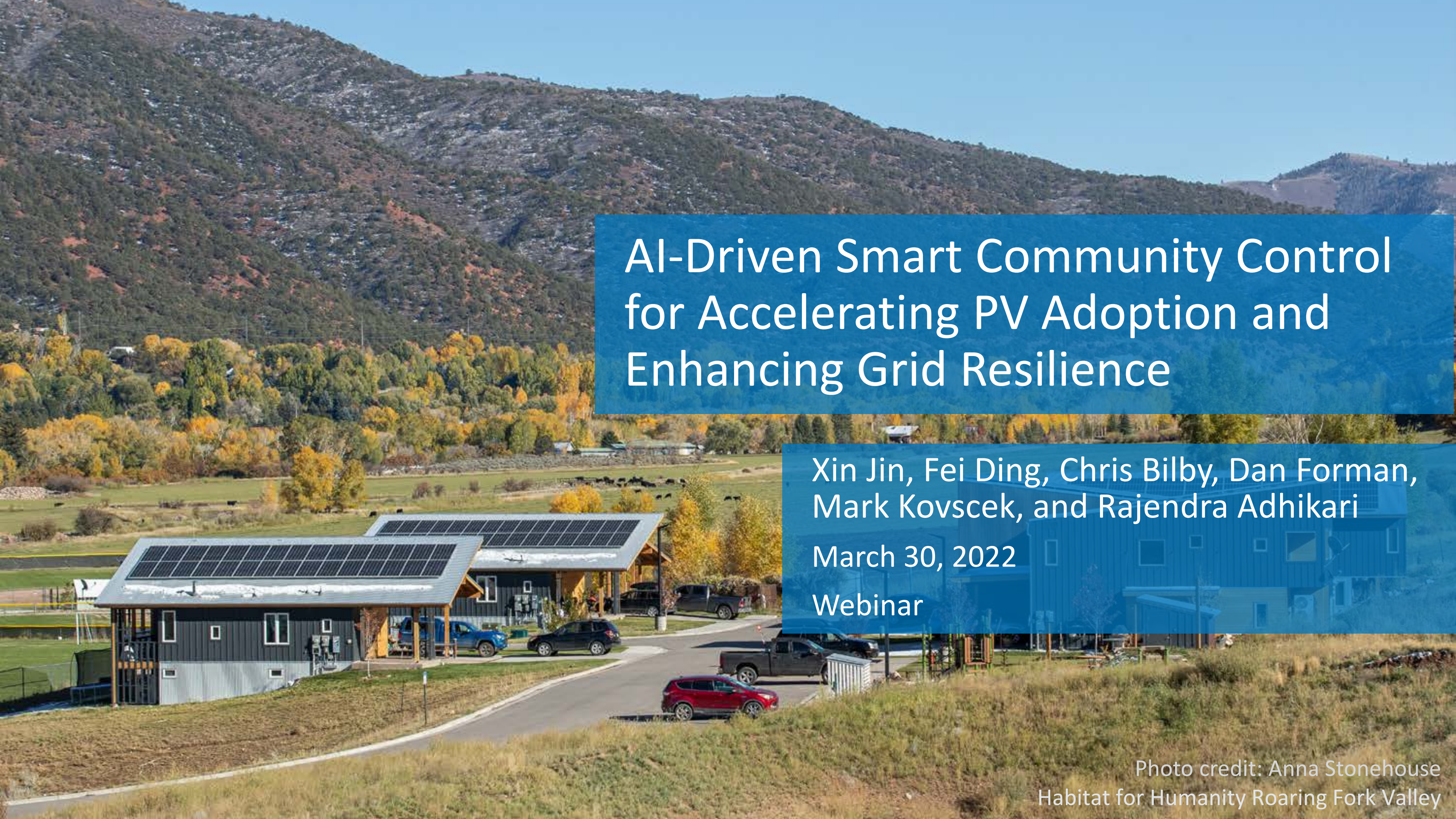


AI-Driven Smart Community Control for Accelerating PV Adoption and Enhancing Grid Resilience

Xin Jin, Fei Ding, Chris Bilby, Dan Forman, Mark Kovscek, and Rajendra Adhikari

March 30, 2022

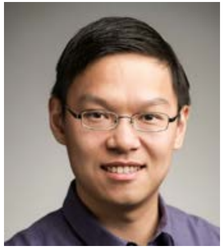
Webinar

Photo credit: Anna Stonehouse
Habitat for Humanity Roaring Fork Valley

Agenda

- Introductions & Project Overview (10 minutes)
- Methodology (10 minutes)
- Partner Presentation (15 minutes)
- Results & Lessons Learned (15 minutes)
- Q&A (10 minutes)

Speakers



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Sensors & Controls Lead,
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NREL

Rajendra Adhikari – Software Lead
Research Engineer
Residential Buildings Group
NREL

Chris Bilby
Research Engineer
Holy Cross Energy

Dan Forman
CEO
Copper Labs

Mark Kovscek
CEO
Conservation Labs

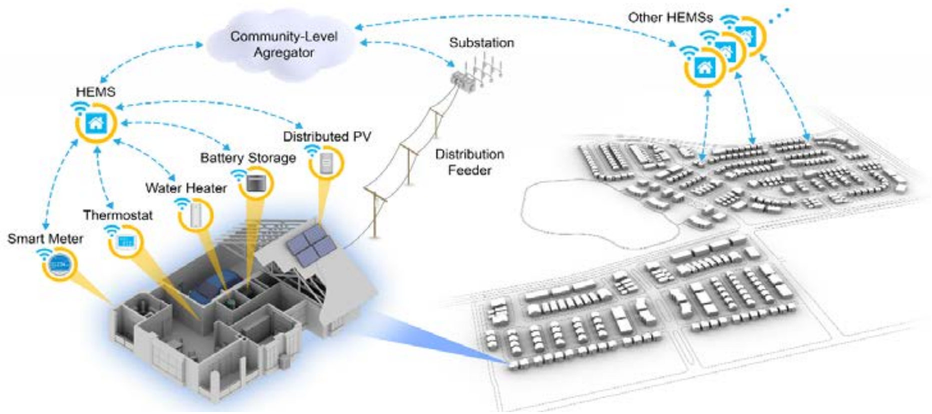
Project Overview

Challenges

- Net zero energy (NZE) communities are emerging, and the high-penetration PV in the communities may cause issues such as overvoltage, voltage flicker, and degraded power factor in the electrical distribution systems.
- Existing solutions have insufficient understanding of behind-the-meter assets or are not able to manage large-scale heterogeneous assets.

NREL is developing and validating a hierarchical, community-scale solution to resolve crucial distribution grid issues arising from high-penetration PV and enhance grid reliability and resilience.

Technical Approach: **Artificial Intelligence (AI) +**
Home Energy Management System (HEMS) + Aggregator



Use cases:

- PV Self-Consumption
- Grid Reliability
- Grid Resilience

Team

Project Team

- National Renewable Energy Laboratory (Lead)
- Holy Cross Energy
- Habitat for Humanity Roaring Fork Valley
- Copper Labs
- Conservation Labs
- Thrive Home Builders
- Fort Collins Utilities
- A.O. Smith

Technical Advisory Group

Electric Utilities

- Duke Energy
- Xcel Energy
- Southern Company

Research Institute

- Rocky Mountain Institute
- Electric Power Research Institute

Academia

- University of Texas at San Antonio
- Colorado State University
- Penn State University
- University of Oklahoma

Technology Vendor / Manufacturer

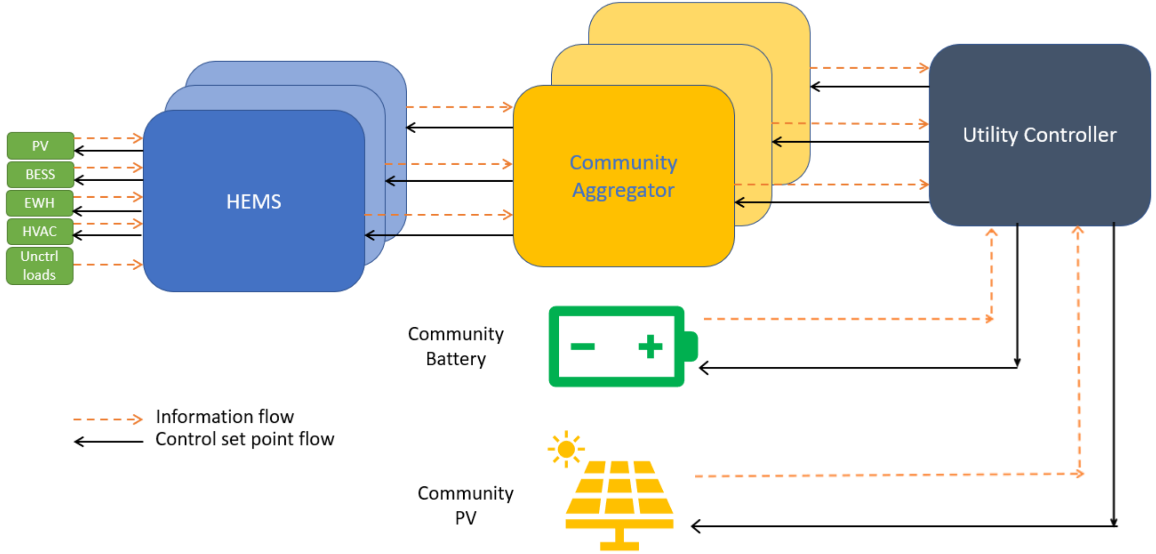
- Itron
- Minsait Advanced Control Systems
- Leaptran
- Smarter Grid Solutions
- Quanta

