Affordable and Equitable Residential Electrification Under Electrical Panel and Service Constraints

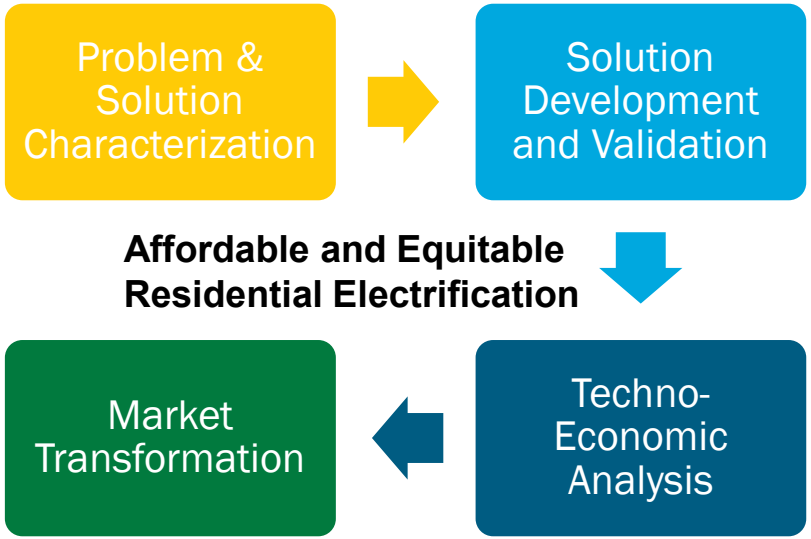
National Renewable Energy Laboratory (NREL)
PI: Xin Jin, Senior Research Engineer
Xin.Jin@nrel.gov
WBS #: 3.2.6.45

Lawrence Berkeley National Laboratory (LBNL)
Co-PI: Iain Walker, Staff Scientist
ISWalker@lbl.gov
WBS #: 3.2.6.49

Project Summary

Objective and Outcome

Develop publicly available resources and tools to characterize residential electrical panel capacity constraints, and **advance affordable and equitable solutions** to electrify the U.S. housing stock under electrical panel and service constraints.



Team and Partners

National Laboratories: NREL, LBNL

Practitioners: Efficiency Vermont, All-Electric California, Redwood Energy

Manufacturers: e-Radio, Legrand, Atom Power

Electric Utilities: Green Mountain Power, Washington Electric Co-op, Vermont Electric Co-op

Stats

Performance Period: 10/1/2023 – 9/30/2025

DOE Budget: $2M, Cost Share: $15k

Key Milestone 1: Evaluate at least five commercially available technologies for load control (Go/No-Go Decision Point, 9/30/2023)

Key Milestone 2: Guidance documents for local code authorities and contractors on minimizing the cost of safe home electrification (End of Project Milestone, 9/30/2024)

Team

Core Team

Xin Jin
PI
NREL

Lixi Liu
ResStock and techno-economic analysis
NREL

Omkar Ghatpande
Digital capacity management
NREL

Jing Wang
Load control assessment
NREL

Yingli Lou
Model-based analysis
NREL

Ilan Upfal
Solution characterization
NREL (SULI Intern)

Iain Walker
Co-PI
LBNL

Alan Meier
Citizen science
LBNL

Brennan Less
Data-driven analysis
LBNL

Bruce Nordman
Digital capacity management
LBNL

Sean Murphy
Data-driven analysis
LBNL

Jeff Deason
Techno-economic analysis
LBNL

Industry Partners

e-Radio

legrand

ATOM POWER

Efficiency Vermont

Redwood Energy

All-Electric California

GREEN MOUNTAIN POWER

Washington Electric Cooperative, Inc.
A Touchstone Energy® Cooperative

VERMONT ELECTRIC CO-OP INC

Problem

- **Decarbonization of homes will require electrification** of currently fuel-fired end uses and introduce new electric end uses such as electric vehicles and heat pumps.
- In many cases, low-capacity and space-limited panels in vintage homes **cannot accommodate the new loads** according to the current rules in the National Electrical Code (NEC)—about 21% of U.S. homes have 100-A or less panel capacity and 44% of homes have two or less open breaker slots in their panels. Older and smaller homes are much more likely to have 100-A panels.
- Due to long wait times or high costs, **upgrading electrical panels is not always feasible**—especially for low-income families—and there are upstream impacts on the distribution grid. Electrical panel and service upgrades may cost customer $2,000-$30,000 and take a few months to carry out due to labor storages and utility coordination.
- There are very few existing studies that characterize the challenge or identify potential solutions.
- NREL and LBNL, along with industry partners, will characterize the panel capacity problem to inform future policy and program design, **identify and evaluate low-cost solutions**, and propose changes to NEC to advance **affordable and equitable electrification**.

Alignment and Impact

This project will accelerate building electrification and support rapid decarbonization of the U.S. residential building stock to the meet the goal of economy-wide net-zero emissions by 2050.

Impacts include:

- **Improved estimates** to better inform electrification policies and program design. Estimates include the number of U.S. homes within the 123 million total dwelling units that may need panel upgrades and the number of homes that could avoid panel upgrades with efficiency or load control solutions.
- **Guidance for homeowners, contractors, and other stakeholders** on how to select from the 50+ existing products to electrify homes under the current NEC without panel upgrades.
- **A system architecture** for digital capacity management to overcome gaps in existing solutions and utilize all rated power capacity. Embody the technology in open industry technology standards.
- **Proposed changes** in future NFPA 70 NEC provisions and facilitate the adoption by local authorities and practitioners.

