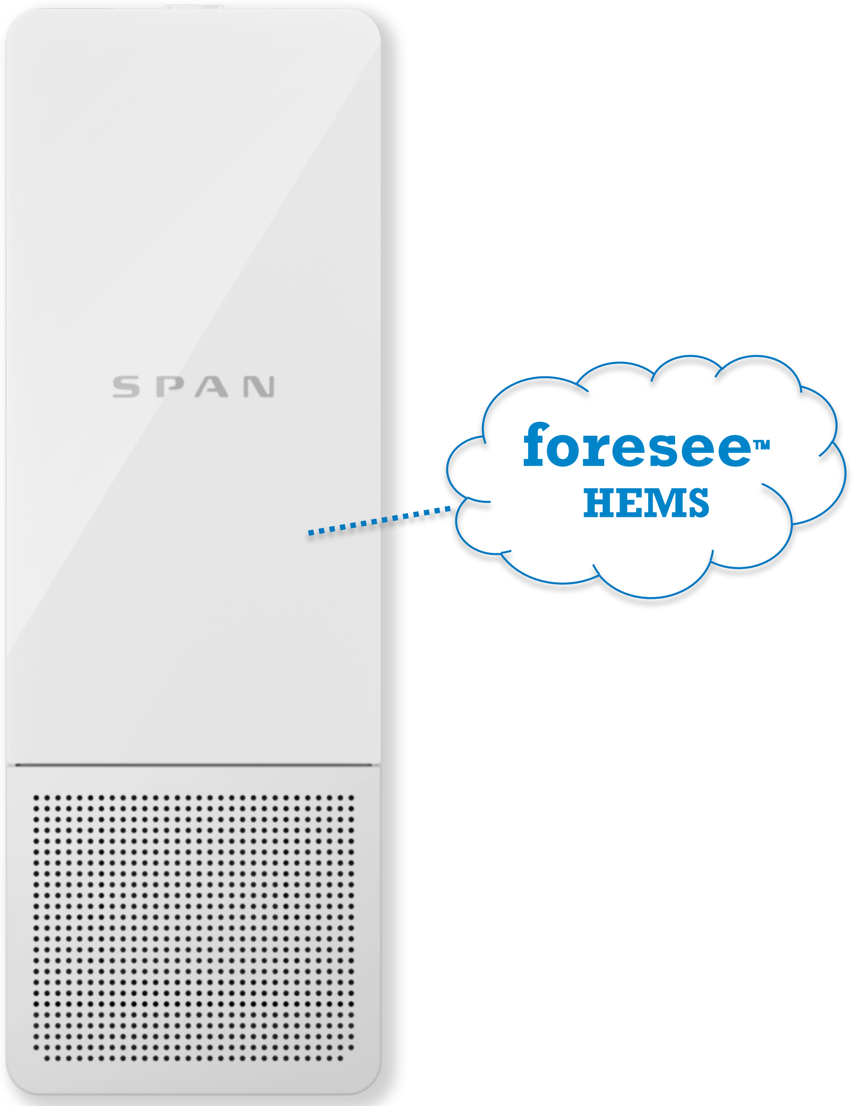
# Smart Electrical Panel-Based Home Energy Management System (HEMS)

## Enhancing utility bill savings, carbon emission reduction, and energy resilience




National Renewable Energy Laboratory (NREL)
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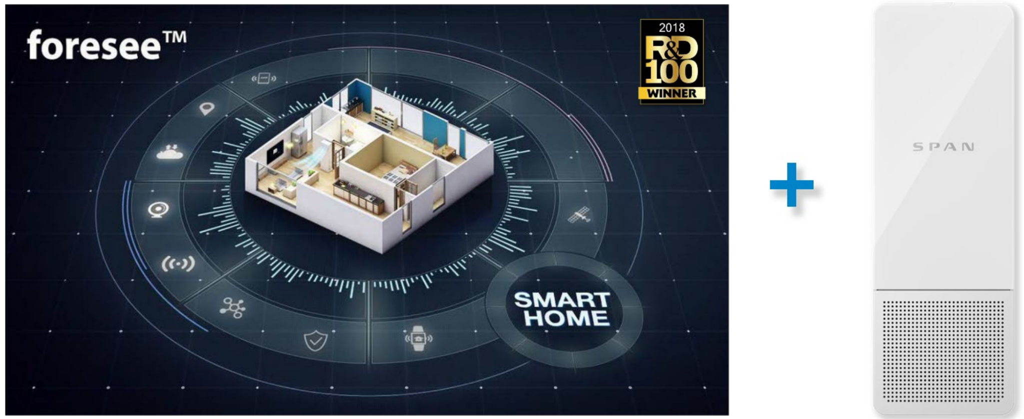
WBS # 3.2.6.88, FY21 CRADA Lab Call

# Project Summary

## Objective and Outcome

Develop and field demonstrate a smart electrical panel-based home energy management system (HEMS) that helps homeowners save on utility bills, reduce carbon emissions, and enhance resilience.