Project Timeline

- 10/2018 — Project started
- 3/2020 — Construction of the Fort Collins community delayed; identified Basalt Vista as the alternative field pilot site.
- 6/2020 — Simulation studies completed
- 3/2021 — Hardware-in-loop laboratory experiment completed
- 7/2021 — Recruited field pilot participants at Basalt Vista
- 10/2021 — Field deployment completed; field demonstration started
- 4/2022 — Project ends, equipment decommissioning

Hierarchical Control System

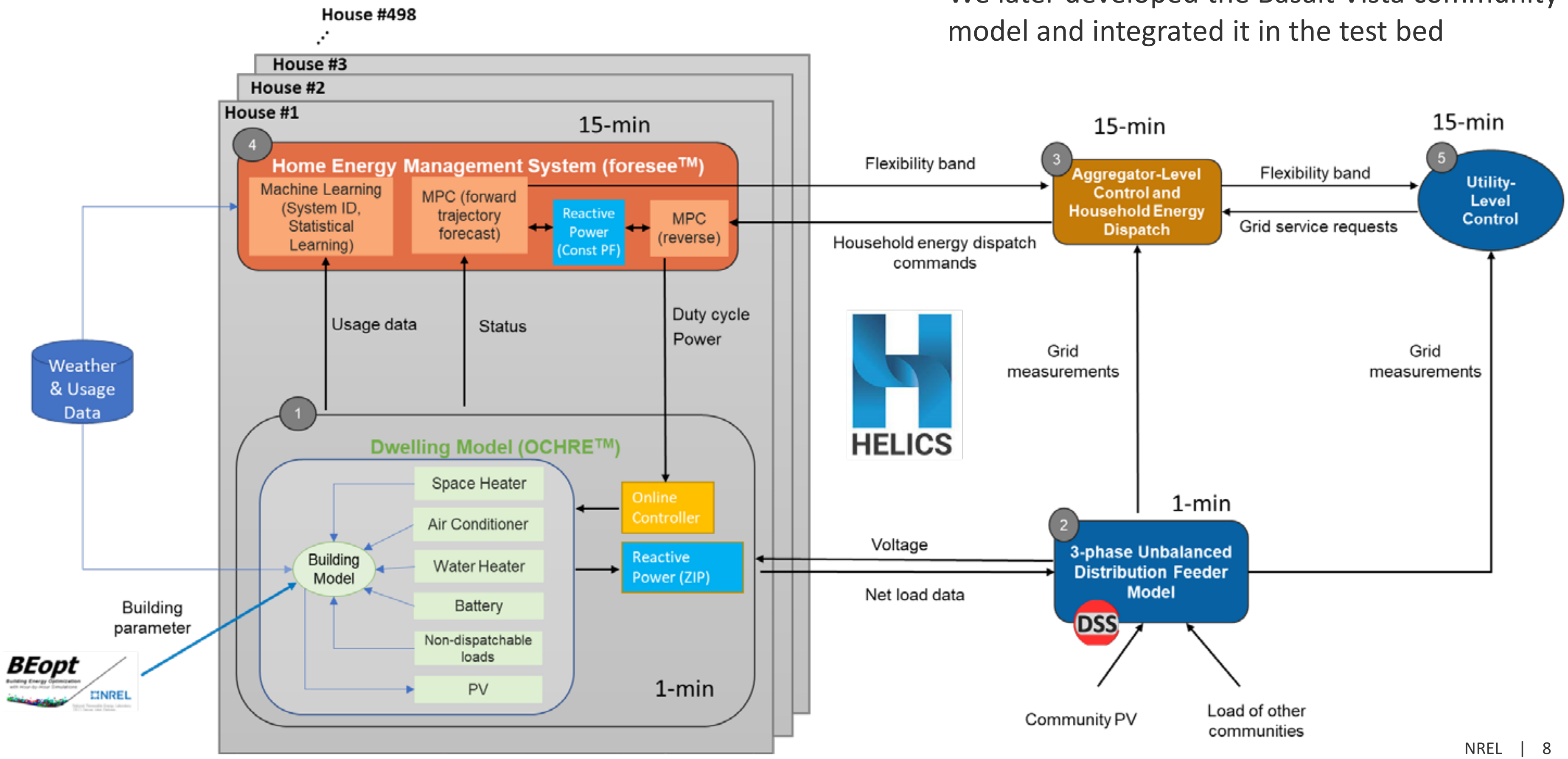
The goal of the project is to develop a field-proven control system that can manage the behind-the-meter loads and distributed energy resources and coordinate them across different homes to improve grid reliability and resilience.



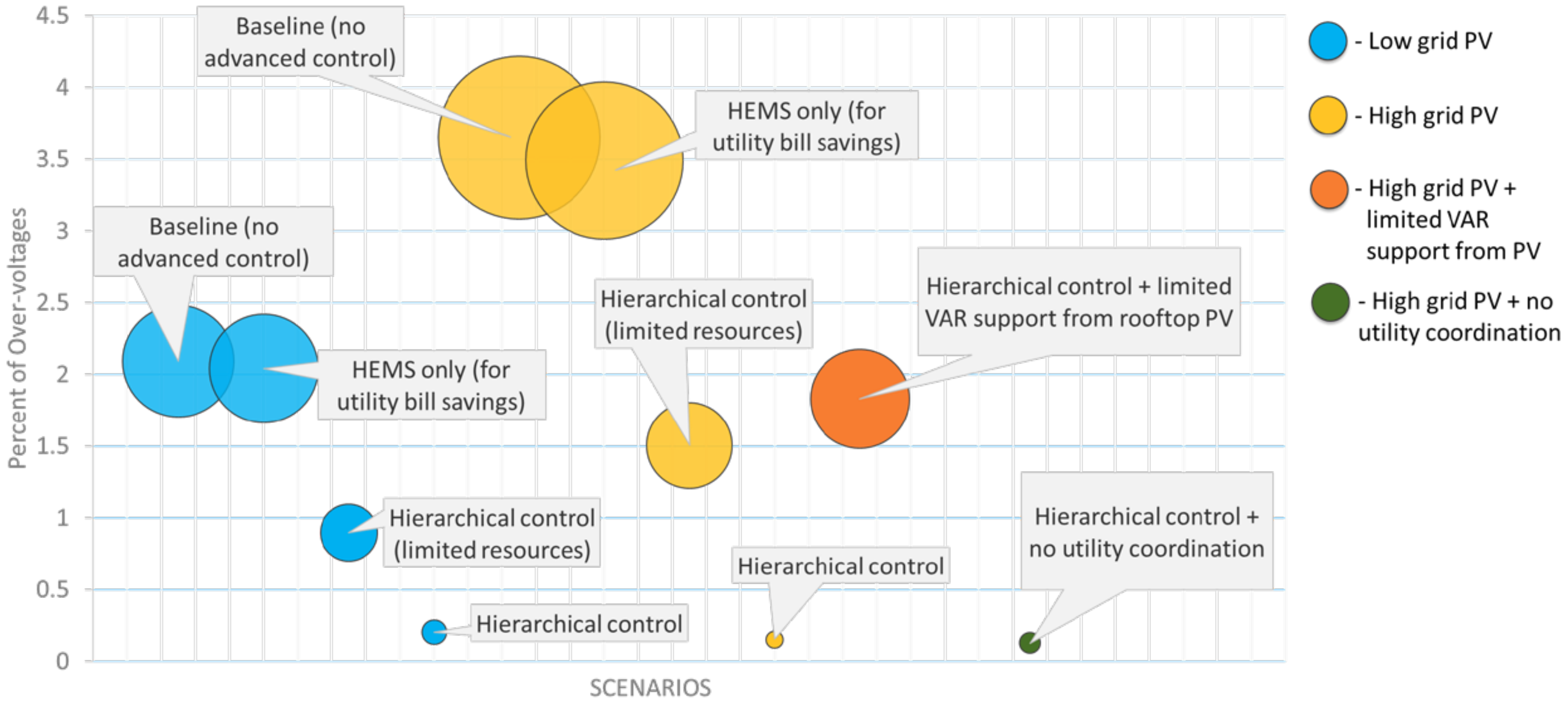
Hierarchical control system consisting of HEMS, community aggregator, and utility controller

Simulation Test Bed

- The 500-home Fort Collins community was originally modeled in the simulation test bed
- We later developed the Basalt Vista community model and integrated it in the test bed

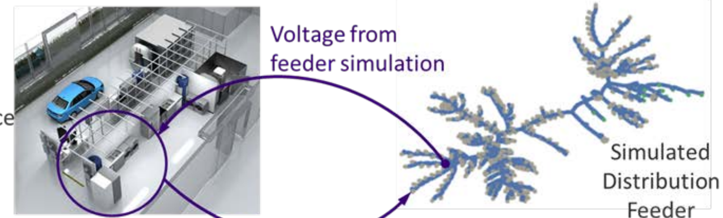


Simulation Study for Grid Reliability



Hierarchical control algorithms successfully reduced the frequency and severity of overvoltages.