Approach – Overview

1. Characterize the Problem	2. Characterize Current Solutions	3. Solution Development and Validation	4. Techno-Economic Analysis	5. Market Transformation
• Citizen science panel survey • Data-driven peak load analysis • Model-based national scale analysis (ResStock) • Industry data gathering **POP**: Q1—Q3	• Evaluate the functionality and cost of existing solutions • Assess potential of load control • Field survey and workforce outreach **POP**: Q2—Q4	• Architecture design • Development of the digital capacity management solution • Possible paths to market **POP**: Q3—Q7	• Framework for analysis at the building scale • Scale up to the U.S. residential building stock • Estimate impact of NEC revisions • Dissemination **POP**: Q4—Q8	• Proposed changes and interpretation of the NEC • Development of resources and tools for homeowners, code officials, and practitioners **POP**: Q6—Q8

Approach – Hybrid Method to Characterize the Panel Capacity Problem

Industry Data Gathering

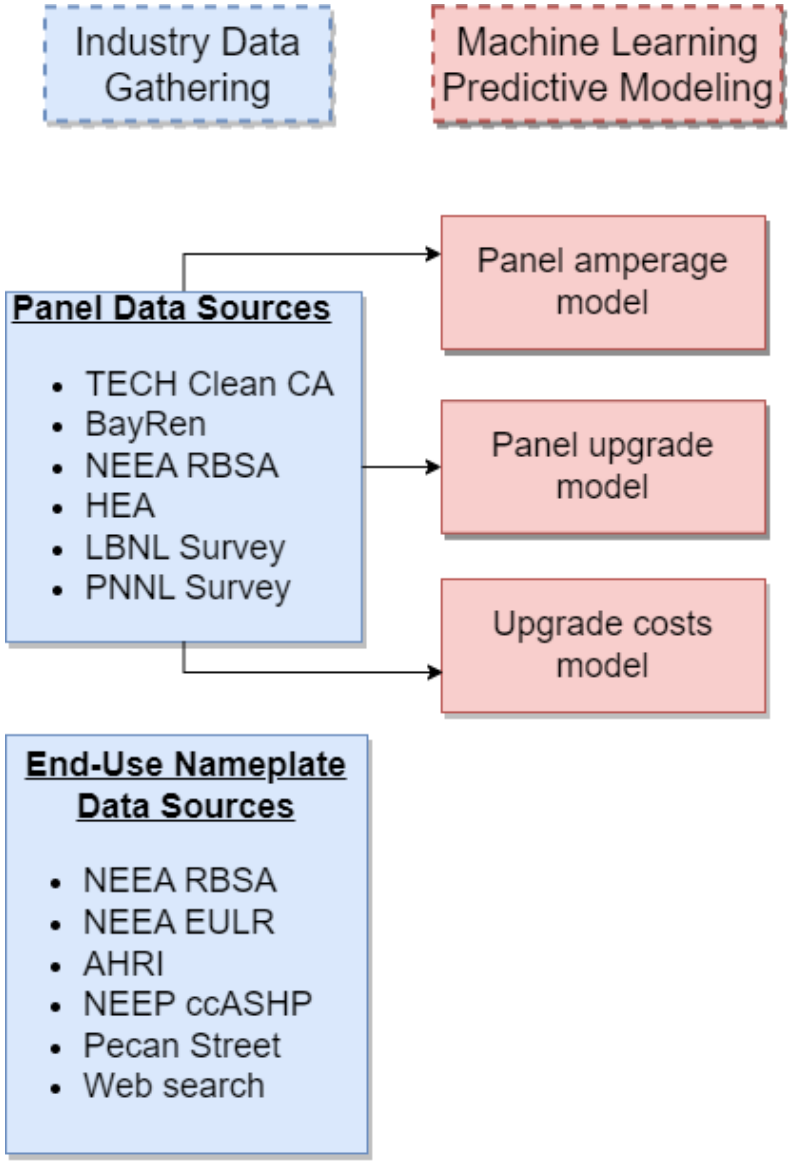
Panel Data Sources

- TECH Clean CA
- BayRen
- NEEA RBSA
- HEA
- LBNL Survey
- PNNL Survey

End-Use Nameplate Data Sources

- NEEA RBSA
- NEEA EULR
- AHRI
- NEEP ccASHP
- Pecan Street
- Web search

Approach – Hybrid Method to Characterize the Panel Capacity Problem



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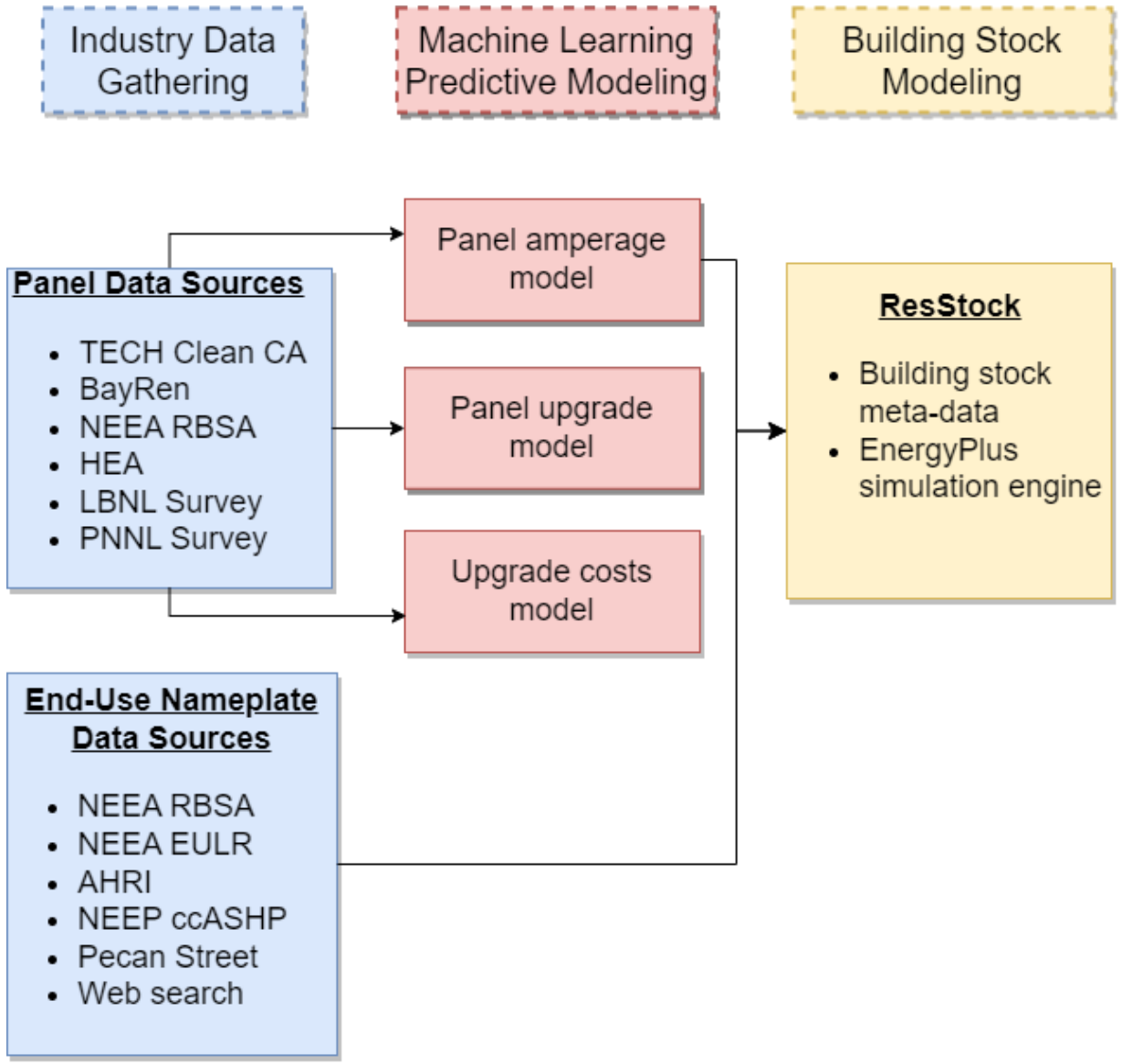

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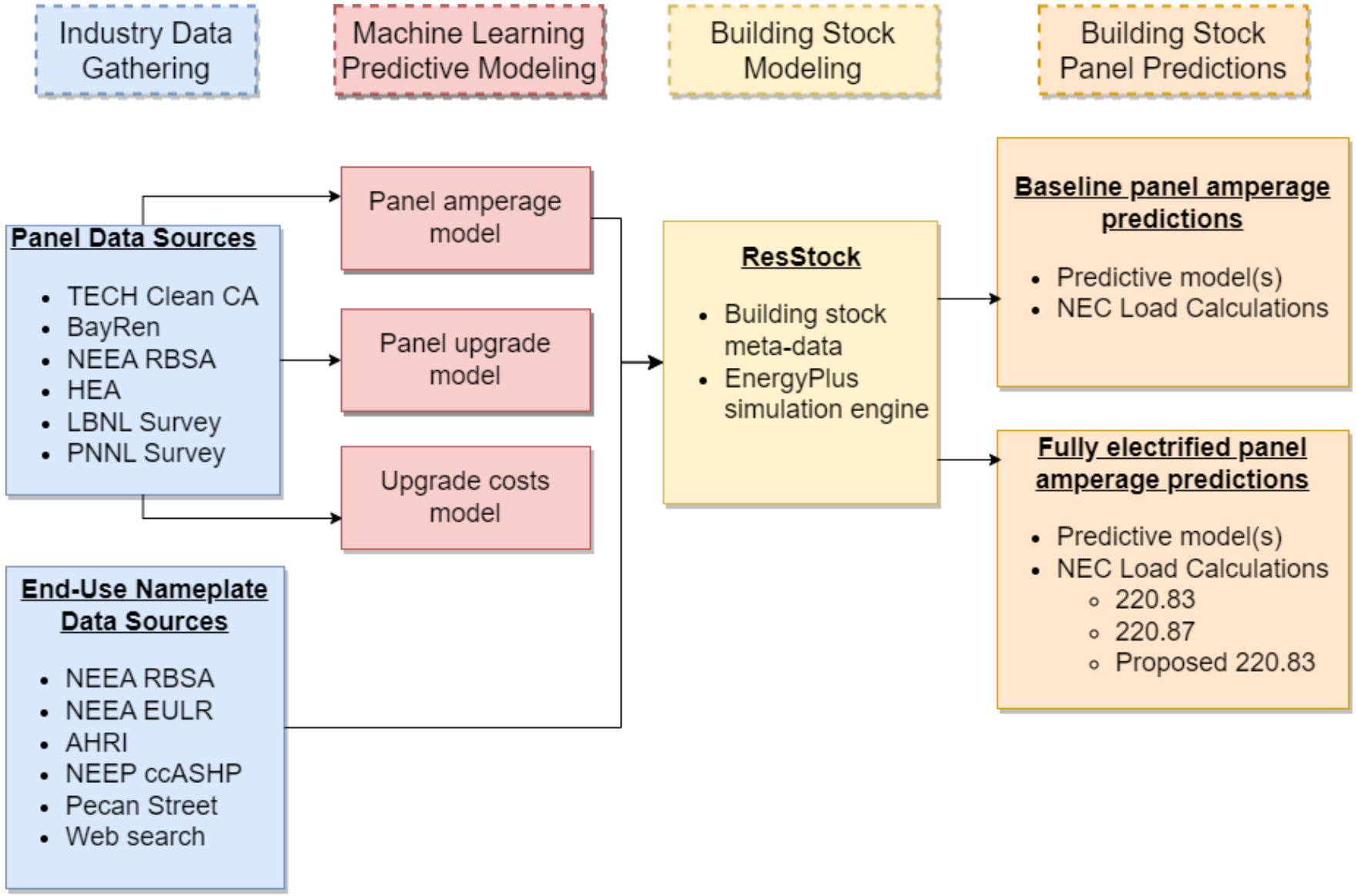