Integrating NREL's foresee$^{TM}$ HEMS with Span smart panel

## Team and Partners

NREL: Xin Jin (PI), Rajendra Adhikari, Prateek Munankarmi, Bethany Sparn

SPAN: Jack Weinstein, Brad Davids, Julia Sachs

## Stats

Performance Period: 10/1/2021 – 9/30/2023

DOE Budget: $710k, Cost Share: $140k

Milestone 1: Show new algorithms meet the performance targets (FY22 Q4, Go/No-Go Decision Point)

Milestone 2: Lab validation of the prototype panel (FY23 Q2)

Milestone 3: Demonstrate successful operation of the prototype panel in a pilot home for at least 1 month with the goal of 10% energy bill savings and carbon emission reduction (FY23 Q4, end of project milestone)

# Problem

- About **three million** electrical panels are installed in the United States every year.
- Smart panels are crucial for **residential electrification** and **decarbonization.** However, most smart panels manage end uses by turning on/off circuits, which is not ideal for **connected appliances.**
- NREL's foresee™ is a HEMS that coordinates the operation of connected appliances, batteries, and rooftop solar. It is a software solution and needs sensors and actuators to fully function.
- foresee™ and smart panels are **complementary solutions** for energy management. Integrating foresee™ with smart panels would greatly improve user experience and provide better value.
- Span has deployed thousands of smart panels across the United States since 2018. Built upon our past collaborations, Span has strong interest in working with NREL to explore the benefits of integrating foresee™ with Span panels.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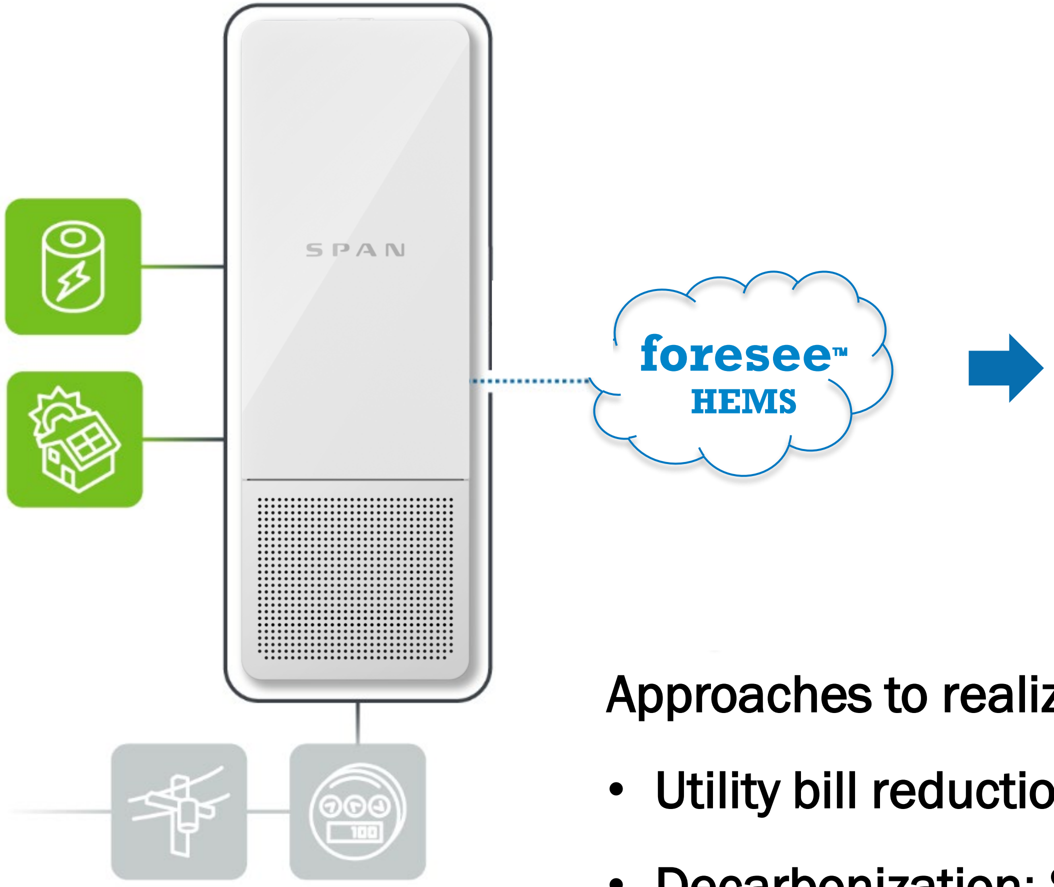
# Alignment and Impact