Hardware-in-Loop Laboratory (HIL) Experiments



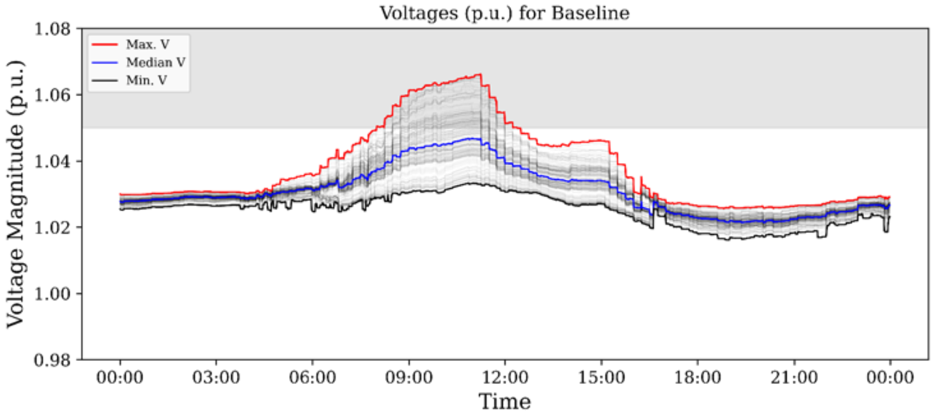
Supercomputer

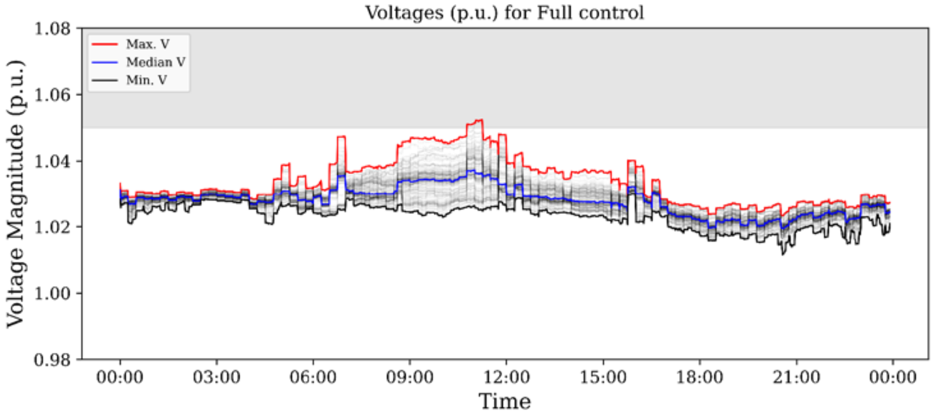
Smart home HIL with physical devices in a lab home and simulated homes and distribution feeder on the supercomputer

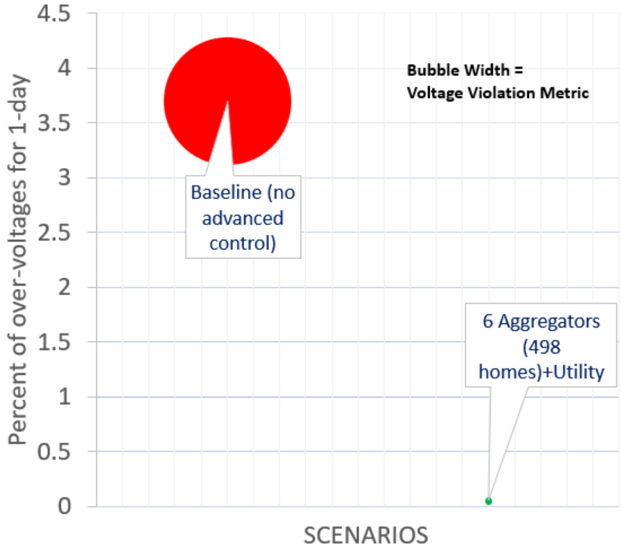
Physical equipment in the lab home verifies control performance at the device level, and the actual load profile from the lab home is injected back to the simulated community on the supercomputer.

HIL Experiment – Grid Reliability (Shoulder Season)

Community-scale voltage data from grid reliability experiments



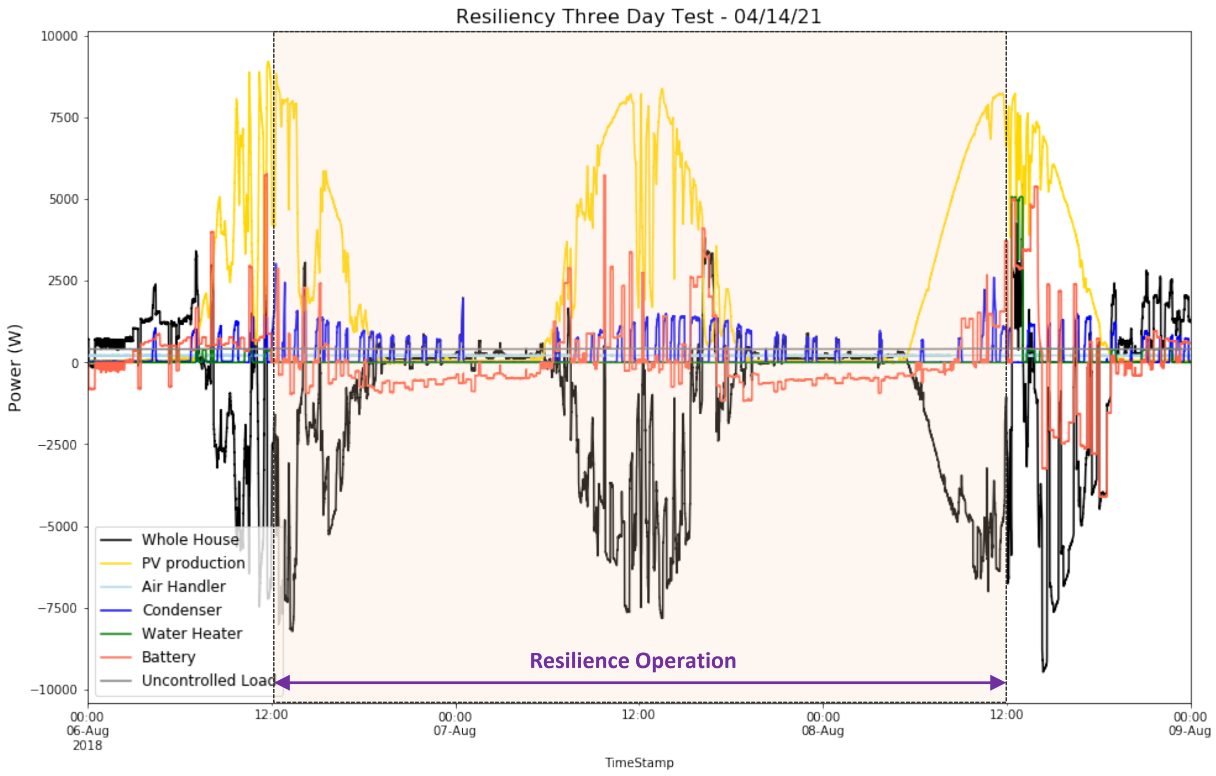




- Shoulder season was selected for HIL experiments because of the low load and high PV generation.
- The hierarchical control system significantly reduced overvoltages in the community.

HIL Experiment – Grid Resilience (Summer Season)

Lab home power data from grid resilience experiments

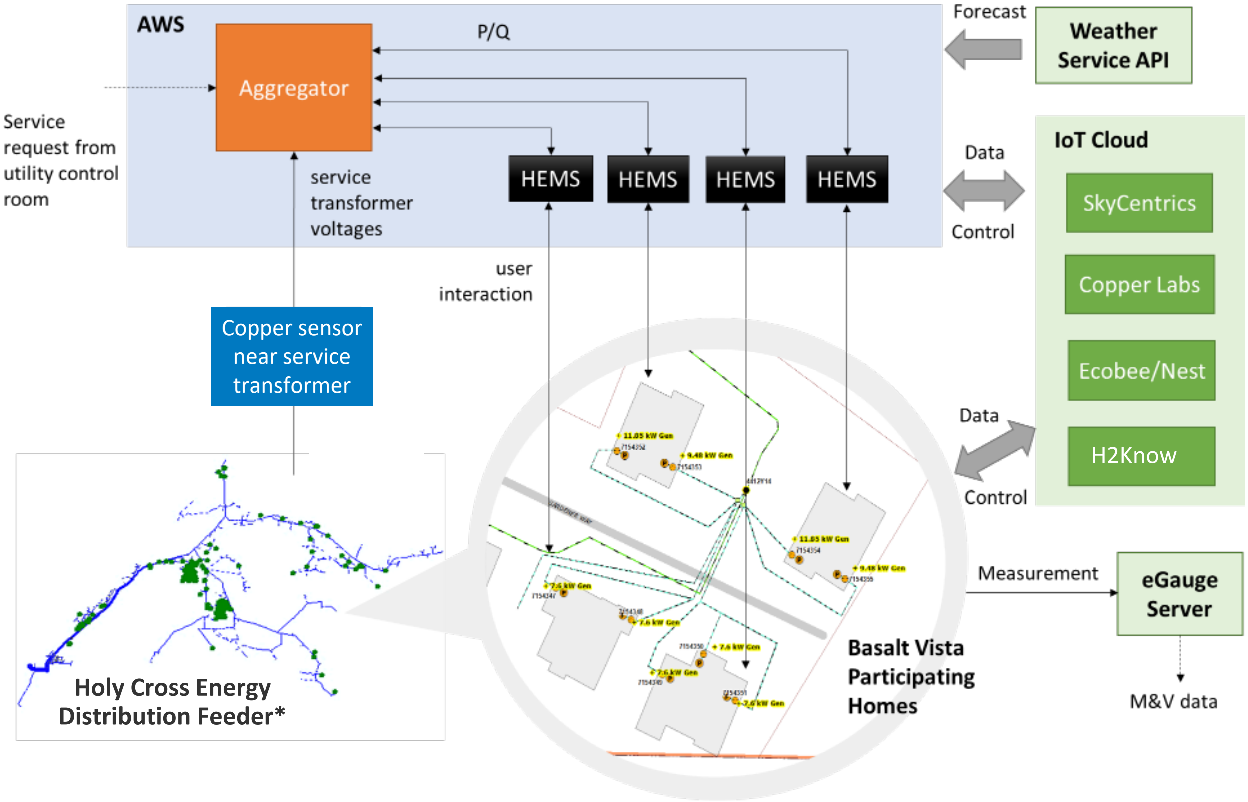


- A two-day resilience experiment was performed with the community operated as a "soft microgrid."
- The HEMS operated the lab home following the reference signal from the aggregator.
- The home exported excess power to the grid during the day and powered critical loads with battery during the evening to **minimize power import from the grid**.
- All the critical loads were supported, and no overvoltage issues were observed during the resilience operation.