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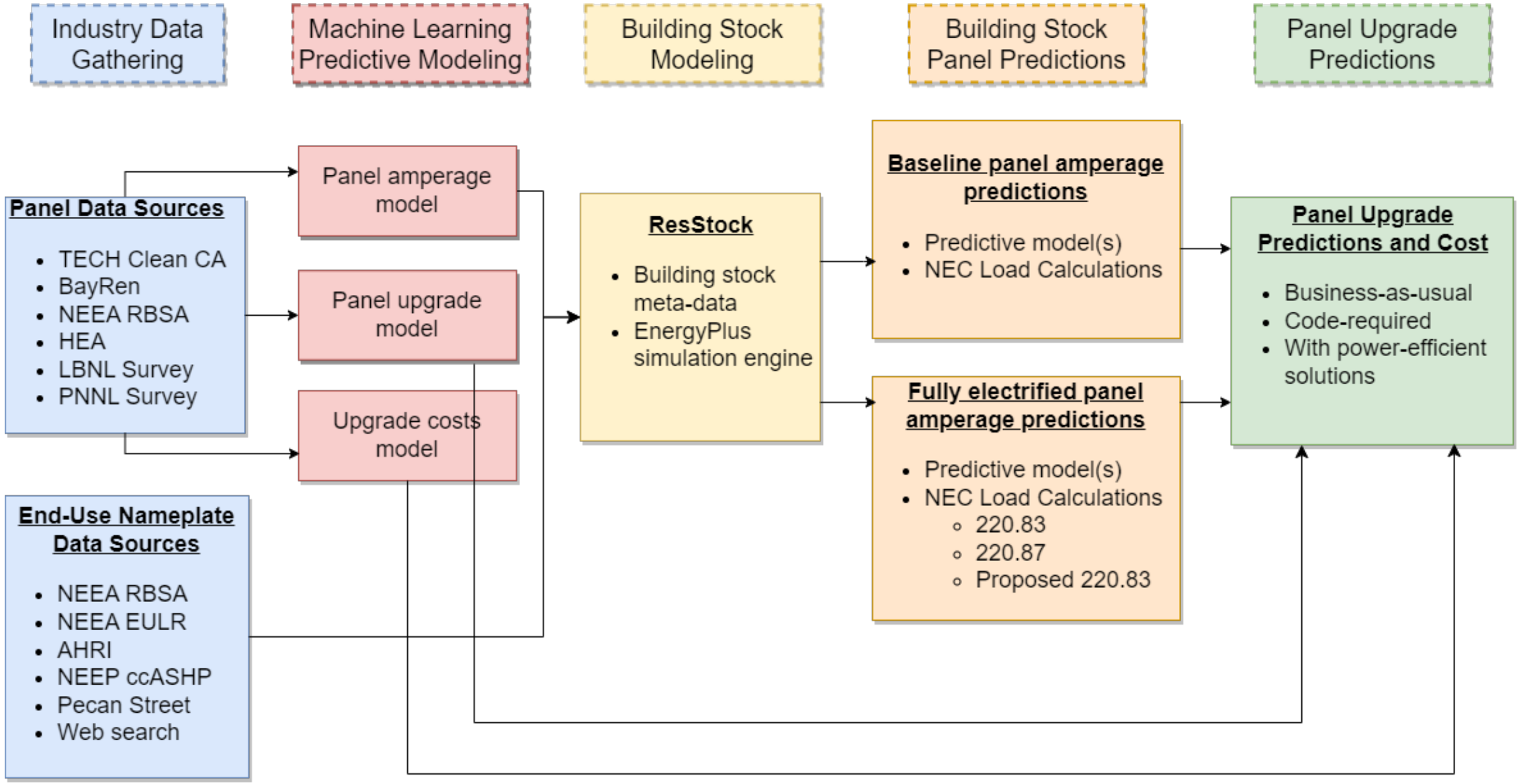


Approach – Characterize Current Solutions

Evaluate existing solutions

- Review use cases, evaluate functionality, and collect cost information

Assess load control solutions

- Model load control solutions and perform simulation-based assessment

Document case study

- Partner with practitioners to document case studies and disseminate with stakeholders

Example Solutions for Avoiding Panel or Service Upgrade

Circuit-sharing device

NeoCharge Smart Splitter. https://getneocharge.com/products/neocharge-smart-splitter?variant=41833619325123

Smart breaker

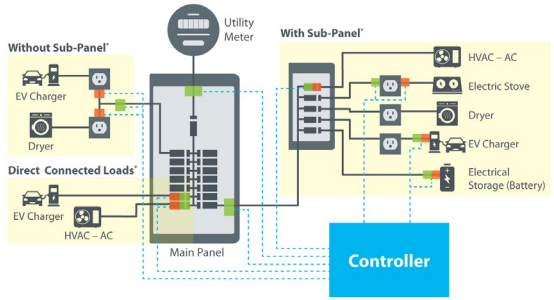
Eaton Smart Breakers. https://www.eaton.com/us/en-us/catalog/electrical-circuit-protection/energy-management-circuit-breaker.html

Meter collar

ConnectDER Meter Collar. https://connectder.com/plug-play-solar/

Lower power appliance

Rheem Performance Platinum Plug-in Heat Pump https://hotwatersolutionsnw.org/partners/news/120-volt-heat-pump-water-heater-product-overview