This project will increase smart panel market adoption, support rapid electrification and decarbonization in residential buildings, and help achieve the goal of a net-zero emission U.S. building sector by 2050.

Wide adoption of our technology will have significant impact and can benefit all stakeholders:

- **Building occupants**: Provide 10% utility bill savings to typical homes, reduce their carbon footprint, and enhance resilience during outages.
- **Electric utilities:** Help electric utilities improve demand flexibility via load shifting or curtailment, avoid distribution system upgrades by limiting whole-home instantaneous demand, and enable a net-zero grid.
- **Societal benefits**: Reduce operational carbon emissions by shifting building loads to time periods of low grid carbon intensities. When fully adopted, our technology can help Span achieve significant carbon emissions across the United States.

# Approach – Exploring Energy Management Functionalities





Approaches to realize the benefits:

- **Utility bill reduction:** Save energy, shift load, or reduce peak demand
- **Decarbonization:** Self-consume PV or use low-carbon grid electricity
- **Enhanced resilience:** Active load control and curtail non-essential loads

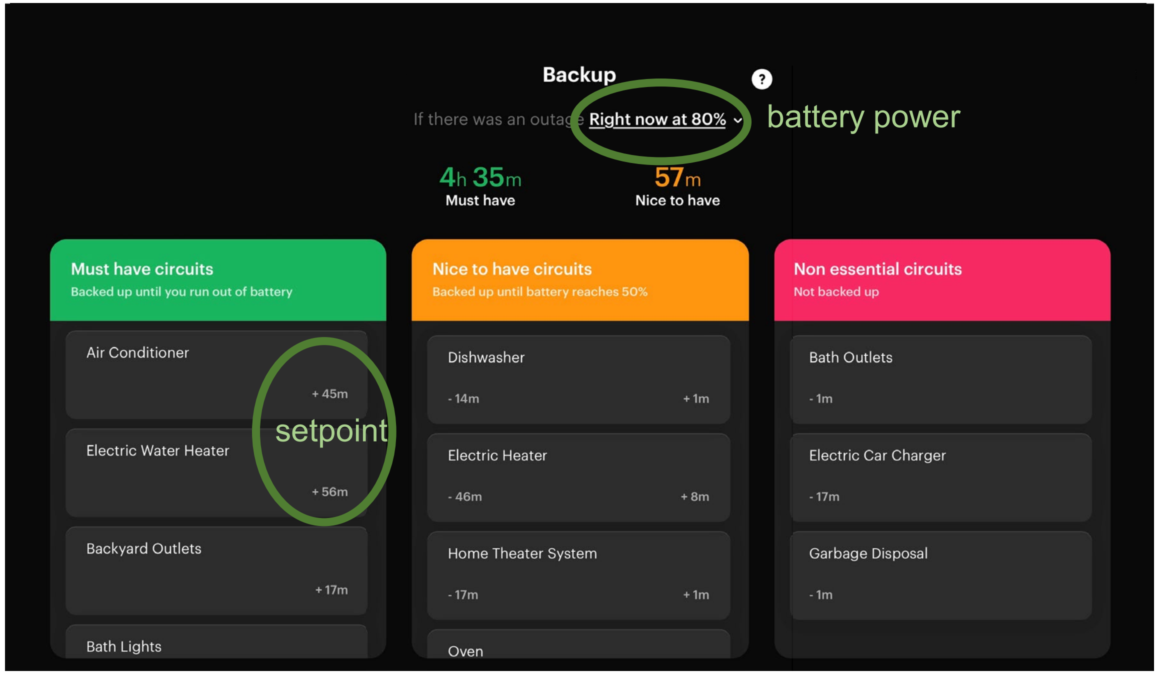
# Approach – Integration Strategy for HEMS and Smart Panel

