not real)

- Smart-DS ([ARPA-E] grid data): geographically accurate, but openly sharable distribution system
- Scenario data: load profiles, distributed PV profiles, PV and distributed storage installations
- Entire Bay Area at customer level
- Verification (statistics for line length, substation locations load profiles, etc.) included collaboration with 5 utilities

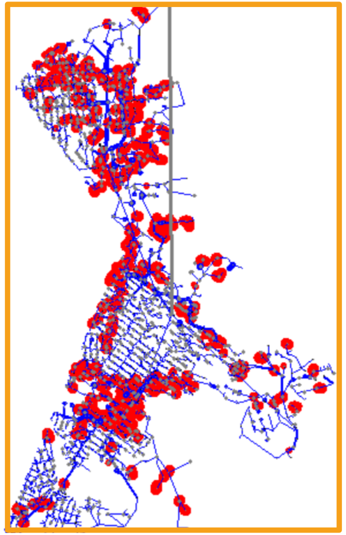


B. Palmintier and B.-M. Hodge, "Smart-DS: Synthetic Models for Advanced, Realistic Testing: Distribution systems and Scenarios," presented at the ARPA-E Energy Innovation Summit, National Harbor, MD, March 14, 2018.

Base DER Scenario: 14% gen from distributed solar (Aligned with Baseline Standard Scenario)



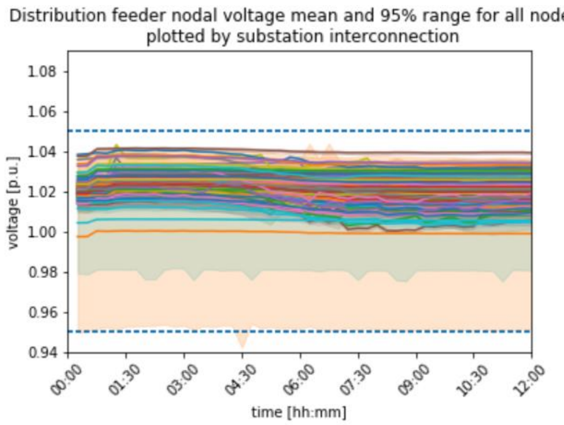
High DER Scenario: 58% gen from distributed solar and storage (Aligned with NRPS80)



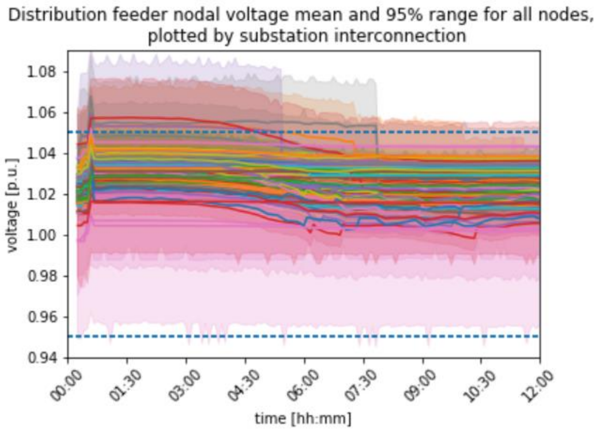
● solar installation

Technical Accomplishments and Progress: Grid Modeling

- Full San Francisco Bay Area model with no solar or storage modeled and running
  - Voltage excursions in some regions with charging
- Co-simulation runs of base case with 370k EVs and charging stations in preliminary stages
  - 40 distribution regions, 667 feeder models each spanning medium voltage to customer level (69kV down)
  - These initial results show expected feedback of the co-simulation though detailed analysis on EV impacts are pending further EVSE infrastructure placement