Digital capacity management

Approach – Digital Capacity Management

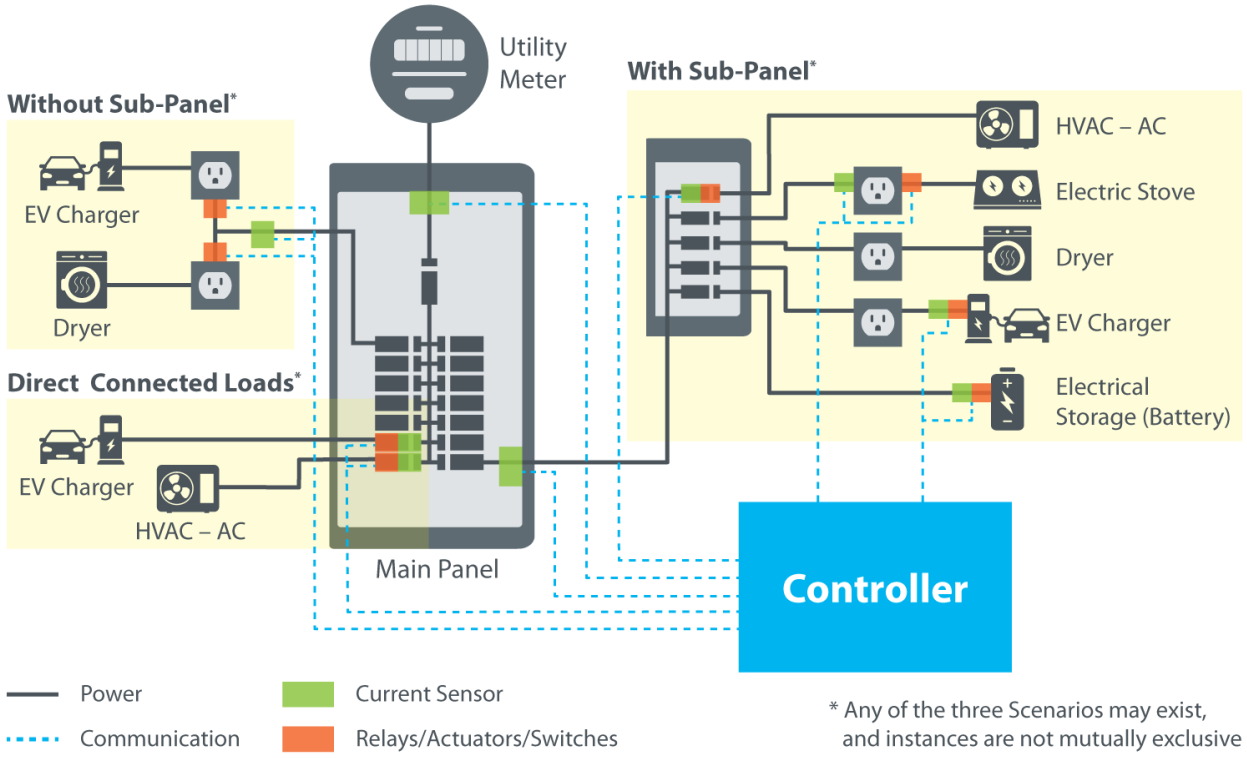
Design architecture for digital capacity management

Develop an advanced solution for full-scale digital capacity management

Construct a prototype and conduct laboratory validation

Describe possible paths to market

- A novel system to depower non-critical loads when an electrical panel capacity limit is neared or breached, before the circuit overcurrent protection trips any breakers.
- Sensors and controllers can be in the circuits or in the appliances; a simple communication hub will be needed.
- A future open technology standard for manufacturers to create interoperable devices, as they do for many IT ecosystems.



Concept diagram of the digital capacity management solution for powering and controlling large electrical end uses with different configurations

Approach – Techno-Economic Analysis of Alternatives

Analysis

- **Build a framework** to compare alternative solutions to panel/service upgrades.
- **Select the least-cost alternative** to enable electrification given specific building characteristics.

Scale

- **Scale results** to the entire U.S. residential building stock by using ResStock.
- **Assess** how the least-cost alternatives vary across building characteristics and geographic factors.
- **Evaluate impacts** across building types, levels of current capacity, and regional NEC requirements.

Code Revision

- **Determine** how availability of low-cost solutions and NEC revisions could accelerate adoption of building electrification measures.
- **Estimate regional and national impact** that could be unlocked by suggested NEC revisions.

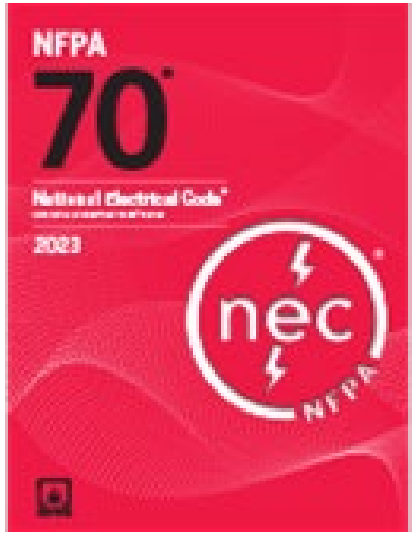
Dissemination

- **Publish results** with a substantial focus on implications for disadvantaged communities.
- **Document findings** to support NEC revisions.

Approach – Market Transformation

Propose changes and interpretation of the NEC :

- NEC is a safety-first code and is based on many assumptions about how loads will draw power and how their usage will be correlated.
- Our suggested revisions, based on data from millions of homes, will accelerate home electrification without change in safety.
- Suggested revisions will focus on sections that are relevant to decisions around panel sizing in existing dwellings undergoing renovation.