| Options for hosting foresee HEMS | Communication with smart panel | Pros | Cons |
|---|---|---|---|
| Cloud-based **foresee** | Cloud-to-cloud (if the smart panel supports cloud API) | Easier to develop, maintain, and update; low cost; scalable | Possible communication latency; resilience may be affected by loss of communication |
| Hybrid approach: cloud-based **foresee** with local gateway | Wired communication with the smart panel via local gateway | Resilient; ideal for controlling PV/battery inverters that do not support IoT solutions | Require a gateway device and communication port on the smart panel |
| Fully embedded as part of the panel's internal software | Internal communication | Full access to panel data without latency; resilient; inherently secure | Higher requirement on smart panel's computational power |

# Approach – Strategies for Normal and Resilience Operation

foresee™ proactively adjusts HVAC and water heater setpoints and manages battery storage to provide value in both normal and resilience operation.

*Screenshot of the Span app and examples of **foresee**-controlled devices (circled)*




*Functionalities of the smart panel-based HEMS*

| Operational Mode | Functions |
|---|---|
| Normal | • User-preference-driven optimization to reduce energy cost, thermal discomfort, and emissions<br>• Adjust HVAC and water heater setpoints and battery power to provide demand flexibility |
| Resilience | • Prioritize "must have" circuits and power other circuits with excess energy<br>• Adjust HVAC and water heater setpoints to coordinate with PV/battery and extend the length of resilience operation |

# Approach – Validate and Demonstrate the Expected Benefits

We took a three-pronged approach to validate and demonstrate the smart panel-based HEMS.

**Extensive simulations**

Validate the performance of the smart panel-based HEMS under different operation modes in representative homes.

Refined algorithms for the prototype

**Hardware-in-the-loop laboratory experiments**

Evaluate the smart panel-based HEMS with physical equipment in NREL's lab home to de-risk the field deployment

Lab-validated prototype

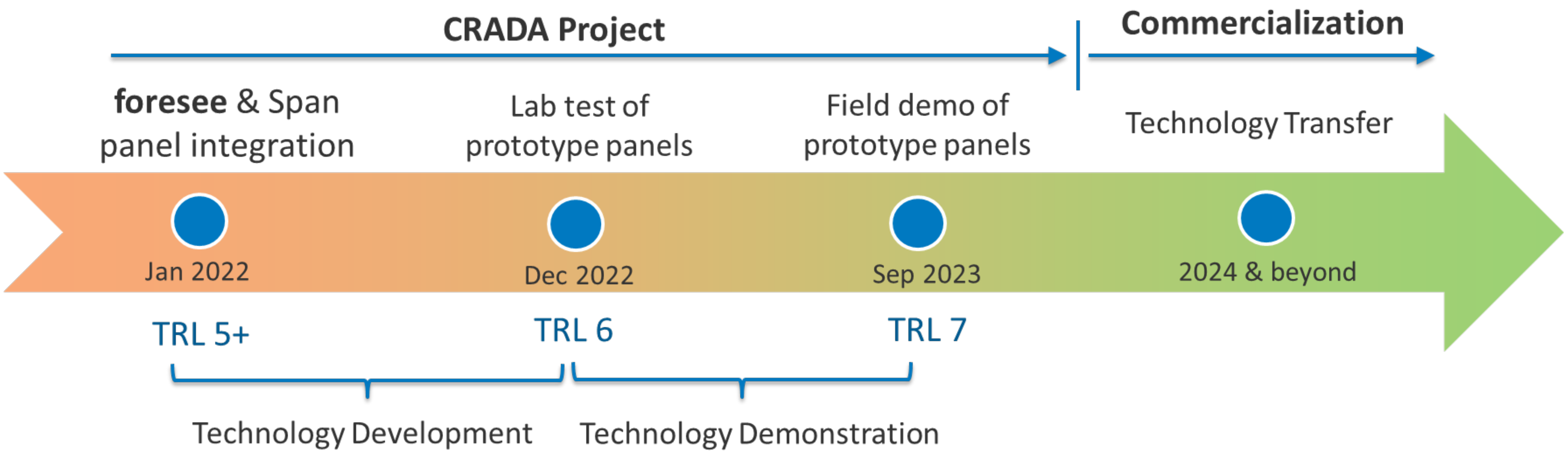
**Field demonstration**

Deploy and demonstrate the smart panel-based HEMS in homes across the United States

Field data to validate the real-world performance and support resilience analysis

# Approach – Commercialization and Market Transformation

- The prototype development started at TRL 5 and will reach **TRL 7** by the end of the project.
- After a successful field demonstration, Span will work with NREL's Technology Transfer Office to explore the next step in commercialization.
- **Widespread adoption** of smart panel-based foresee$^{TM}$ could accelerate the adoption of behind-the-meter solar and battery storage and support residential electrification and decarbonization.