Distribution System Voltage without charging

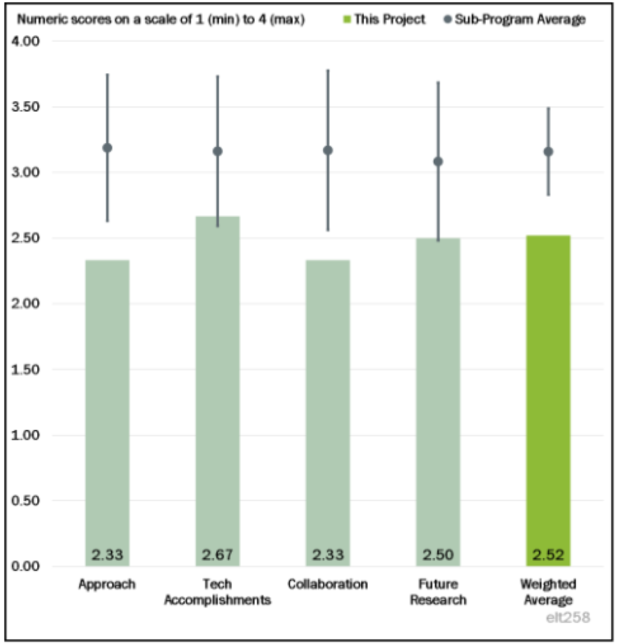


Distribution System Voltage with charging

Responses to Previous Year Reviewers' Comments

Concerns raised at the last AMR:

- *... [this is] a control technique that hinders EV drivers with a high level of inconvenience, how would driver behavior be accounted for?*
  - Response: The control provides price incentives to personal vehicles that choose the charging station with cheapest solution. Additional flexibility is provided through the ride-hail fleet.
- *… engagement with utilities that serve the area being simulated [are not included]. Will grid scenarios be reviewed by utilities?*
  - Response: The team is leveraging the Smart-DS project for the synthetic grid which engaged several utilities and industry representatives to define a representative network. The project has engaged the US Drive Grid Integration Tech Team with several utility participants
- *… What is so important about developing this model—will not having it make any significant difference to society, energy security, fossil fuel consumption, climate change?*
  - Response: This project aims to show how targeted infrastructure deployment and control coordination across the grid and transportation system could leverage flexibility of EVs to support a more renewable grid and reduce the cost of charging. Which supports DOE's goal to reduce barriers to EV adoption.



Collaboration and Coordination

The project is being developed in close collaboration between two National Laboratories leveraging key capabilities and models at each lab:

- NREL: Project coordination, transportation and grid scenarios, co-simulation and HELICS, grid modeling (Smart-DS and OpenDSS), TEMPO, control scheme
- LBNL: Transportation and grid scenarios, mobility agent-based modeling (BEAM), control scheme.

Coordination with other DOE-funded projects:

- VTO SMART (Systems and Modeling for Accelerated Research in Transportation) Mobility and VTO Analysis: mobility options and vehicle adoption/characteristics
- VTO Smart Charge Management Projects (RECHARGE, DirectXFC): consistent tech attributes and energy storage characteristics
- SA: Transportation and Grid Annual Technology Baseline and Standard Scenarios
- GMLC HELICS+: jointly developing shared transportation model interface standard
- ARPA-E Smart-DS: Building on existing rich data set.

Remaining Challenges and Barriers

GEMINI-XFC is progressing as planned and there are **no major barriers**

Research challenges currently being tackled:

- XFC Infrastructure requirements: BEAM modeling has demonstrated ability to project XFC load for a selected scenario, but refinements are needed to cover all the dimensions considered in GEMINI-XFC.
- Assess the impact on distribution networks: Now that co-simulation setup is complete, a distribution upgrade analysis is needed for higher adoption scenarios that adequately identify potential modifications.
- Co-simulation and design control strategies: envisioned but needs to be fully conceived and implemented in HELICS.

Proposed Future Research

Milestone Name/Description	End Date	Type
Assess impact of widespread uncoordinated XFC on distribution networks (first key question)	9/30/2021	Go / No-Go Annual Milestone
Assess strategies to mitigate the negative impact on distribution networks from widespread XFC of light-duty and commercial vehicles (second key question)	3/30/2022	Quarterly Progress
Assess communication requirements to enable coordinated XFC of light-duty and commercial vehicles (third key question)	6/30/2022	Quarterly Progress
Project completion. Model and result/insights documentation	9/30/2022	Annual Milestone