NFPA 70 National Electrical Code: https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=70

Develop resources and tools for homeowners, code officials, and practitioners:

- Many low-cost solutions do not have widespread acceptance because code officials and local jurisdictions are not familiar with these technologies.
- The proposed project will give local authorities and practitioners confidence in adopting these unfamiliar provisions.
- We will work with leading practitioners to develop freely available solution guides, calculation tools, and implementation guidance documents to simplify panel assessments and ensure the best use of existing panels.

Progress – National Survey of Electrical Panel Capacities

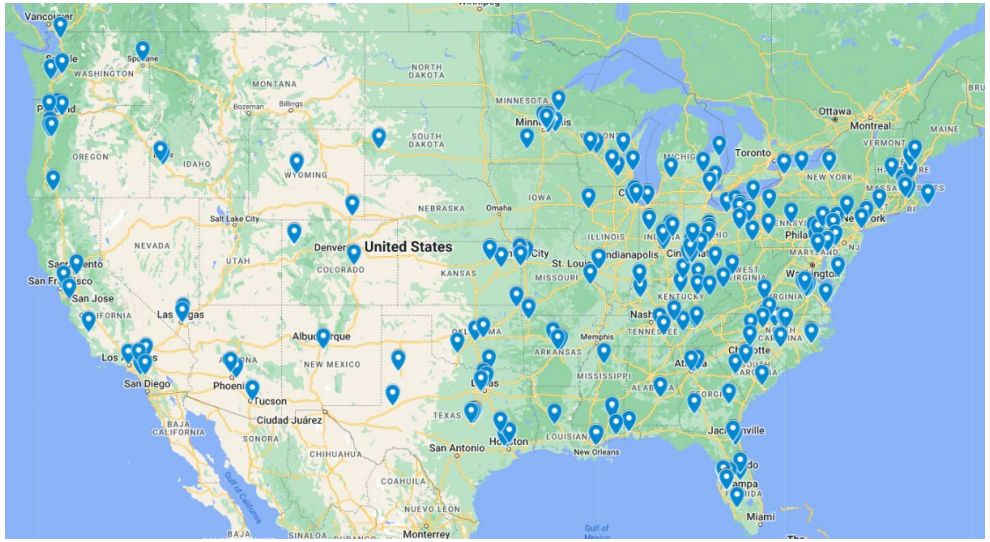
Approach:

- Surveyed occupants of single-family homes on Amazon Mechanical Turk with a short questionnaire and requested photos of their electrical panels. Compensation of $2-$7/participant was provided.
- Characteristics collected: location, floor area, building age, primary heating fuel, major electrical appliances, major gas appliances, existence of PV/battery/EV.

Results:

- Collected ~300 homes with legitimate data, covering most states and still receiving 1-2 homes/day.
- About 60% of single-family homes have 200-A panels.
- Gas-heated homes have panels with lower capacities than electrically heated homes.

Typical photos obtained through survey (whole panel and main)



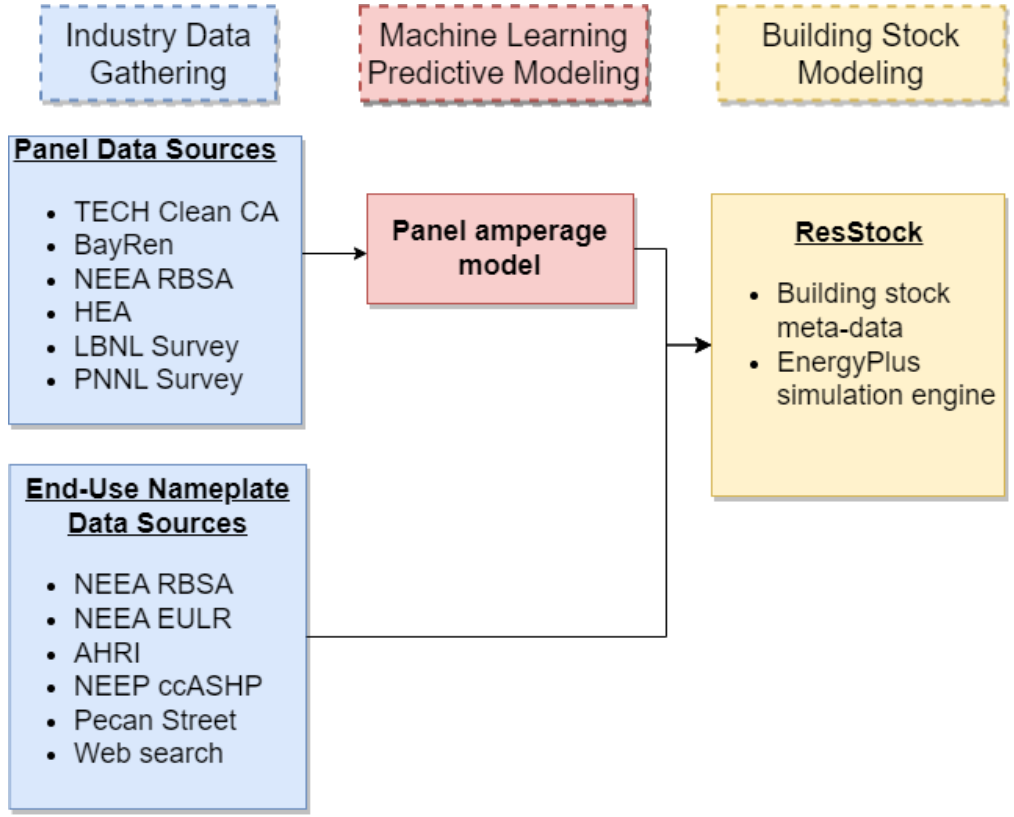
Submissions by zip code

Progress – Data-Driven Estimation of Panel Capacities

Develop a model that can predict panel amperage based on building characteristics and installed equipment.

