Project ID: elt258

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

Matteo Muratori (PI and Presenter)

Colin Sheppard, Tim Lipman, Bryan Palmintier (Co-PIs)

N. Panossian, P. Jadun, H. Laarabi, R. Waraich, R. Desai, A. Von Meier

June 3, 2020

DOE Vehicle Technologies Office (VTO) Annual Merit Review

Overview

TIMELINE

- Project start date: December 2019
- Project end date: September 2022
- Percent complete: 7%

BUDGET

- Total project funding: $3.0M
  - DOE share: $3.0M
  - Contractor share: $0
- Funding for FY 2019: $496K
- Funding for FY 2020: $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**: gold-plate the grid (i.e., upgrade all systems to enable worst-case, fully coincident loads) or use integrated planning to codesign 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:

- Understand future requirements for XFC
- 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	Criteria	End Date	Type
Document progress towards definition of future mobility/power scenarios requirements and format (Complete)	Presentation to DOE	12/30/2019	Quarterly Progress Measure (Regular)
Document progress on forecasts XFC electricity demand	Presentation to DOE	6/30/2020	Quarterly Progress Measure (Regular)
Document progress on coordination scheme and analysis	Presentation to DOE	9/30/2020	Annual Milestone (Regular)
Full scenario definition	Presentation to DOE	12/30/2020	Quarterly Progress Measure (Regular)
Document progress on finalizing coordination scheme and analysis	Presentation to DOE	6/30/2021	Quarterly Progress Measure (Regular)
Assess impact of widespread uncoordinated XFC on distribution networks (first key question)	Submit draft paper/report to DOE	9/30/2021	Annual Milestone (Regular)

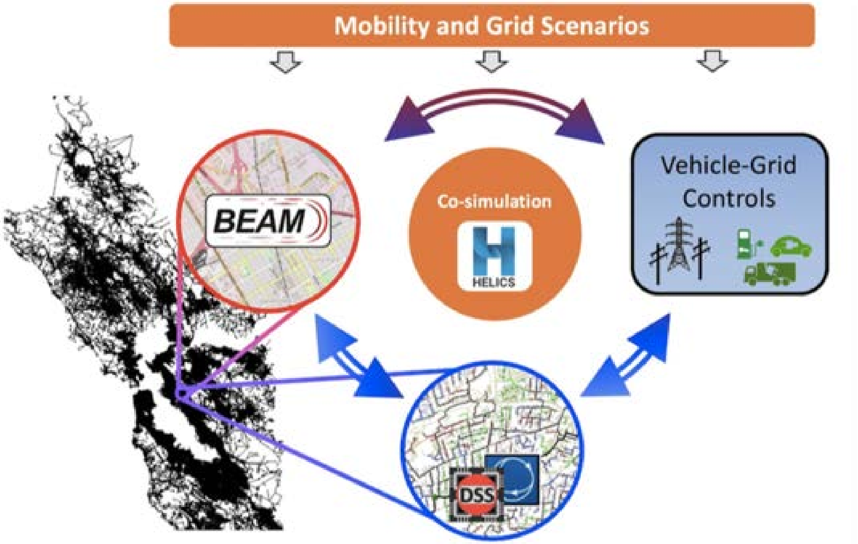
Name	Description	Criteria	Date
Demonstrate integrated modeling system (go/no-go)	Proof-of-concept integrated simulation with GEMINI framework	Presentation to DOE	3/30/2021
Demonstrate analysis usefulness (go/no-go)	Demonstration and analysis of GEMINI framework applied to first key question	Submit draft paper/report to DOE	9/30/2021

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:

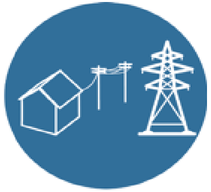
Large metro regions (e.g., San Francisco, Denver, etc)