<u>Research for the remainder of FY 2021:</u>

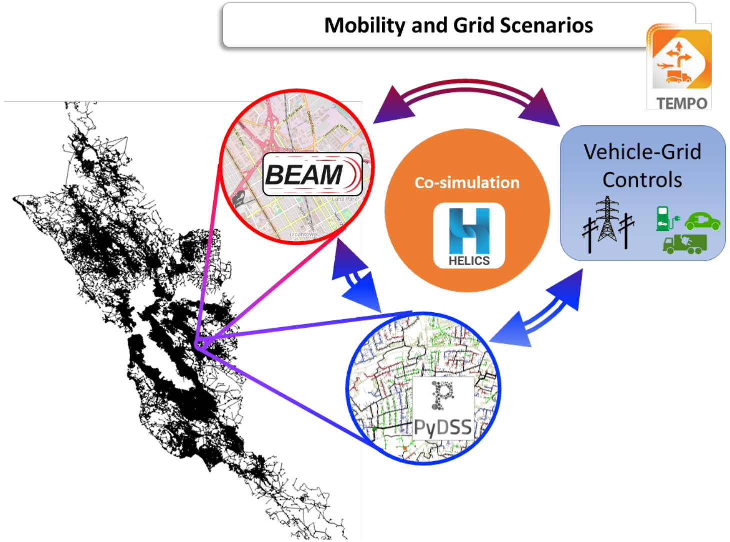
- Continue refinement on charging infrastructure disaggregation and resulting spatially resolved L1/L2 and XFC electricity demand for baseline scenario
- Expand current prototype PyDSS/BEAM HELICS co-simulation to full San Francisco Bay Area
- Define an approach to identify reasonable infrastructure upgrades for future scenarios that meets the intent of the GEMINI-XFC control approach but considers balanced improvements
- Conceive, design, and start development of the coordination and control scheme through HELICS co-simulation that minimizes grid impacts of XFC for personal and commercial light-duty vehicles.

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

Summary

As electrification of transportation progresses, new **synergies and interconnections with the electricity systems** will arise. Fully realizing the potential of these integrated systems while meeting mobility needs requires **unprecedented coordination among the charging infrastructure, grid, and vehicles.**

GEMINI-XFC **combines high-fidelity grid and transport modeling at an unprecedented level of resolution** and codesigns a smart system based on advanced controls that leverage load flexibility and distributed energy resources to optimize the integration of extreme fast charging (XFC) across a full regional scale.



Thank you!

The GEMINI Team at NREL and LBNL

www.nrel.gov

NREL/PR-5400-79963

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NREL Transforming ENERGY

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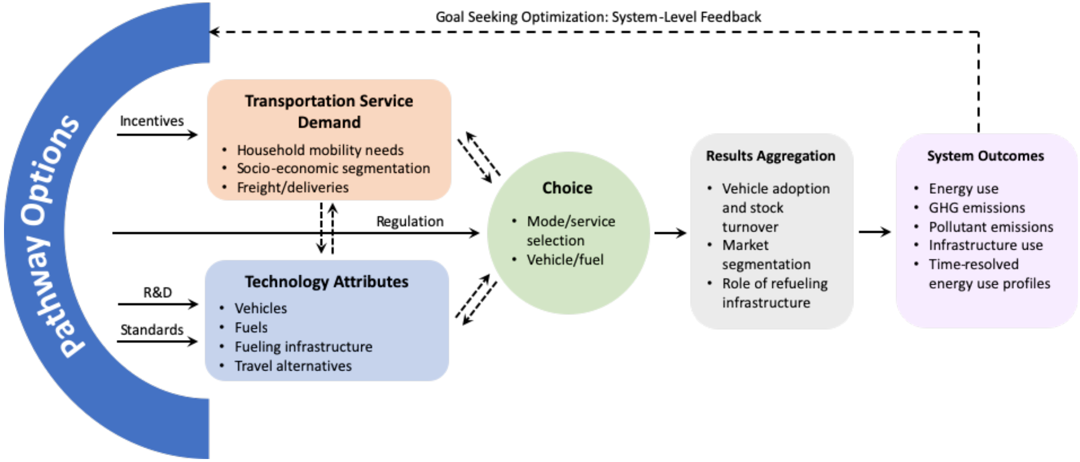
Technical Back-Up Slides

Transportation Energy & Mobility Pathway Options (**TEMPO**) Model

TEMPO was conceived at NREL by a Laboratory Directed Research and Development (LDRD) project (FY 2019–2020) aimed at developing the **core foundation of an integrated transportation demand model** to better understand future transportation systems.



CHALLENGE

- What is the potential for **radical transformations** of transportation supply and demand?
- How might **interconnections** with other sectors and infrastructure evolve?
- Which fuels/technologies will be adopted and in which **market segments**?