Basalt Vista Field Pilot Study

- Construction of the 500-home community in Fort Collins was delayed due to water rights issues.
- We identified Basalt Vista as the alternative field pilot site and received generous support from Holy Cross Energy and Habitat for Humanity Roaring Fork Valley.
- Basalt Vista is an affordable housing community constructed for local schoolteachers. It has 12 duplex/triplex buildings with a total of 27 all-electric, net zero energy homes.

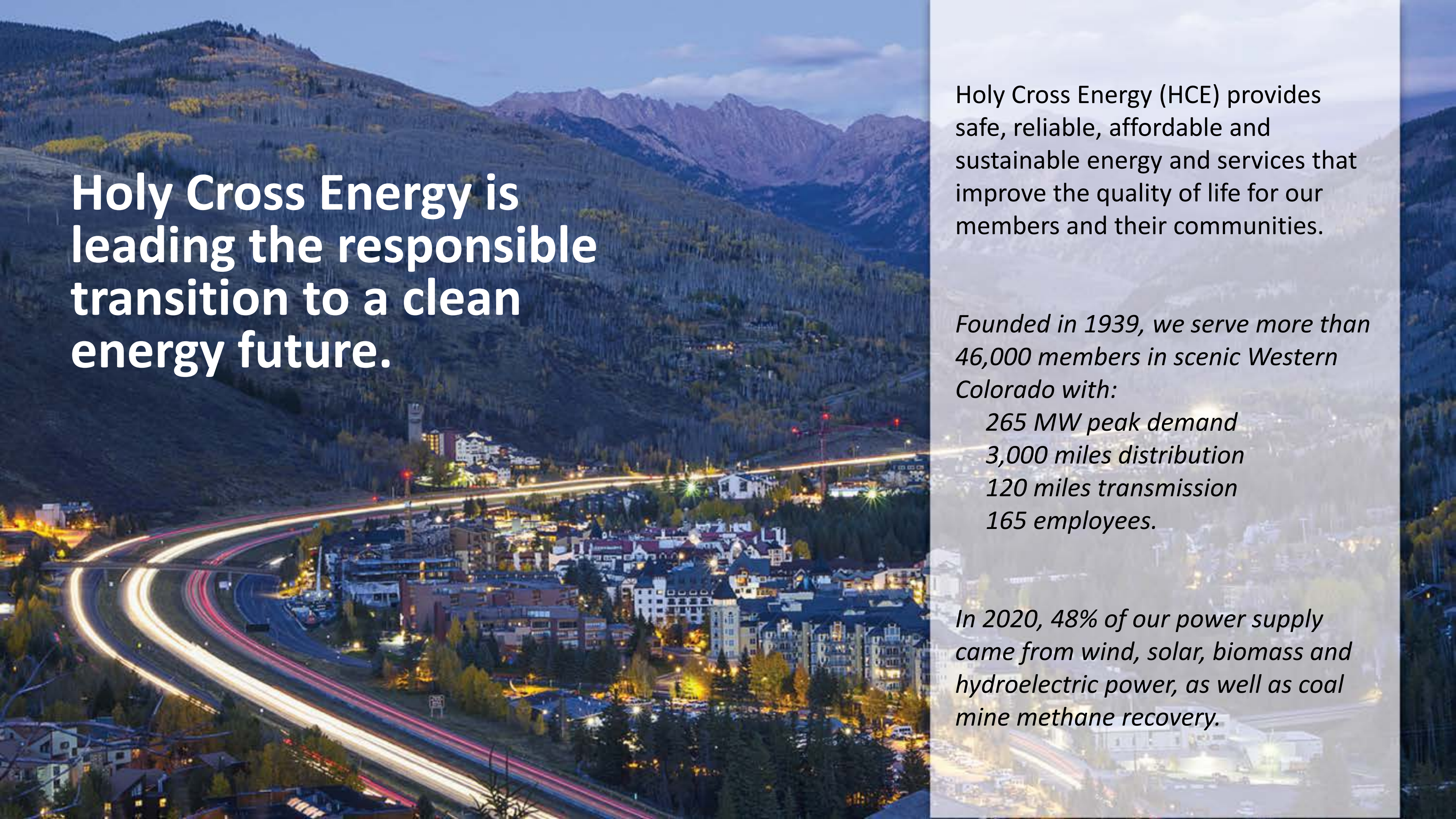
Cloud Deployment of HEMS and Aggregator for Field Pilot Study



*https://www.nrel.gov/docs/fy20osti/75414.pdf

Partner Presentations

Holy Cross Energy | Copper Labs | Conservation Labs



Holy Cross Energy is leading the responsible transition to a clean energy future.

Holy Cross Energy (HCE) provides safe, reliable, affordable and sustainable energy and services that improve the quality of life for our members and their communities.

Founded in 1939, we serve more than 46,000 members in scenic Western Colorado with:

265 MW peak demand
3,000 miles distribution
120 miles transmission
165 employees.

In 2020, 48% of our power supply came from wind, solar, biomass and hydroelectric power, as well as coal mine methane recovery.

Our "Journey to 100%"

These actions will allow HCE to achieve its vision of

100% carbon-free power supply by 2030

Carbon-neutral or better across the enterprise by 2035

in a way that does not sacrifice affordability, safety, or reliability for the sake of sustainability.

- **Energy Efficiency:** obtain an additional 0.25% per year of energy efficiency improvements
- **Cleaner Wholesale Power Supply:** incorporate new, clean, dispatchable resources into HCE's power supply mix
- **Local Clean Energy Resources:** continue our existing agreements for energy from local biomass, hydro, solar, and coal mine methane projects
- **Distributed Energy Resources:** support installation of at least 2 MW per year of new rooftop solar and battery storage
- **Smart Electrification:** encourage the expanded use of electricity for transportation, building heating and cooling, and industrial processes

Live Learning Lab

Basalt Vista Affordable Housing Partnership

- Habitat for Humanity, Pitkin County, Basalt School District
- 27 homes for teachers and local workforces.
- 4 selected for field deployment
- Designed to ZNE building with all electric construction
- Adjacent to Basalt High School

HOLY CROSS ENERGY
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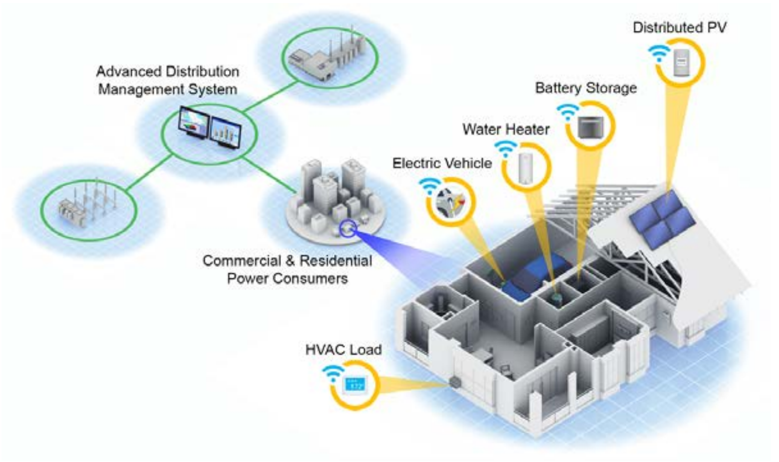
Basalt Vista Case Study 1: Optimal Power Flow (OPF)

Project Goal: Demonstrate the ability for a Distribution Utility to control and dispatch Distributed Energy Resources (DERs) to provide value to the grid as well as to the individual consumer.