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



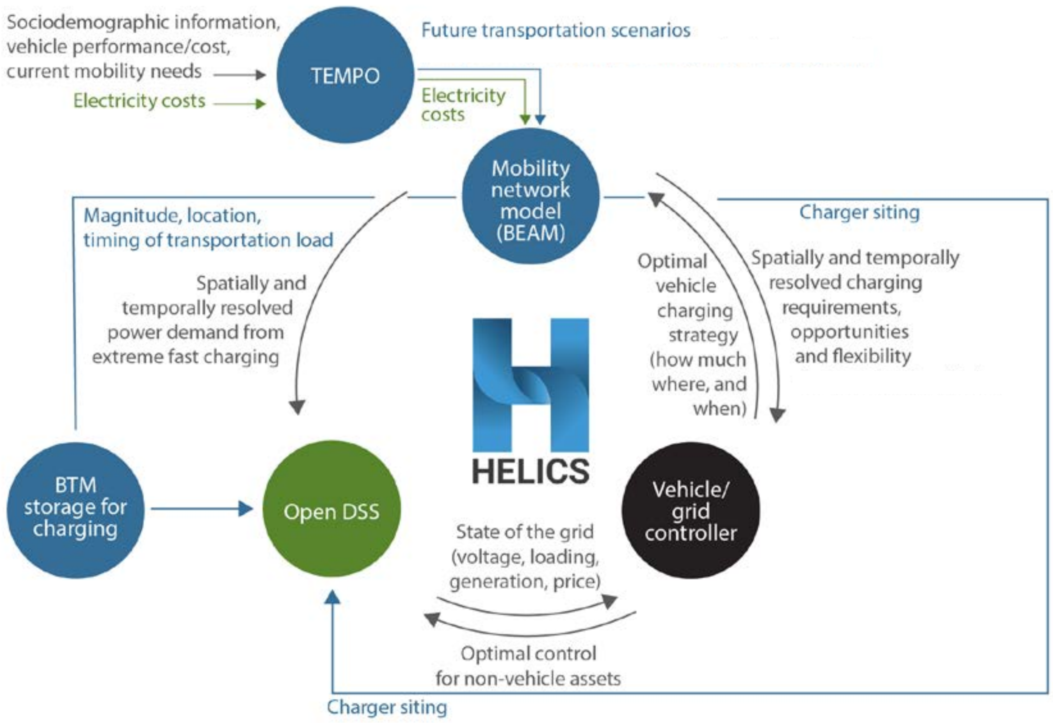
Temporal resolution:

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

Technical Accomplishments and Progress: Co-Simulation Setup

- **HELICS** will coordinate execution timing and data flows among all participating sub-models (TEMPO, BEAM, OpenDSS, BTMS)

- The **vehicle/grid controller** will implement the optimal control scheme for each scenario and send simulated control signals to other models.



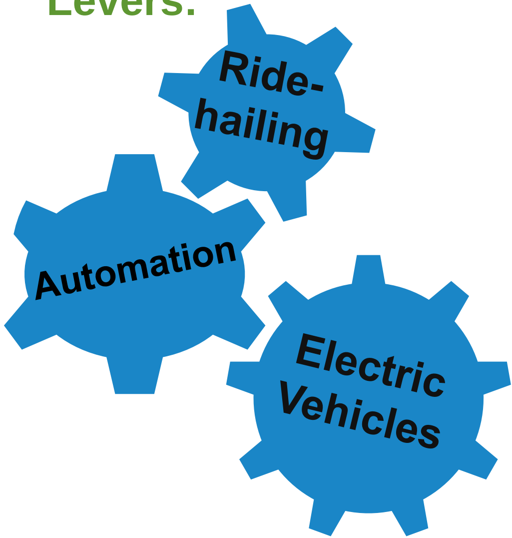
BEAM: Behavior, Energy, Autonomy, and Mobility
BTMS: Behind-the-Meter Storage
DSS: Distribution System Simulator
HELICS: Hierarchical Engine for Large-scale Infrastructure Co-Simulation
TEMPO: Transportation Energy & Mobility Pathway Options

Technical Accomplishments and Progress: Transportation Scenarios (Preliminary)

TEMPO

Scenario	Questions to Answer	Description
Base	What is the baseline state to compare future scenarios to?	Business as usual (aligned with EIA AEO Reference)
High EV Adoption	Impacts of XFC under high electrification? Can smart controls mitigate these impacts?	High EV adoption, business-as-usual mobility options, and consumer behavior (limited ride-hailing, sharing, automation)
Advanced Mobility	What are the impacts of disruptive mobility changes? Are different controls needed?	High EV adoption and disruptive mobility changes (widespread ride-hailing, sharing, automation)

Key Scenario Levers:



Potential sensitivities to explore:

- Charging availability and preferences
- Automation (geofenced?)
- XFC station design (plug power, storage, photovoltaics [PV])
- Plug-in hybrid electric vehicle (PHEV)/battery electric vehicle (BEV) split and/or BEV ranges
- Consumer behavior (sharing)
- Ride-hail fleet management
- Mobility options (micro-mobility, public transit)

Technical Accomplishments and Progress: TEMPO-BEAM Connection

Exogenous inputs (consistent across models and with other projects)

- Technology attributes (cost, fuel economy)
- Socio-demographics
- Fuel prices

TEMPO

TEMPO scenarios setting BEAM inputs

- PEV adoption (market share, BEV/PHEV split, ranges)
- Ride-hailing penetration
- Vehicle fleet composition
- Propensity for mobility modes
- Automation

BEAM

Additional exogenous inputs for BEAM transportation runs

- Recharging opportunities
- Charging behavior and preference
- Ride-hailing fleet management
- Sharing preference
- Charging stations design

Technical Accomplishments and Progress: Grid Scenarios (Preliminary)

- **Bulk power system** evolution and data (long-term):
  - o Exogenous, from NREL Standard Scenarios (generation mix and wholesale electricity price)
- **Electricity distribution systems** evolution and data (core focus of GEMINI-XFC)
  - o Smart-DS scenarios consistent with selected bulk system scenarios (randomized PV location)

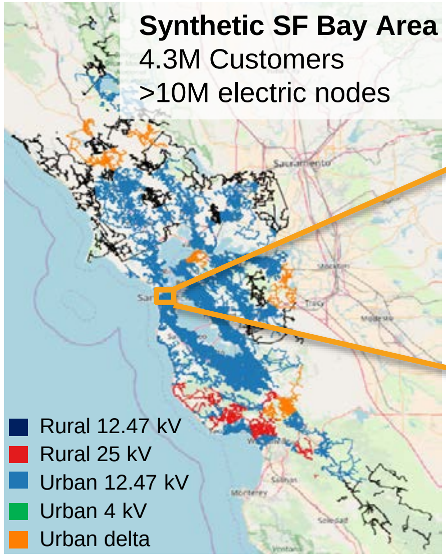
Scenario	Questions to Answer	Description	Potential Sensitivities
Base	• Can smart charging reduce line congestion and increase power quality (e.g., voltage drops from increased distributed charging)? • Can smart charging support grid operation?	• Generation mix (Baseline Scenario): o Low-carbon with 22% natural gas o 14% distributed solar PV • Time-varying electricity price (focus on charge timing) due to California “duck curve” and thermal generation use	• Alternative electricity retail tariffs • Share of generation from natural gas
High DER	• Can smart charging reduce voltage and variability issues from high penetrations of distributed solar? • Can distributed solar and storage reduce congestion and voltage drop challenges from EV fast charging?	• Generation mix (NRPS80 Scenario): o Very low carbon with 4% natural gas and oil o 58% distributed solar with storage • Symbiosis between high EV and high DER (focus on charger location assignment to support distribution systems)	• Alternative electricity retail tariffs • Penetration and clustering of DER

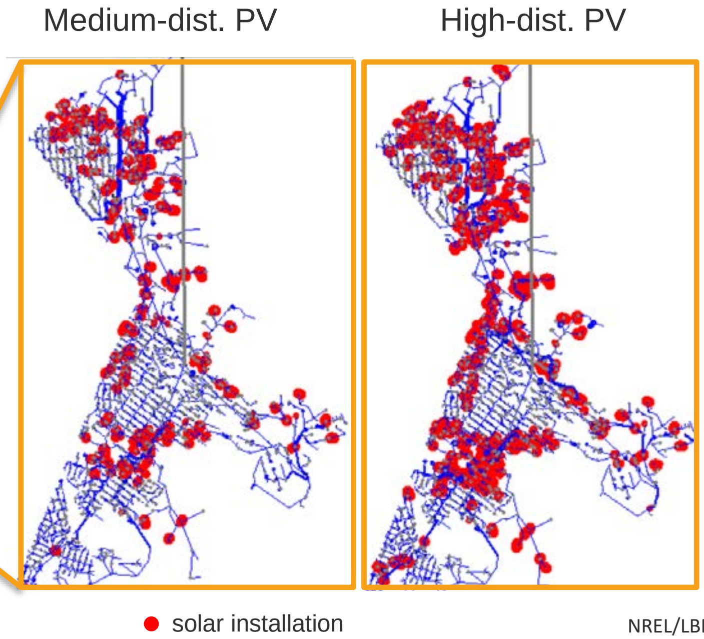
Smart-DS: Synthetic Models for Advanced, Realistic Testing: Distribution Systems and Scenarios
DER: Distributed Energy Resources