PLAN

- Model **household-level** mobility demand and travel choice
- Perform endogenous **out-of-sample forecasting** to explore radical transformation
- Model **time-resolved energy use** for grid model linkages.

https://www.nrel.gov/transportation/tempo-model.html

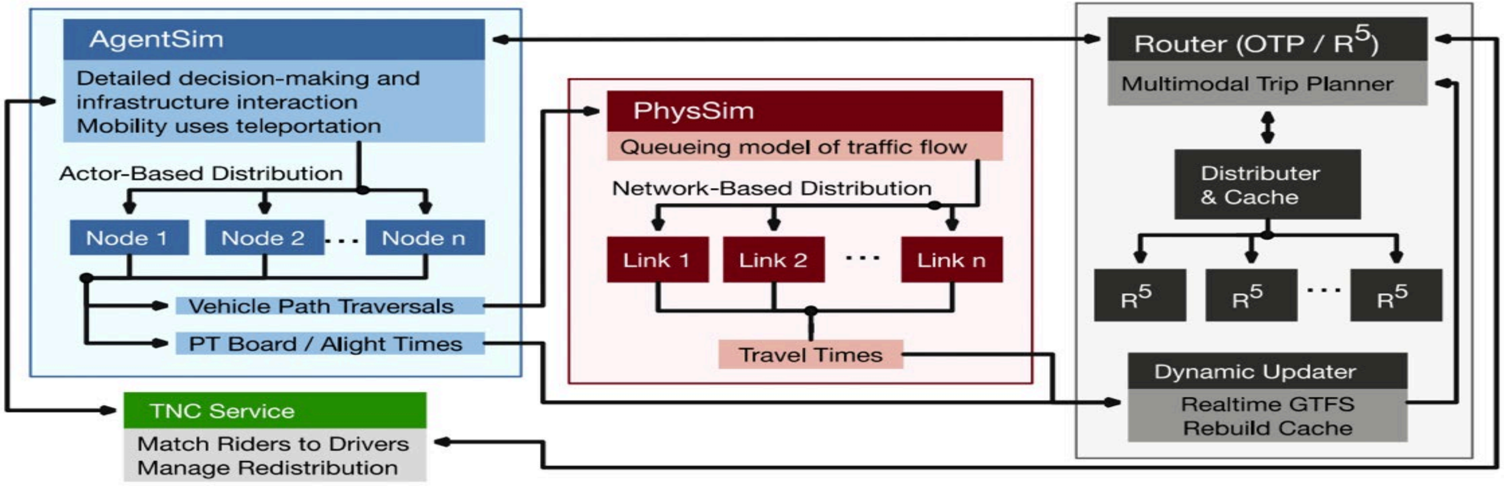
Significance & Impact

- Fills a research gap on sector-wide transportation modeling for long-term multi-sectoral scenarios
- Enables multi-sectoral coupling while providing a proper representation of mobility requirements and constraints

BEHAVIOR, ENERGY, AUTONOMY, AND MOBILITY (BEAM) MODEL

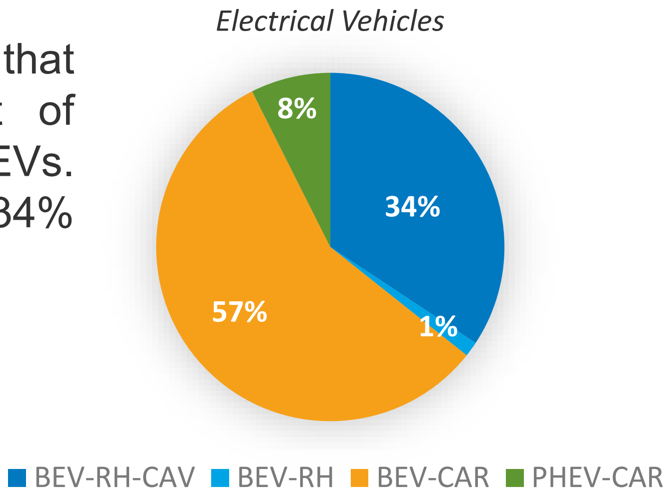
The Behavior, Energy, Autonomy, and Mobility (BEAM) Modeling Framework is an open-source tool that was developed by LBNL to model resource markets in the transportation sector (see http://beam.lbl.gov/). BEAM is an integrated, agent-based travel demand simulation framework. BEAM models the road network, parking and charging infrastructure, transit system, on-demand mobility from ride-hail and vehicle sharing, and a synthetic population with plans and preferences.