- Microgrid controllers coupled with DER
  - Flexible
  - VPP at All Levels
    - Feeder, Community or Individual Buildings
- ADMS: Simple Management and Visibility of DER
- Studied High Penetration of DERs
- Interoperability of different "Systems"
- Market Operations with Smart Inverters
  - VVO, generation/load balance, contingency reserves, Freq response, Flex reserves
- Resilience

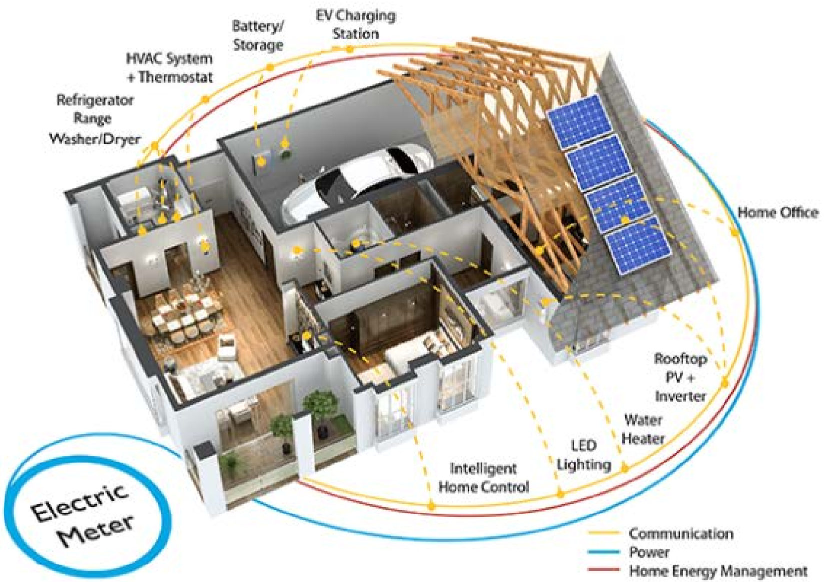
Project Team:

- National Renewable Energy Laboratory
- U.S. Department of Energy
- Holy Cross Energy
- National Rural Electric Cooperative Association
- University of Colorado Boulder
- Survalent
- Heila

Basalt Vista Case Study 2: HEMS Foresee

Project Goal: Demonstrate the ability for a Home Energy Management System (HEMS) to dispatch. Distributed Energy Resources (DERs) to provide value to the grid as well as to the individual consumer.

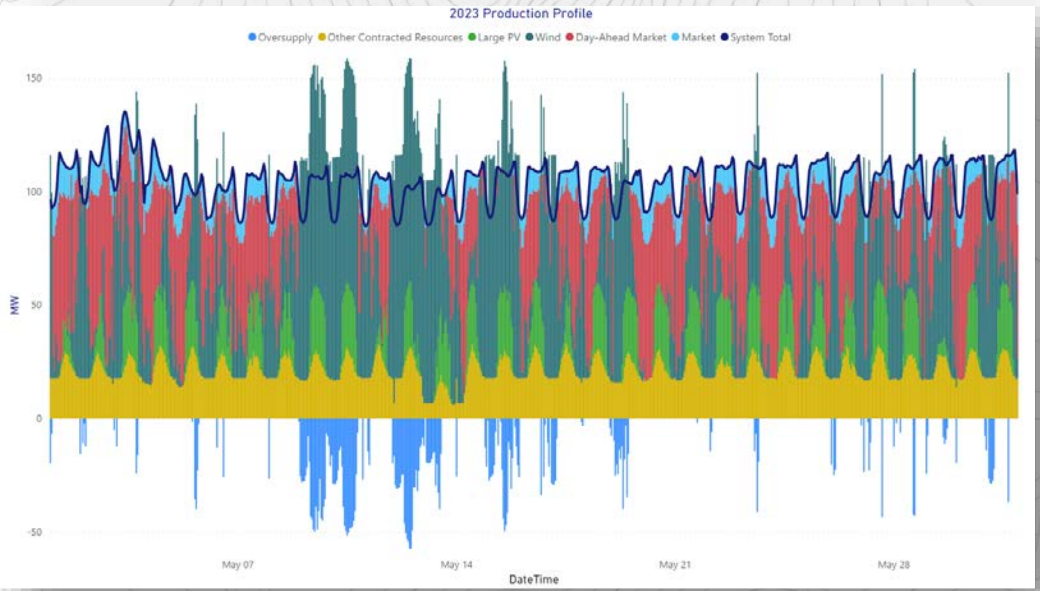
- HEMs coupled with DER
  - Flexible
  - VPP at All Levels
    - Feeder, Community or Individual Buildings
- Adds homeowners' input and preferences
- No ADMS needed creating a stronger layer of security between DERs and System Operations
- Interoperability of different "Systems"
- Forecasting of loads
- Simplified Building to Grid Integration



Load Flexibility – Why do we care?

Value Streams:

- **Capacity Costs** (need for peak demand reduction)
- **Renewable Oversupply** (need for balancing supply/load or load/supply)



Our Approach:

- **Member Option to Control –** Dynamic rates are messaged to participants to provide voluntary price signals and incentives to member's that exercise control over their own DERs and/or usage.
- **HCE Option to Control –** HCE offers a bill credit in exchange for the member giving HCE operational control over the DER.
- **Cover installation costs -** A Service Agreement helps members overcome investment hurdles and repay the DER installation cost to HCE over time.

Fostering DERs for Grid Flexibility

2018

Charge at Home
Free EV home charger and an optional EVSE Rider that allow on-bill payments for the installation cost.

2018

Basalt Vista House Project
An all-electric affordable housing project to demonstrate the value of DER to consumers and the grid.

2018

Time of Day Rate
An optional rate structure to encourage load shifting. Tailored for DCFC and Transit.

- **24c/kWh on-peak (4-9 pm)**
- **6c/kWh off-peak**

2019

Distribution Flexibility Tariff (DFT)
Created an on-bill credit to allow HCE to manage behind-the-meter DER assets.

2019

DER Service Agreement
Expanded the EVSE Rider to allow for a broader application of the tariff-based (service agreement) financing model.

2019

Peak Time Payback & Green Up
Launched programs that pay members for a measured reduction or increase in usage compared with their baseline during a limited number of demand response event hours.

2020

Camus Energy
HCE begins effort on a Zero Carbon Grid Orchestration combining system visibility with DER signaling.

2021

Power+
Combines DER Service Agreement and DFT to offer members a new resilience option using Battery Energy Storage Systems with a 5MW goal.

copper

Wireless Real-Time Energy Management

Dan Forman | CEO
dan@copperlabs.com

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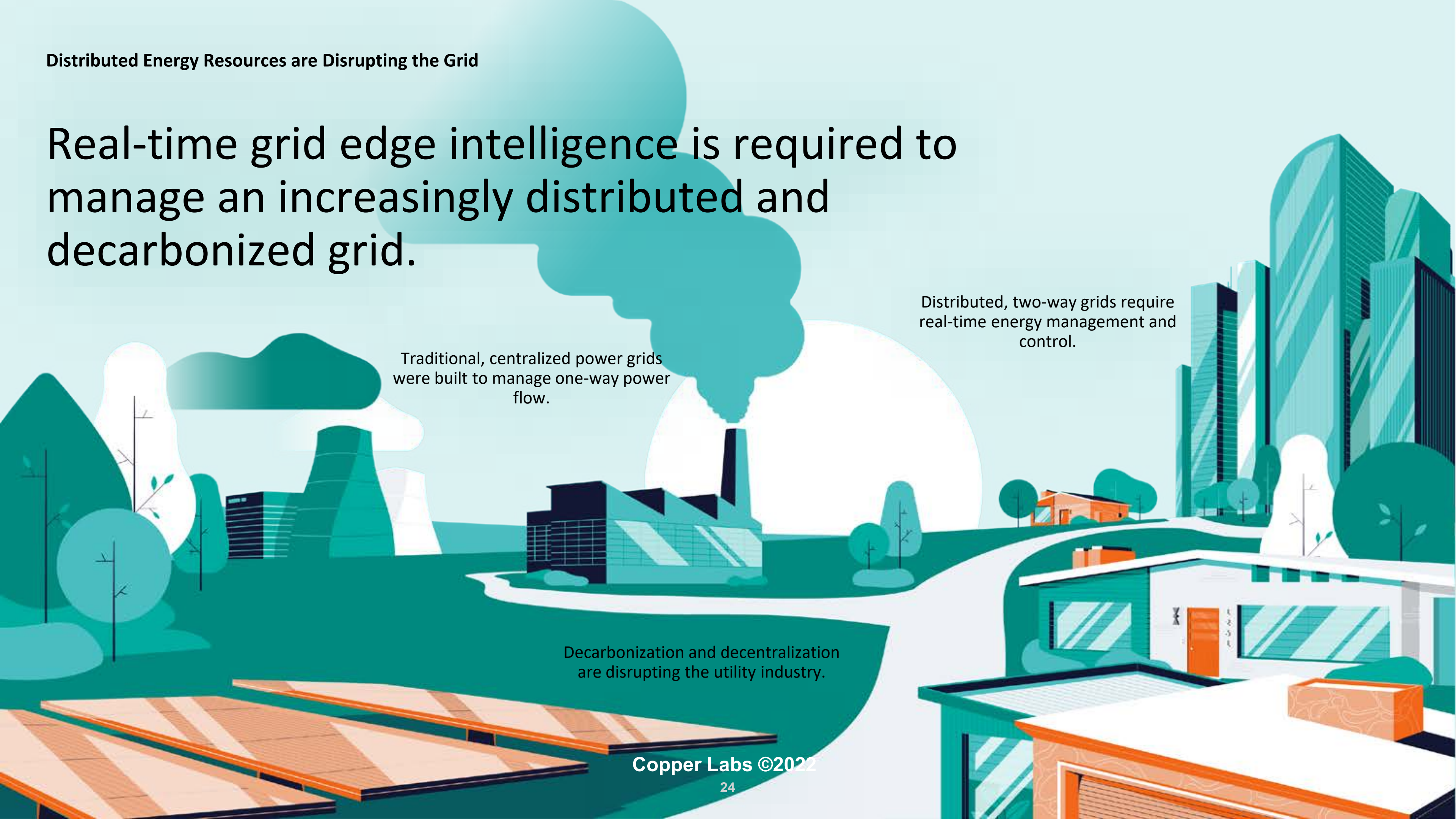
Real-time grid edge intelligence is required to manage an increasingly distributed and decarbonized grid.



Copper delivers real-time electric, gas and water meter data, with or without smart meters.