Technical Accomplishments and Progress: Grid Modeling

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

- Smart-DS (Advanced Research Projects Agency–Energy [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
- Start with city of San Francisco and extend



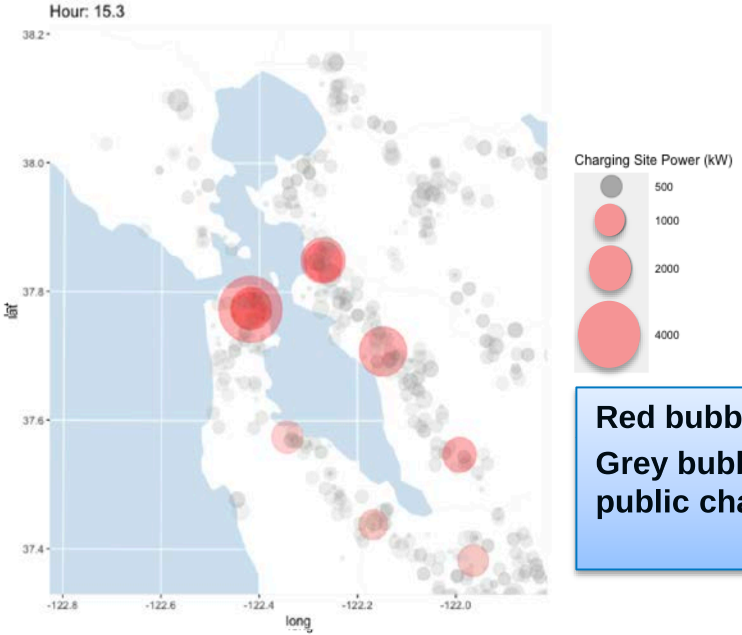


B. Palmintier and B.-M. Hodge, "Smart-DS: Synthetic Models for Advanced, Realistic Testing: Distribution systems and Scenarios," presented at the ARPA-E Energy Innovation Summit, National Harbor, MD, March 14, 2018.

Technical Accomplishments and Progress: XFC Requirements

Hypothetical futuristic scenario (high-tech success in San Francisco Bay Area) to illustrate **spatiotemporal representation of XFC events (>1 MW, or single plug >250 kW)** in BEAM (video plays in slide-show mode).

- High vehicle electrification (46%)
- Widespread transition from privately owned vehicles to ride-hailing (35% of EVs are fully automated driverless vehicles for ride-hailing)
- 19% of the total charging demand is served by XFC (major use at autonomous ride-hailing depots, especially downtown).



Red bubbles: XFC events

Grey bubbles: regular public charging events

Responses to Previous Year Reviewers' Comments

GEMINI-XFC is a new project and was not reviewed last year.

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
- SPIA: 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

Project is progressing as planned and **no major barriers** are identified.

Research challenges currently being tackled:

- Scenarios: Transportation and grid scenarios have been drafted and need to be reviewed (with VTO and externally) and finalized (12/30/20 milestone).
- XFC 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: Need to scale existing prototype of one distribution region (dozens of feeders) running in HELICS to full metro area (~2,000 feeders) and continue to integrate with BEAM charging scenarios.
- Co-simulation and design control strategies: envisioned but needs to be fully conceived and implemented in HELICS.

Proposed Future Research

GEMINI-XFC is a three-year project that started in December 2019.