# Progress – Simulation Scenarios

**Locations:**
- ❑ Boston, MA
- ❑ Sacramento, CA
- ❑ Dallas, TX

**Control methods:**
- ❑ Baseline (ruled-based)
- ❑ foresee

**House models:**
- ❑ 5 houses in each location
- ❑ At least one all-electric home in each location

**Operation modes:**
- ❑ Normal
- ❑ Resilience

- **Scenarios:** 3 locations x 2 control methods x 5 house models x 2 operation modes = 60 scenarios
- **Utility rate:** Time-of-use (TOU) rates from electric utilities of each location
- **Carbon data:** Cambium short run marginal emission data for year 2022
- **Comfort band:** $\pm 1°C$ around setpoint temperature (foresee cases)

**Tools used:**

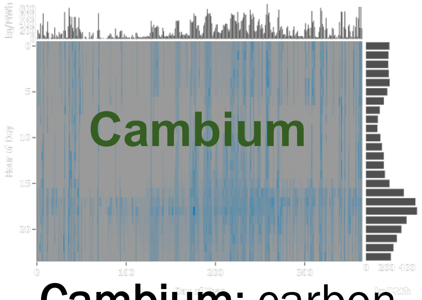

**foresee:** HEMS

ResStock

**ResStock:** building characteristics

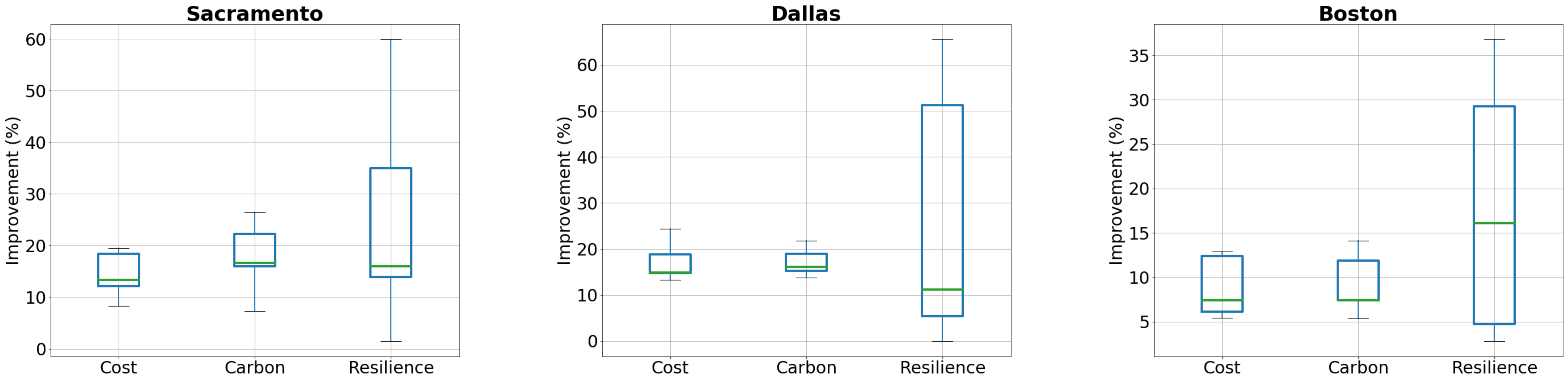
OCHRE

**OCHRE:** control-oriented building model




**Cambium:** carbon emission data

# Progress – Simulation Results




*Resilience is defined as the duration of a home operating in islanded mode with the behind-the-meter solar and battery*

- Most homes have at least a **10% improvement** in energy cost savings, carbon emission reduction, and resilience operation.
- **Cost and carbon reduction** are lower in Boston homes because of gas space heating and thereby limited load control and savings potential.
- **Wide range in resilience results** are due to the high cooling loads in Dallas homes in the summer and natural gas space heating in the Boston and Sacramento homes.