Utility Data Access: 30-second interval
Consumer Data Access: 30-second interval
Customer Engagement: targeted, real-time
Grid Edge Intelligence: real-time voltage and frequency

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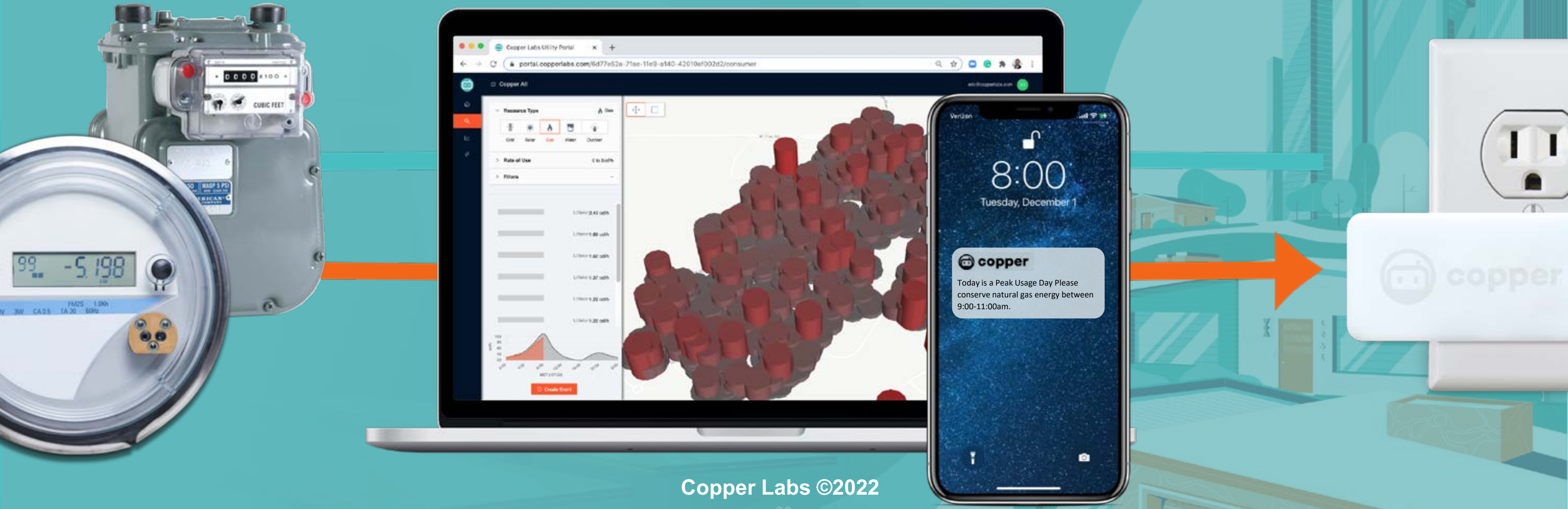
Real-Time Demand Management

Personalized recommendations driven by real-time meter data accelerate consumer engagement in demand management programs.



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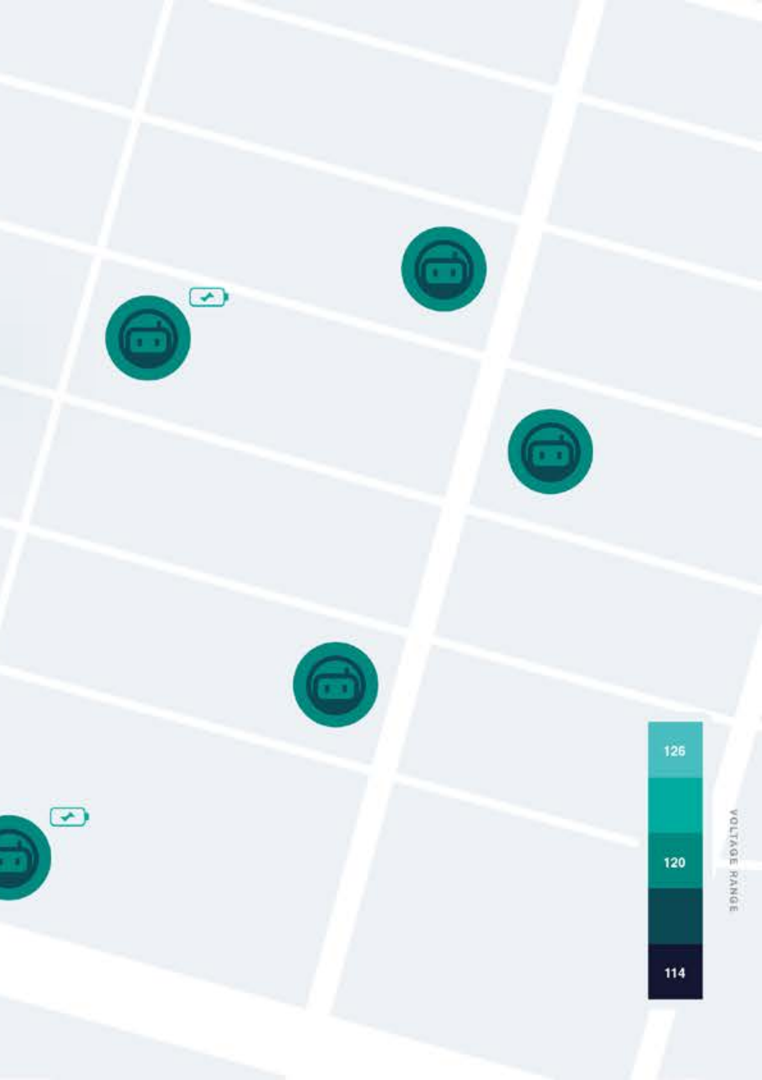
Real-time energy and voltage data deliver the grid edge intelligence needed to balance DERs at scale.

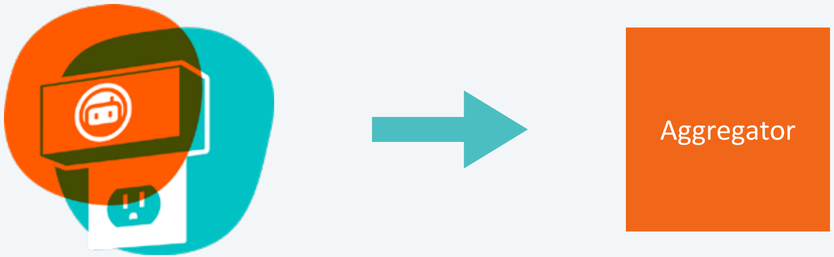
Integrated grid edge intelligence and coordinated DER management help stabilize the grid.

Holy Cross Energy uses Copper's real-time voltage data to integrate DERs while decarbonizing their grid.



Copper wireless energy monitors were installed in each of the pilot homes.

The devices wirelessly collected whole-home energy usage data, and service transformer voltage detection at the outlet level, that was then delivered to the Aggregator.



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NREL
NATIONAL RENEWABLE ENERGY LABORATORY

copper

Wireless Real-Time Energy Management

Dan Forman | CEO
dan@copperlabs.com

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About Conservation Labs

Cost-effective and sustainable water use

- Conservation Labs is a mission-oriented company with a team that is not only passionate about helping the environment but also helping people
- We are a team of data scientists and engineers that averages over 20 years of experience; ranging from work with startups, the government, and global brands
- One of our bold goals is to digitize the globes water use and make a measurable impact to sustainability, energy, and carbon emissions
- We are extending the technology to create more sustainable buildings by optimizing buildings systems

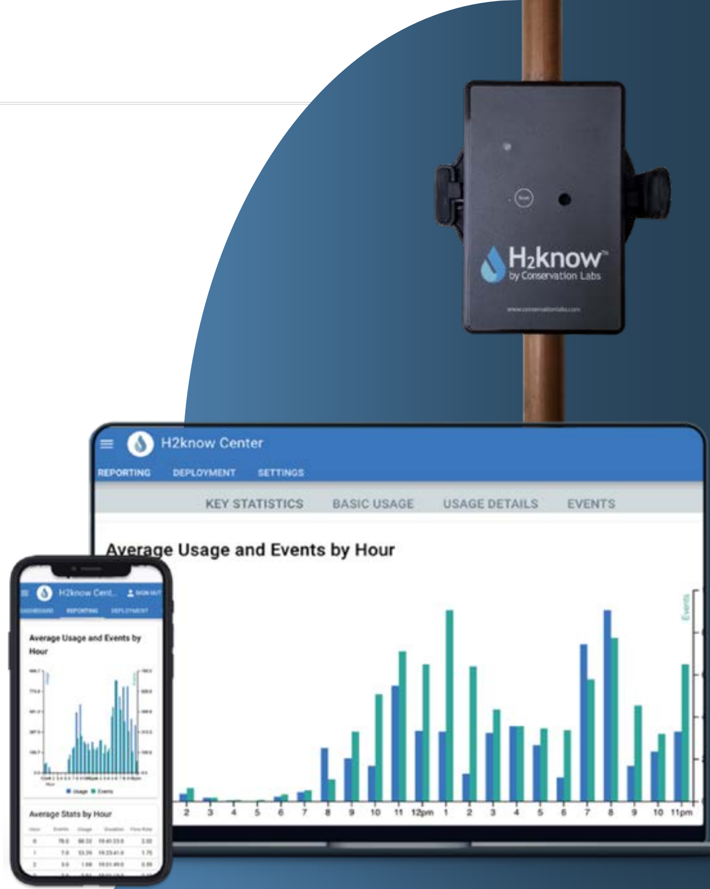
H2know Technology

Smart water technology for connected properties

We invented a way to make **a small, simple microphone** understand water with **machine learning**

H2know by Conservation Labs delivers **water use estimates, actionable water insights, leak alerts, and custom conservation recommendations** with a low cost and easy to install sensor and app.