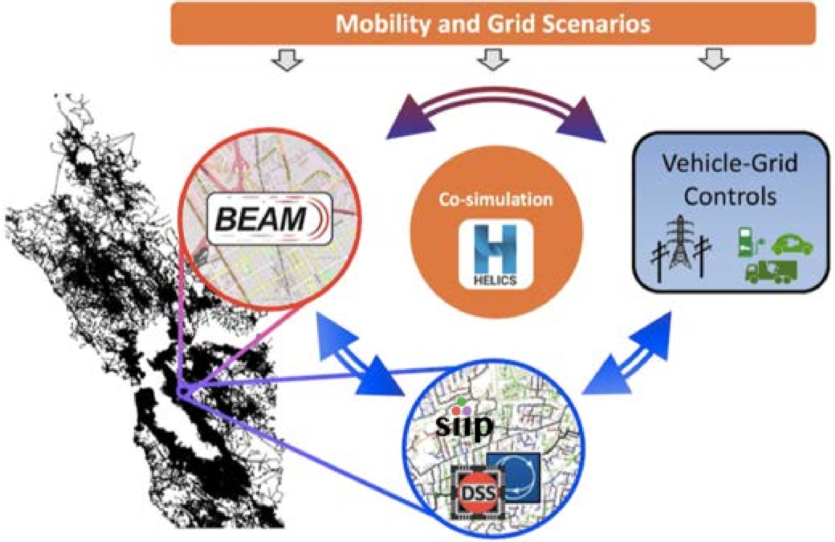
- Significant efforts for the remainder of the project will enable achieving the project objectives.
- Goals for the remainder of FY 2020:
    - Finalize transportation and grid scenarios
    - Continue refinement on forecasts XFC electricity demand
    - Expand current prototype OpenDSS/HELICS grid co-simulation to full San Francisco Bay Area and integrate BEAM
    - Conceive, design, and start develop coordination/control scheme and add to HELICS co-simulation.

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-5400-76718

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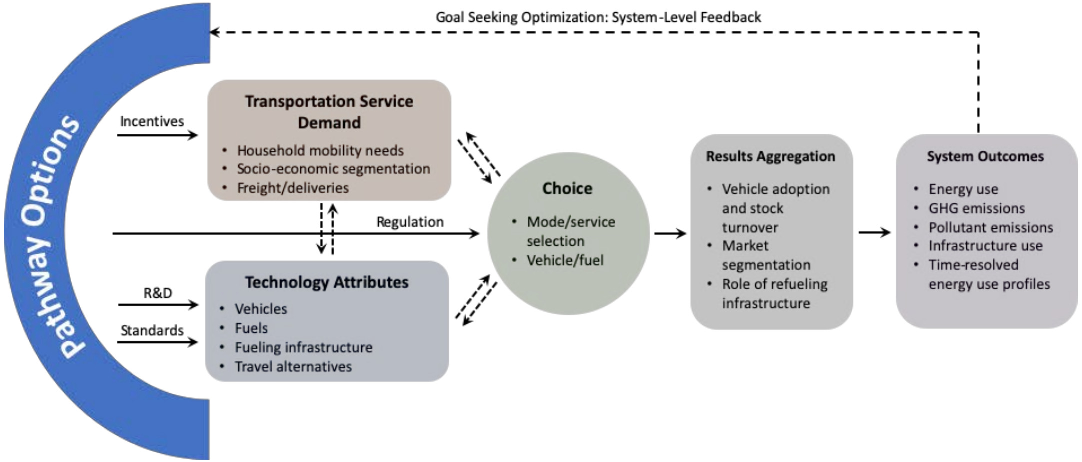
NREL Transforming ENERGY