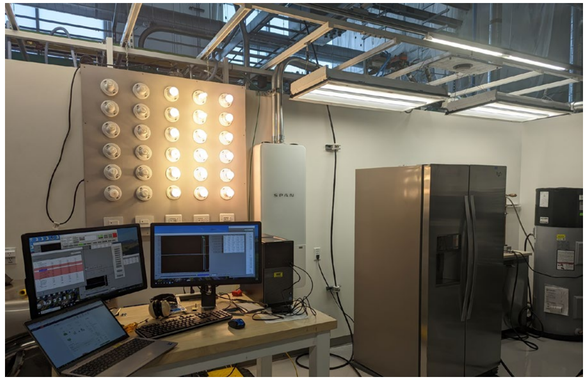
# Progress – Deployment of Prototype Panel


Prototype installed in NREL's System Performance Laboratory (SPL)

Home battery and inverter system (left) and PV emulator (right)

Environmental chambers for HVAC condenser and thermostat

Heat pump water heater with communication module (left) and room air conditioners (right)

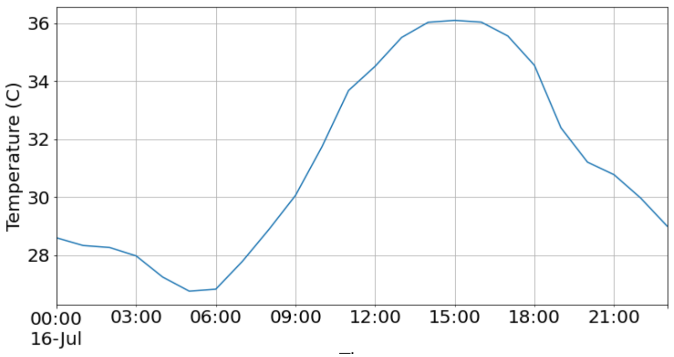


Panel lights, ceiling lights, and refrigerator

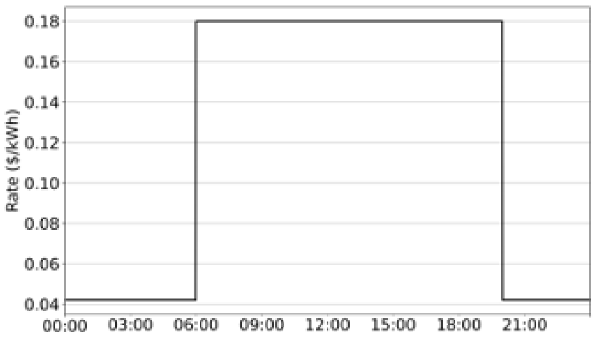
# Progress – Hardware-in-the-Loop Laboratory Experiments

| Scenario # | Description | Season | Grid Mode | Control |
|---|---|---|---|---|
| 1.0 | Baseline, normal operation, summer | Summer | Normal | Default |
| 1.1 | HEMS, normal operation, summer | Summer | Normal | **foresee** |
| 2.0 | Baseline, resilience operation, summer | Summer | Islanded | Default |
| 2.1 | HEMS, resilience operation, summer | Summer | Islanded | **foresee** |