H2know attaches on a main water line and requires **less than ten minutes to install.** No plumber is required, no special tools are required



H2know Technology

Smart water technology for connected properties

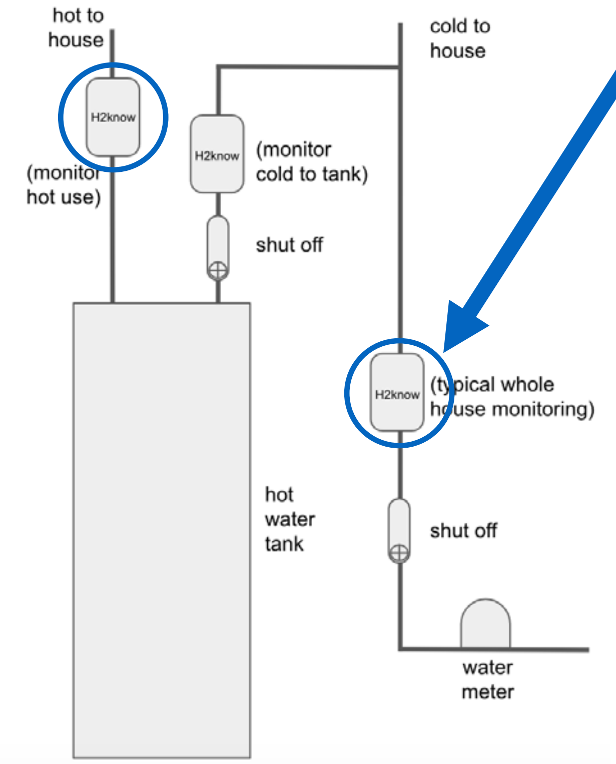
Estimate the water flow every second (e.g., GPM) and calculate the gallons used for every water event

Classify every water event (e.g., fixture, toilet, shower)

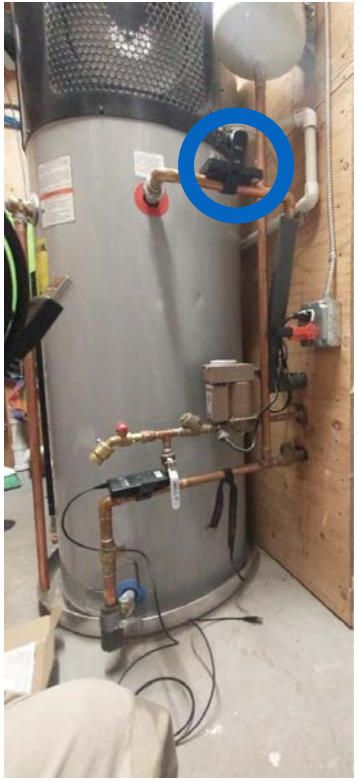
Identify and prevent costly leaks from small to catastrophic

Estimate hot versus cold water use

H2know Technology



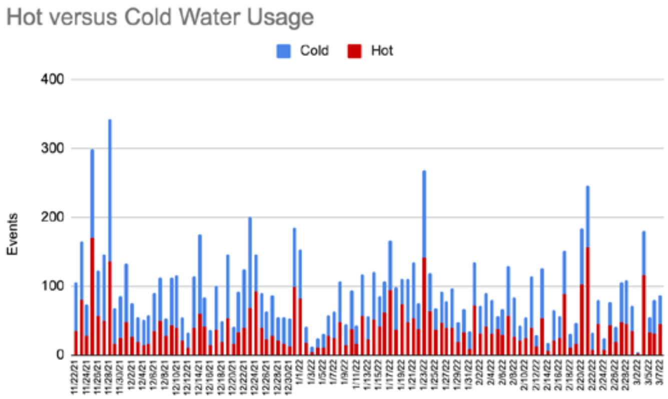
- Typical installation is on the main line after the water meter.
- To assess H2know for monitoring hot water use, two additional sensors were installed.
- The optimal sensors for this use case is two, one on the main and one on the hot to house.
- A future version of H2know may assess both hot and cold use from a single sensor on the main

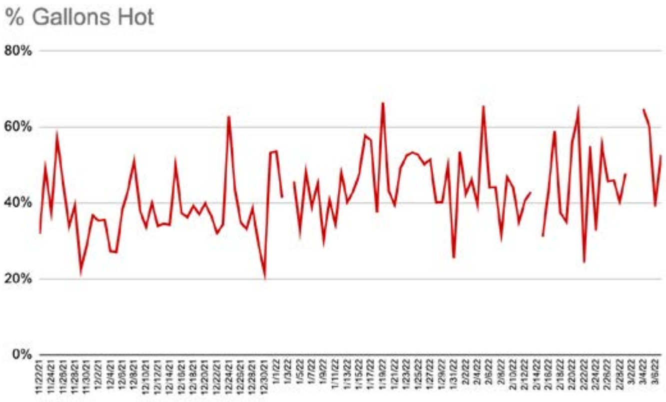


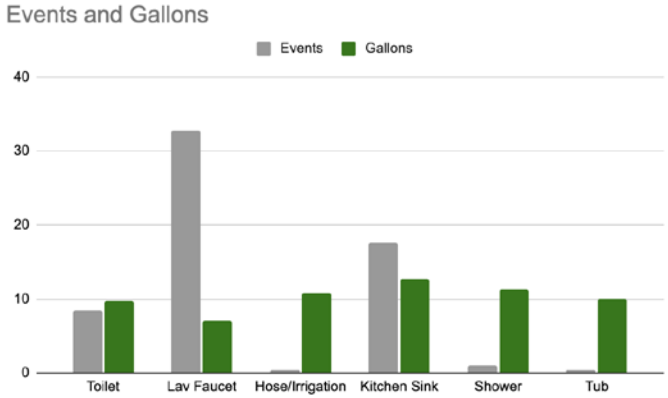
Understanding Hot Water Use - Example Home

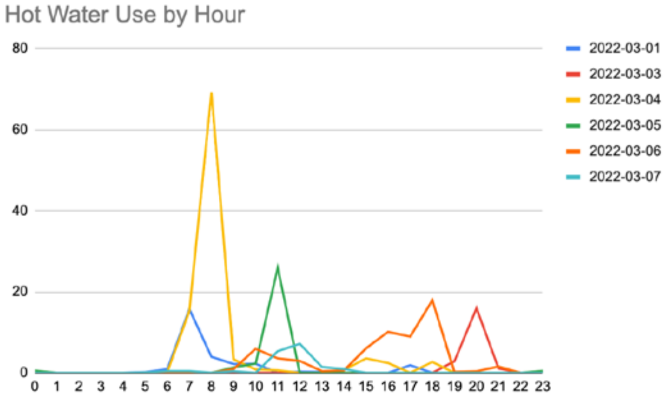
Data from 11/22 to 3/7 for a single household

- Average daily hot water use is from 22% to 66% of total use with an average of 42%.
- Drivers of hot water use include number of people in the household and distribution of fixture use.
- Hourly hot water use can vary significantly by time of day





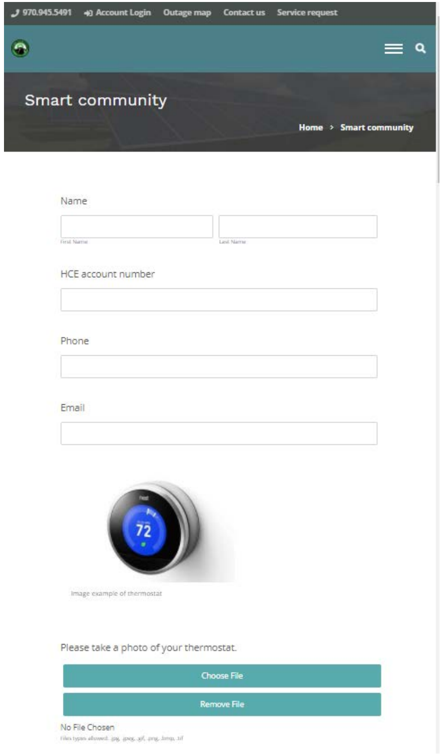




Field Pilot Results and Lessons Learned

Field Pilot Participant Recruitment

Recruitment flyer



Sign-up webpage

- NREL worked closely with Habitat for Humanity and HCE to recruit field pilot participants.
- NREL presented the field deployment plan at the Basalt Vista HOA Board meeting in June 2021, and the recording was shared with homeowners on YouTube.
- The Habitat staff met with homeowners in person and sent out reminder emails to encourage them to sign up.
- HCE received six applications, and four homes submitted final written confirmation.