BERKELEY LAB

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

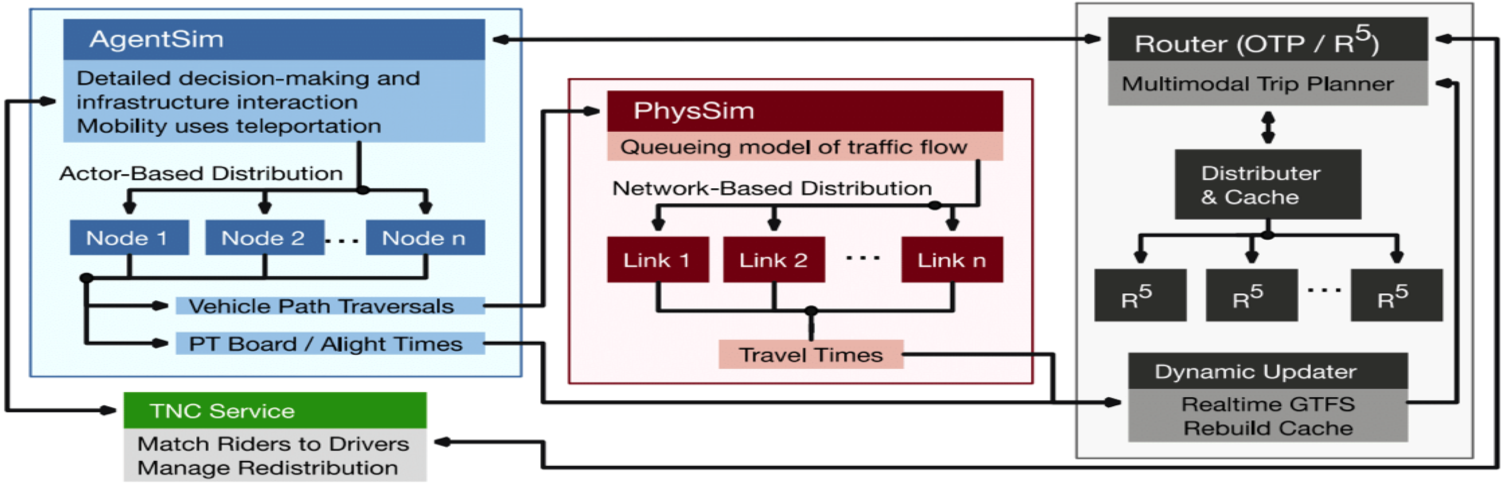
Significance & Impact

- 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

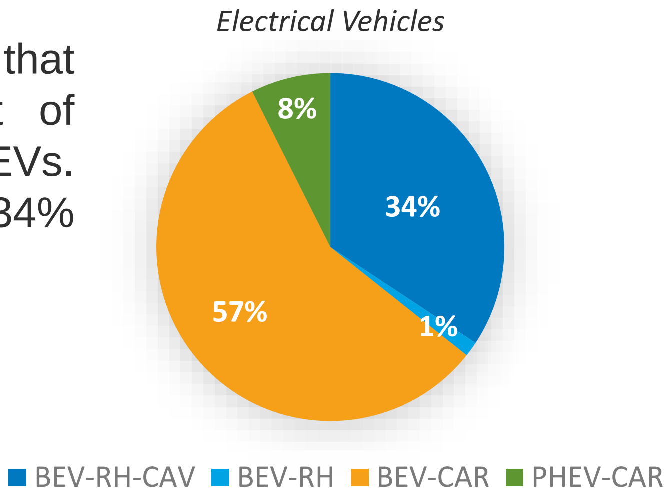
The Behavior, Energy, Autonomy, and Mobility (BEAM) Modeling Framework is an open-source tool that was developed by LBNL to model resource markets in the transportation sector (see http://beam.lbl.gov/). BEAM is an integrated, agent-based travel demand simulation framework. BEAM models the road network,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

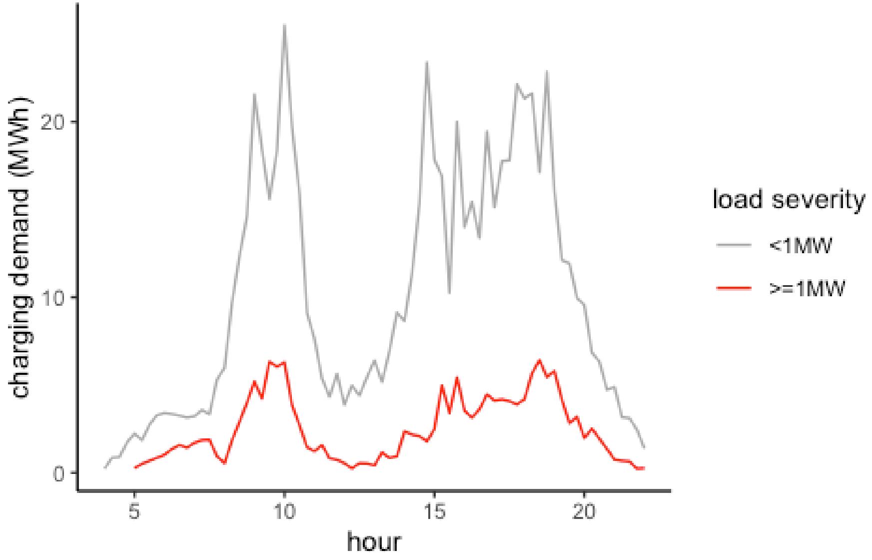
BEAM ARCHITECTURE BEAM VIDEO



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.