Outdoor air temperature




Time-of-use rate plan



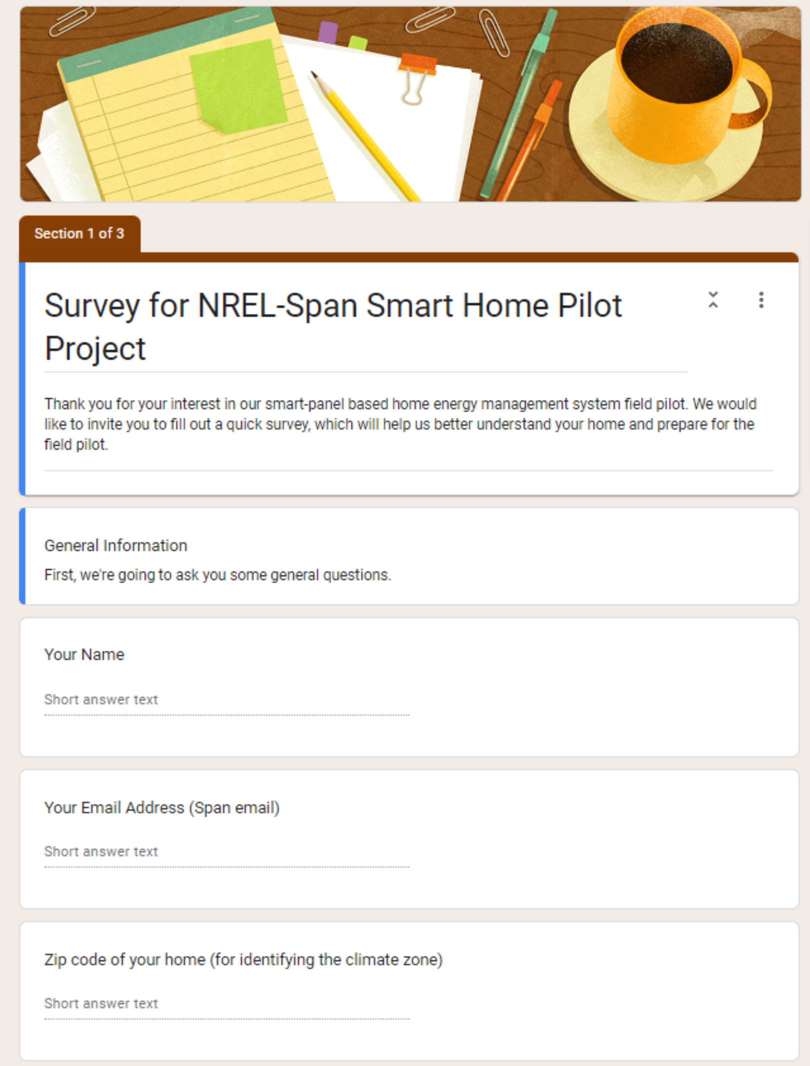

- **Simulated time:** July 16, 2022
- **Simulated home:** 1690 sqft, built in 2000, equipped with central air conditioner, electric furnace, and heat pump water heater

- HIL experiments for validating the prototype's performance with a Dallas home and weather data.
- During normal operation, the smart panel-based **foresee** achieved **10.4% energy savings** and **44.4% energy cost savings** on a typical summer day, exceeding the 10% cost savings performance target.

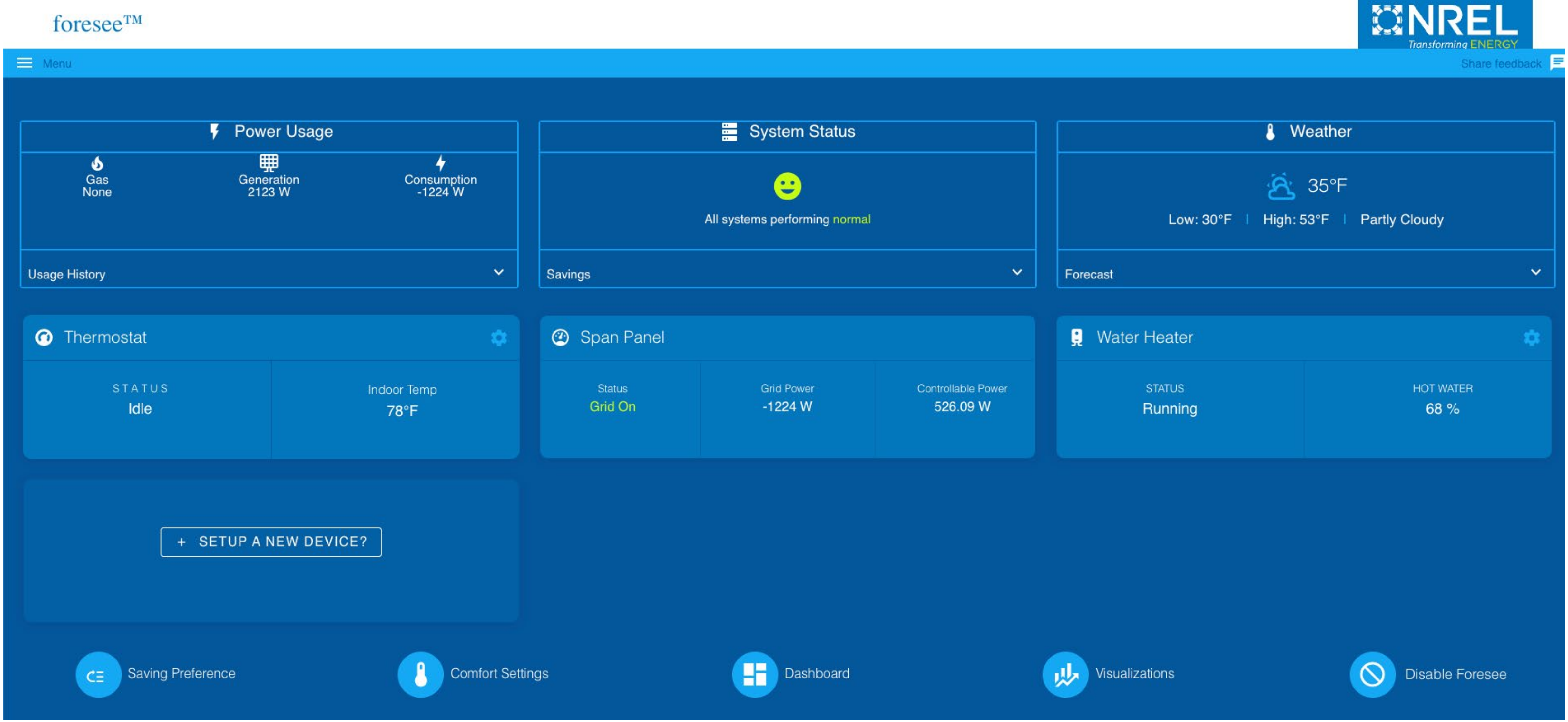
# Progress – Field Pilot Participant Recruitment