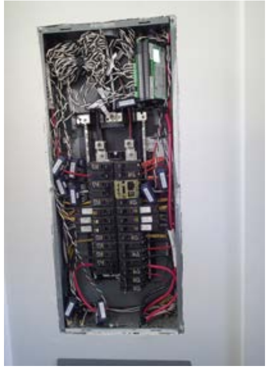
Field Deployment at Basalt Vista

Home #	1	2	3	4
Construction Phase	Phase 1	Phase 1	Phase 2	Phase 2
Building Type	2-bedroom duplex	2-bedroom duplex	3-bedroom duplex	3-bedroom duplex
Thermostat	Ecobee	Generic	Generic	Generic
Water Heater	A.O. Smith HPWH	A.O. Smith HPWH	A.O. Smith HPWH	A.O. Smith HPWH
PV Inverter	Two 5-kW SMA inverters	Two 5-kW SMA inverters	Solar Edge HD wave inverter (7.6 kW)	Solar Edge HD wave inverter (7.6 kW)
Battery	Blue Ion	Blue Ion	No	No
Distribution Transformer	Transformer #1	Transformer #1	Transformer #2	Transformer #2

Photo credit: Anna Stonehouse
Habitat for Humanity Roaring Fork Valley

Field Deployment at Basalt Vista

Exterior



Electrical panel with current transformers

Utility meters and Copper gateway

A.O Smith heat pump water heater

Ecobee thermostat

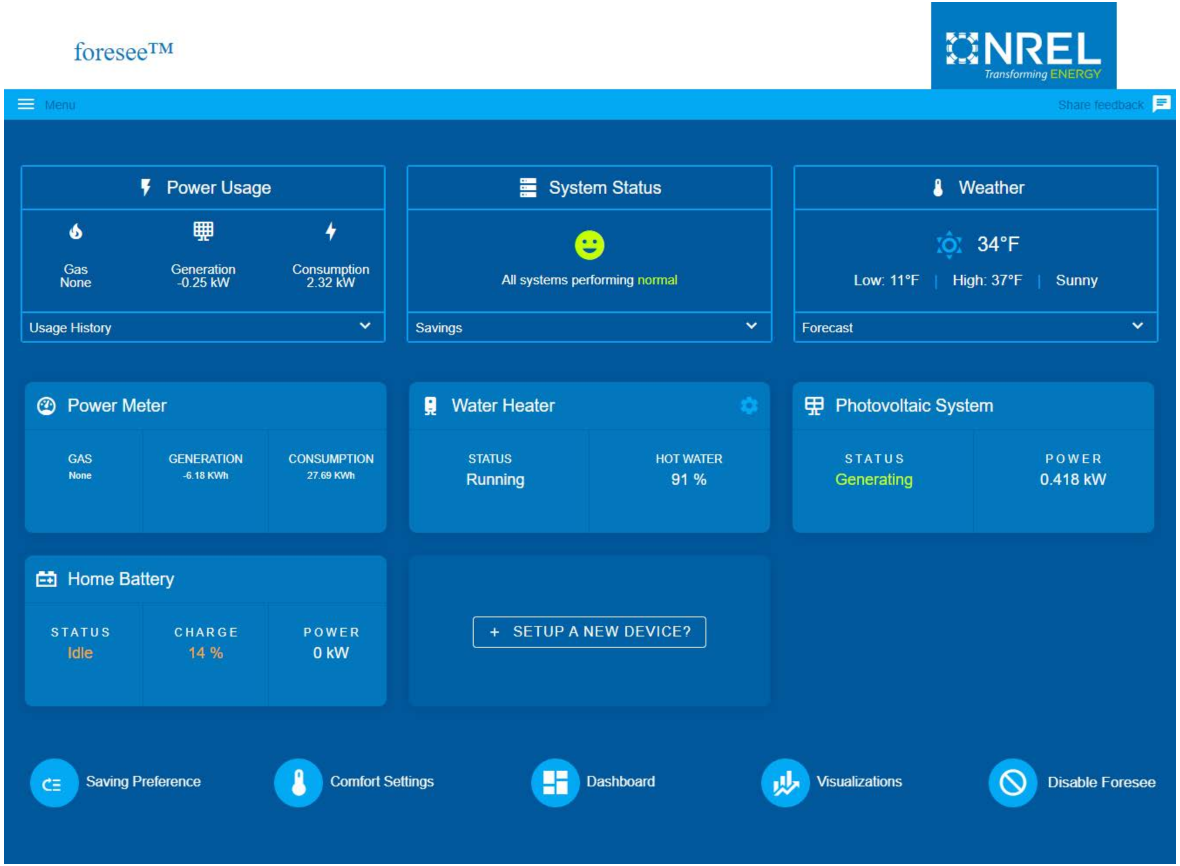
SMA Sunny Boy PV inverters

SMA Sunny Island battery inverter

H_2know water flow sensor

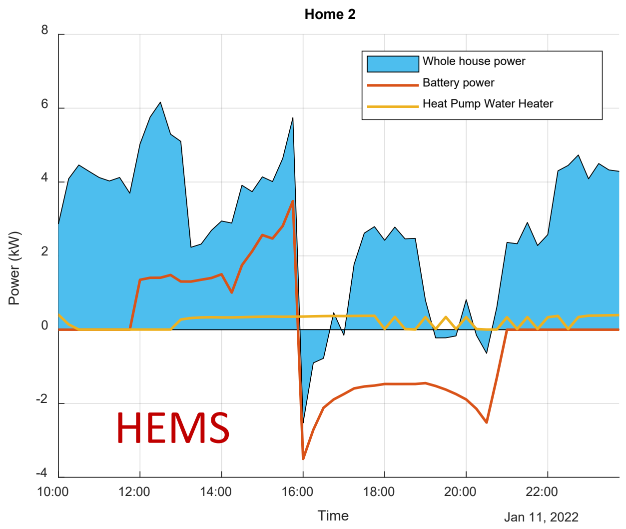
Communication box and service transformer

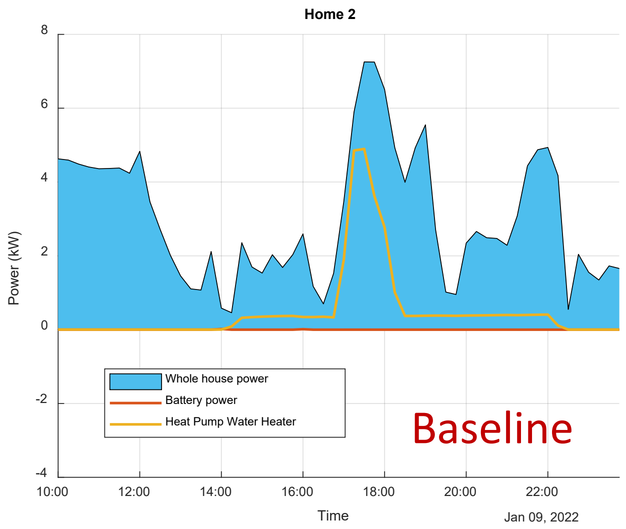
foresee™ HEMS for Managing Behind-the-Meter Assets



- The hierarchical control system (foresee + aggregator) was deployed on the NREL-managed Amazon Web Services platform.
- A homeowner-facing user interface was developed for homeowners to monitor the home status and control certain devices.
- Homeowners can access the web-based user interface on https://foresee.nrel.gov/ with their log in credentials.

Field Experiment Results – Home 2





- Experiments were implemented to demonstrate the load shifting capabilities.
- Holy Cross Energy's time-of-use rate with 4 pm–9 pm peak period was used in the experiment.
- A 3.1 kW average load reduction and 4.5 kW peak demand reduction were achieved during the 5-hour peak period.
- The home battery provided significant load reduction along with the heat pump water heater, whereas the heat pump did not contribute much to the load reduction due to the consideration of thermal comfort.

Week-Long Experiment – Home 2

- The control system operated autonomously for a week, demonstrating its robustness in the real-world environment
- The battery system charged during off-peak and discharged during peak on each day to provide homeowners with utility bill savings

Week-Long Experiment – Aggregator

Note:
There are two horizontal axes (top and bottom) for the foresee control week and the normal (no control) week.

Average reduction: 4.65 kWh / day during peak pricing period

- The aggregator was activated to coordinate the homes and reduce the peak load while ensuring HEMS priorities.
- Peak load was shifted away from the peak pricing period on most days.
- The **foresee** HEMS tried to balance between individual home's optimal strategy (e.g., charging batteries, pre-heating building, etc.) and aggregator objectives (e.g., reducing peak load).

Lessons Learned

1. Community partnership is key to successful recruitment
2. Dedicated personnel with site access is crucial for fixing unexpected issues
3. A reconnaissance trip would help derisk the field deployment
4. Homeowner’s internet is reliable for cloud communication most of the time
5. Anticipate the need for occasional power cycling – smart plugs can help
6. Snow covering on the solar panels greatly affects the PV generation
7. Tradeoff between grid control and homeowner satisfaction

Achievements

Award

- Best Technical Presentation Award, 15th International Conference on Energy Sustainablility (ES2021), June 2021

Recognition

- DOE recently selected a portfolio of "Connected Community" projects in varying climates, geographies, building types, and building vintages with varying uses of DER and other coordinate control technologies in a landscape of different utility, grid, or regulatory structures and resource bases.
- Our project has been featured on DOE's website as one of the early pilots of connected communities: https://connectedcommunities.lbl.gov/projects/ai-driven-smart-community-control-accelerating-pv-adoption-and-enhancing-grid-resilience

News Release/Media Report

- Colorado Mountain Homes Prepare To Pilot Autonomous Energy Management, NREL News, Nov 1, 2021.
- NREL to evaluate AI energy management system for solar microgrid, PV Magazine, Nov 11, 2021.
- NREL pilots new AI-enabled Smart Community concept in Colorado, Smart Energy International, Nov 4, 2021.
- Virtual Power Plants And The Future Ubiquity Of Energy Creation, Forbes, Nov 24, 2020.

Achievements

Journal Articles

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Conclusions

- We developed and demonstrated a scalable control system for managing the behind-the-meter loads and distributed energy resources
- Results from laboratory and field experiments showed the control system can effectively reduce potential overvoltages and improve grid resilience
- Lessons learned from this project can directly benefit future field deployment in residential communities
- Future work may include incorporating decarbonization in the objective function, islanded operation, and commercialization with industry partners.

Thank You

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