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

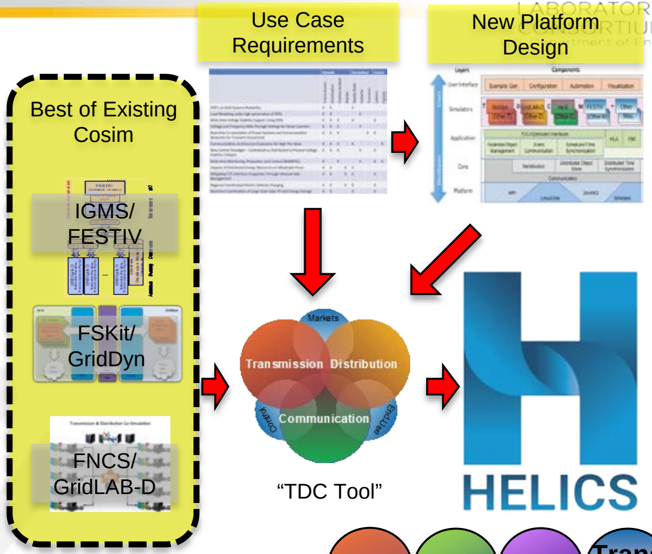
Project funding: GMLC2017: 1.4.15, GMLC 2020: 1.3.2

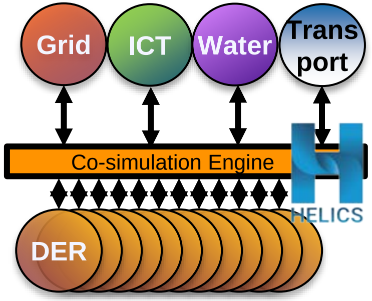
High-performance co-simulation to combine best-in-class tools for breakthrough integrated energy analysis

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:**
  - o Discrete Event
  - o QSTS
  - o 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

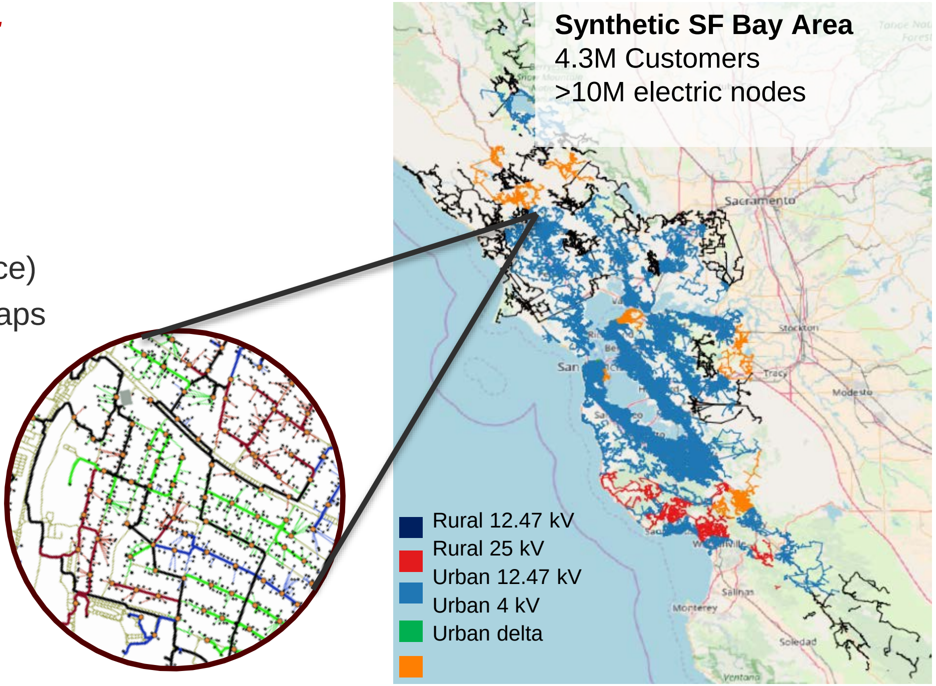
***Full-scale "Realistic but not real" power grid test systems** for testing new algorithms, analysis techniques, etc.*

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



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