Methods

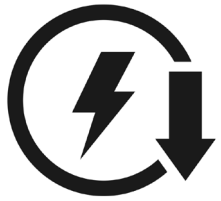
- Construct a **20,000-household data set** of panel amperage, building characteristics, and installed equipment
- Standardize fields and values to align with **ResStock**
- Build **machine learning** models to predict panel amperage
- Characterize external validity by testing model on national Mechanical Turk survey data and comparing to reported regional and national panel amperage data



Status

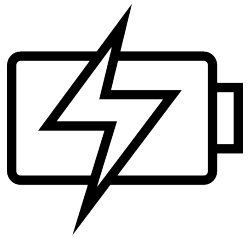
- Data set construction and machine learning pipeline complete.
- Tuning models to improve performance of predictions.
- Applying the machine learning model to ResStock to characterize how panel amperage varies across building stock and enable estimates of the need of panel upgrades in electrification retrofits.

Progress – Identifying Alternatives to Panel/Service Upgrades



Load Reduction

Low-power appliances, load shedding

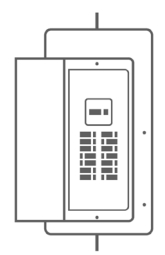


Load Shifting

Battery energy storage system, battery-integrated appliances

Slot Saver

Circuit-sharing plugs, combined appliances, tandem circuit breakers



Smart Controllers

Smart electric panels, smart circuit breakers, home energy management system

- Four groups of solutions with 50+ existing products have been identified as alternatives to panel/service upgrades for home electrification.
- Industry partners will summarize their first-hand experience of deploying those solutions in the field.
- We will identify gaps that will lead to the development of new solutions.

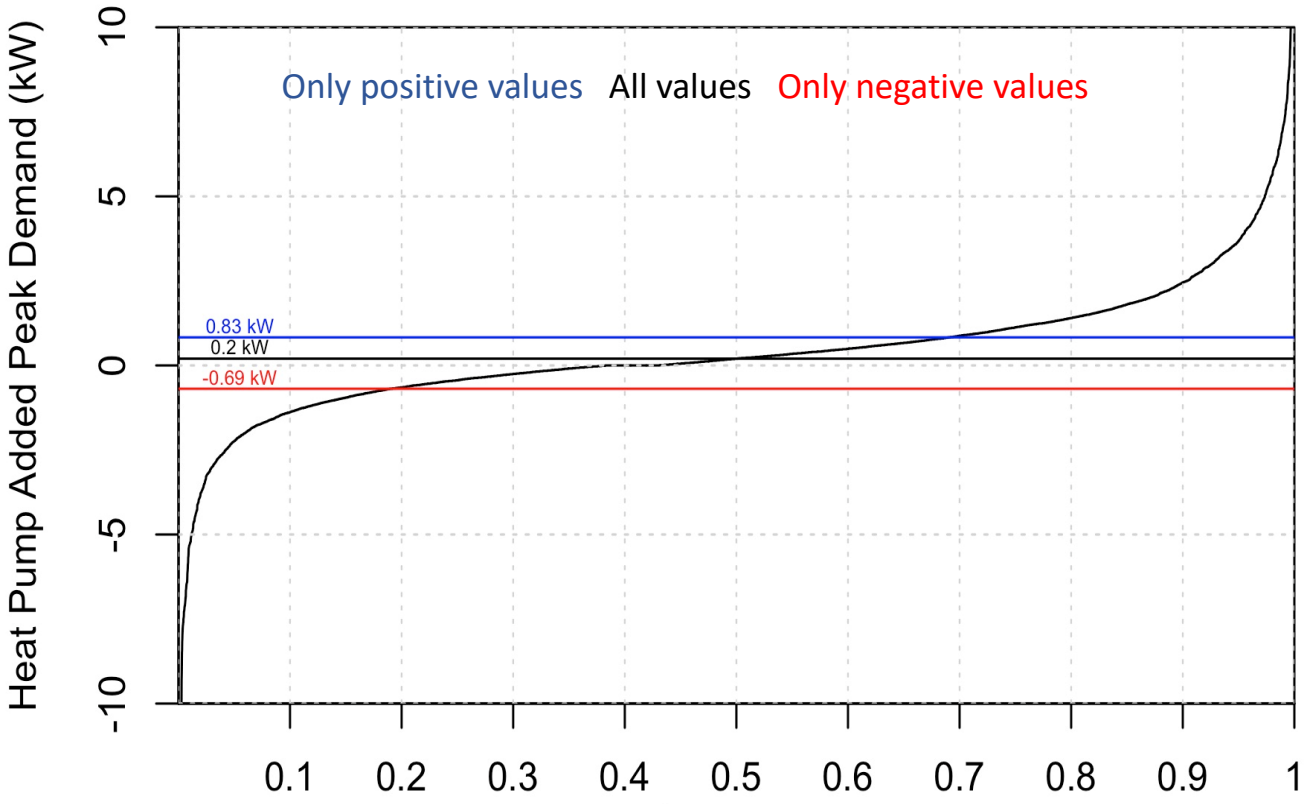
Progress – Architecture for Digital Capacity Management

- Characterized modulation capabilities of residential loads
- Defined detailed system operational architecture
  - Defined capabilities
  - Current/power sensing
  - State determination
  - Timing
  - Shedding and modulating loads
- Developing python code to implement the above architecture
- Next steps include development of a prototype, initial evaluation at LBNL, and full-scale laboratory validation at NREL's System Performance Laboratory