- **Recruiting participants** in a field pilot for demonstrating the new capabilities of the Span panel enabled by the integration.
  - Due to the cost and project timeline, we only target homes that already have Span panel installed.
- **Surveys** were performed to understand the characteristics of the potential sites and the suitability for the field pilot.
  - Received five responses with homes from four different climate zones.
- The team will have **one-on-one conversations** with the homeowners and obtain approval from the DOE central institutional review board.
- **Field pilot** will start in FY23 Q4 and last for three months.

*A screenshot of the survey webpage*



# Progress – User-Friendly Dashboard for the Field Pilot



# Future Work

- **Finalize** field pilot homes and **deploy** the smart panel-based foresee.
- **Perform field experiments** in the pilot homes to demonstrate the smart panel-based foresee achieves the performance targets.
- Work with NREL's Technology Transfer Office to explore the next steps in commercialization of the developed technology.
- **Disseminate research findings** (non-proprietary information only) in technical publications or presentations.
- Assist Span to design strategies/roadmap to achieve its ambitious goal of **carbon emission reduction across the United States.**

# Thank You

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# REFERENCE SLIDES

# Project Execution

| | FY2023 | | | | FY2024 | | | |
|---|---|---|---|---|---|---|---|---|
| Planned budget | $417,824 | | | | $0 | | | |
| Spent budget (as of 3/31/23) | $151,265 | | | | $0 | | | |
| | Q1 | Q2 | Q3 | Q4 | Q1 | Q2 | Q3 | Q4 |
| **Past Work** | | | | | | | | |
| Q1 Milestone: Utility bill savings and carbon emission reduction | | | | | | | | |
| Q2 Milestone: Circuit-level MEL monitoring and analytics | | | | | | | | |
| Q3 Milestone: Resilience enhancement | | | | | | | | |
| Q4 Milestone: Show new algorithms meet the performance targets | | | | | | | | |
| Q1 Milestone: Deploy prototype panel in laboratory | | | | | | | | |
| Q2 Milestone: Laboratory validation of the prototype panel | | | | | | | | |
| **Current/Future Work** | | | | | | | | |
| Q3 Milestone: Field pilot preparation | | | | | | | | |
| Q4 Milestone: End of project milestone | | | | | | | | |

- **Go/no-go decision point** (FY22 Q4): The foresee-integrated smart electrical panel improves a home's utility bill savings (under time-of-use, real-time pricing, or demand charge rate plans), reduces carbon emissions, and extends resilience operation period by at least 10%.
- **End of project milestone** (FY23 Q4): Demonstrate successful operation of the prototype panel in a pilot home for at least 1 month. Demonstrate use cases with the goal of 10% energy bill savings and carbon emission reduction.

# Team

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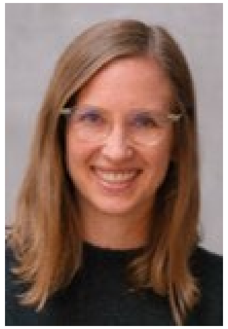

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