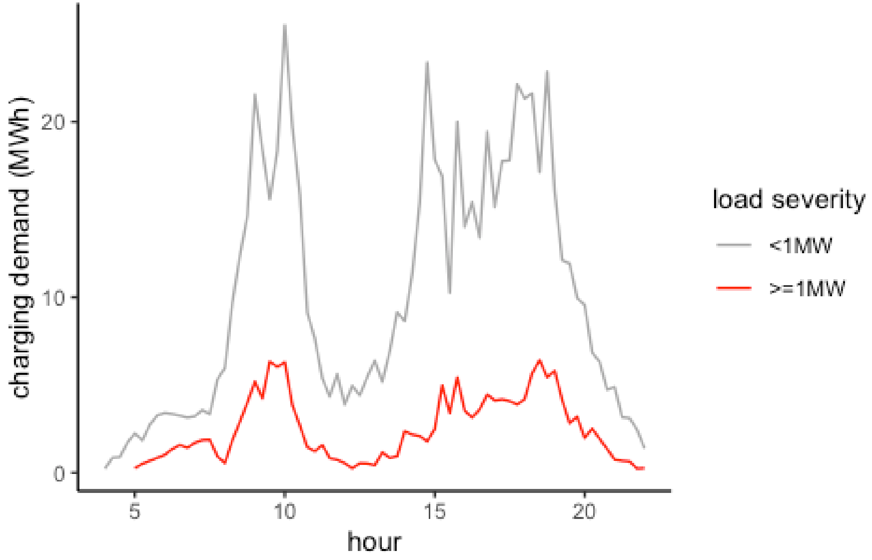
BEAM ARCHITECTURE   BEAM VIDEO



Technical Accomplishments and Progress: XFC Requirements

- In this San Francisco Bay Area scenario, we assume that technology has disrupted mobility: high retirement of privately owned vehicles and significant penetration of EVs. 46.4% of the total number of vehicles are EVs, and 34% are fully automated driverless vehicle ride-hailing.





- 19% of the total charging demand is served by automated vehicles (CAV) ride-hail (RH) depots with a load above 1 MW, which is considered as XFC.

Project funding: GMLC2017: 1.4.15, GMLC 2020: 1.3.2

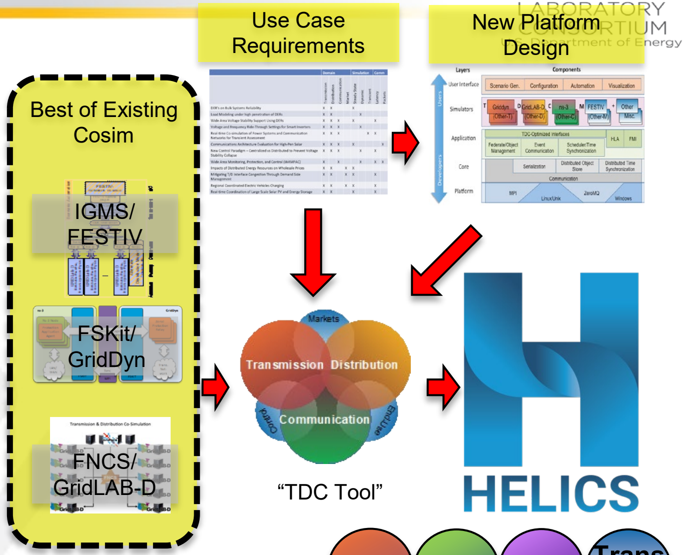
HELICS™: Hierarchical Engine for Large-scale Infrastructure Co-Simulation

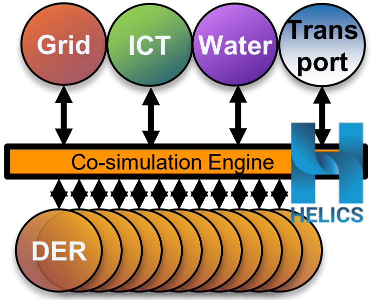
High-performance co-simulation to combine best-in-class tools for breakthrough integrated energy analysis

Capabilities:

- **Scalable:** 2–100,000+ Federates
- **Cross-platform:** HPC (Linux), Cloud, Workstations, Laptops (Windows/OSX)
- **Modular:** mix-and-match tools
- **Minimally invasive:** easy to use lab/commercial/open tools
- **APIs:** C++, C, Python, MATLAB, Java, Julia, HMI, FMI, etc.
- **Open Source:** BSD 3-clause
- **Many Simulation Types:**
  - Discrete Event
  - QSTS
  - Dynamics
- **Co-iteration enabled:** "tight coupling"

v2.4.2 available now at https://www.github.com/GMLC-TDC/HELICS





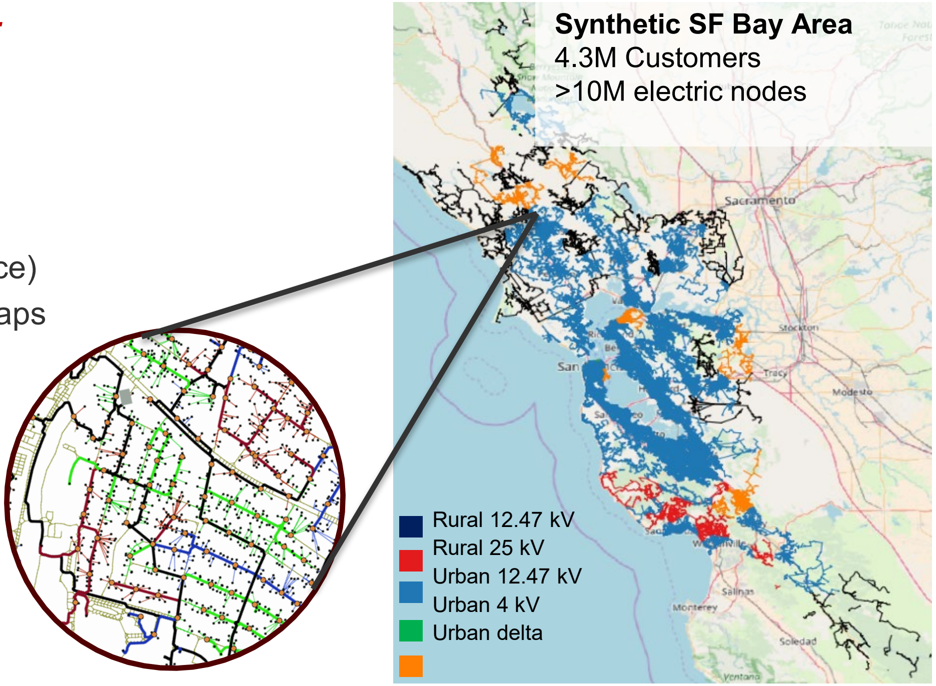
B. Palmintier, et al., "Design of the HELICS High-Performance Transmission-Distribution-Communication-Market Co-Simulation Framework," Workshop on Modeling and Simulation of Cyber-Physical Energy Systems, Pittsburgh, PA, 2017.

Smart-DS: Synthetic Models for Advanced, Realistic Testing: Distribution Systems and Scenarios

Full-scale "Realistic but not real" power grid test systems *for testing new algorithms, analysis techniques, etc.*

Features

- Actual building geo-location/types from Parcel Data
- Fully synthetic grid built using RNM-US
- Full electrical details: from every house to transmission
  - Lines: HV, MV, LV (Transmission, Distribution, Service)
  - Substations, Transformers, Switches, Regulators, Caps
- Detailed Mix-and-Match Scenarios: PV, Storage, etc.
  - Bottom-up building-level loads (P&Q) from ResStock/ComStock
  - 1 year at 15-min timeseries load, solar, etc.
- Extensive validation: Statistical, Powerflow, Expert



Key features for GEMINI-XFC

- Based around actual street map (Open Street Map)
- Synthetic data allows easy sharing/publication of results
- Diversity of common U.S. distribution network designs

NREL
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TEMPO Primary Scenario Assumptions

- **Base**
  - Vehicle cost and performance consistent with AEO 2018
  - Non-ZEV ban starting in 2035 (consistent with CA phase out)
  - Technology penetration consistent with 2035 fleet (less turnover of vehicle stock)
- **High EV Adoption**
  - Vehicle cost and performance improvements for PEVs based on NREL Annual Technology Baseline (ATB) 2020 Advanced scenarios
  - Non-ZEV ban starting in 2035
  - Technology penetration consistent with 2040 fleet (higher turnover of vehicle stock)
- **Advanced Mobility**
  - High EV Adoption
  - + Advanced ride-hailing (50% reduction in cost and time)
  - + Option for households to drop personally owned vehicles
  - + Automation assumed for ride-hailing fleets (reduced cost)
- **Max EV Adoption**
  - Advanced Mobility
  - + Technology penetration consistent with 2050 fleet (almost full turnover of vehicles after non-ZEV ban)

Scenarios intended to capture range of possible futures and impact on XFC operation