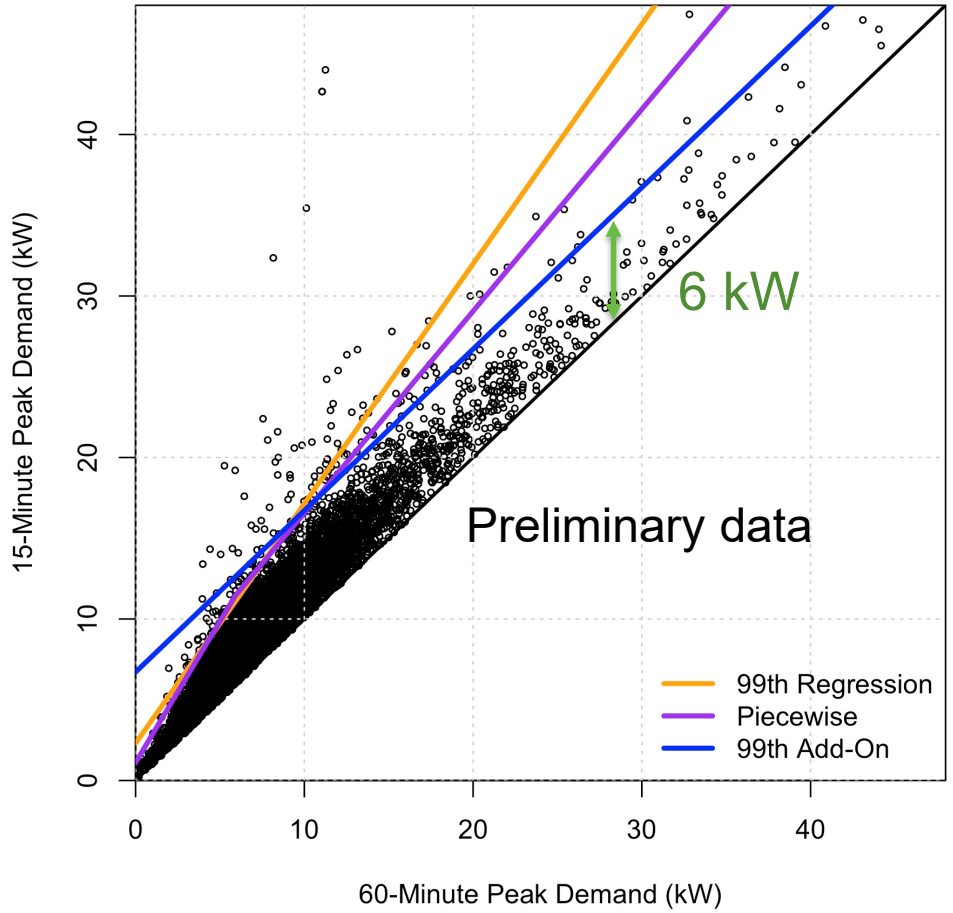
NREL's System Performance Laboratory with typical household appliance for evaluating the prototype for digital capacity management

Photo by Dennis Schroeder / NREL

Progress – Field Data Analysis on Peak Demand



15-minute data from 9,093 Vermont homes shows very little peak demand increase after cold climate heat pump upgrades (data source: VEIC, Efficiency Vermont)



Assess 15- and 60-minute peak demand with data from 14,000 homes to assess head room in panels for revisions in NEC 220.87

Progress – Potential Revisions in the National Electrical Code

Examples of Suggested Revisions

Current NEC	Examples of Suggested Revisions
Bottom-Up Load Calculation (section 220.83)	
• Has basic assumption for things like lighting loads (3W/ft^2) • New HVAC loads added at 100% of nameplate • Other loads: 8 kW minimum + 40% thereafter	• New lighting loads (1.7W/ft^2) • All new loads added at 40% of nameplate
Data-Based Load Calculation (section 220.87)	
• Uses metered data • Highest hour from a year or highest 15 minutes in a month (that must contain operation of heating or cooling, whatever is higher) • Multiplies by 1.25 and adds load at 100%	• Take 60-minute peak and add 6 kW to get 15-minute peak • All new loads added at 40% of nameplate

Timing for Proposed NEC Revision

- Need new revisions submitted by Sept. 2023 for 2026 code.
- Revisions being reviewed by other industry partners with code development experience, such as New Buildings Institute and Peninsula Clean Energy.

Future Work

- **Problem Characterization:** Integrate data-driven models with ResStock to generate an improved estimate of the number of electrical panels that may need upgrade to support electrification.
- **Solution Characterization:** Evaluate commercially available technologies for load control and identify gaps to inform the development of new solutions (Go/No-Go Decision Point).
- **Digital Capacity Management:** Design and develop a solution for full-scale digital capacity management, construct a prototype, and conduct laboratory validation.
- **Techno-Economic Analysis of Alternatives:** Compare the cost-effectiveness of technologies for avoiding panel upgrades at building scale and then scale to the entire U.S. res. building stock.
- **Market Transformation:** Develop guidance documents for local code authorities and contractors on minimizing the cost of safe home electrification (End of Project Deliverable)

Thank You

NREL and LBNL
Xin Jin (PI), Senior Research Engineer, Xin.Jin@nrel.gov
Iain Walker (Co-PI), Staff Scientist, ISWalker@lbl.gov
WBS #: 3.2.6.45 (NREL), 3.2.6.49 (LBNL)

REFERENCE SLIDES

Project Execution

	FY2023				FY2024			
Planned budget	$1M				$1M			
Spent budget (as of 3/31/2023)	$362,078							
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Past Work								
Q1 Milestone: Citizen science panel characterization								
Q2 Milestone: Methodology for data-driven and model-based characterization of panel capacity constraints								
Current/Future Work								
Q3 Milestone: Review and evaluate low-power electrification solutions								
Q4 Milestone: Capacity management and system achitecture design								
Go/No-Go Decision Point: Evaluate at least 5 commercially available technologies for load control and identify gaps.								
Q1 Milestone: Simulation framework for evaluating least-cost solutions								
Q2 Milestone: Technoeconomic analysis and least-cost solutions								
Q3 Milestone: Impact of alternative solutions and potnetial NEC revision								
Q4 Milestone: Guidance document for minimizing the cost of safe home electrification								