2024 PROJECT PEER REVIEW

U.S. DEPARTMENT OF ENERGY
BUILDING TECHNOLOGIES OFFICE

BTO Peer Review: Alfalfa

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Alfalfa

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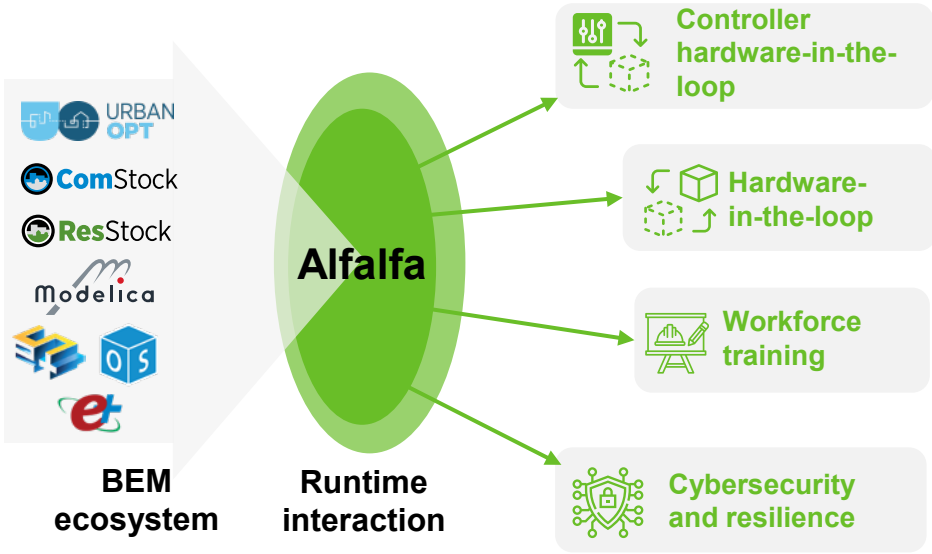
WBS 3.2.6.71

Project Summary

OBJECTIVE, OUTCOME, & IMPACT

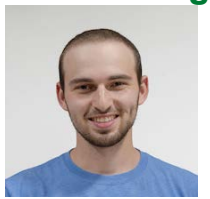
Alfalfa-based testbeds enable building equipment, control products, and workforce development tools to interact with dynamic building simulations representing the desired building, system, weather, and grid configuration. Alfalfa is used to de-risk implementation of load flexibility prior to field deployment, reducing the costs and timelines associated with adoption of decarbonization technology at the grid edge.



TEAM & PARTNERS

National Renewable Energy Laboratory

Anya Petersen



Tobias Shapinsky

Lauren Klun

STATS

Performance Period: 10/2022-ongoing

DOE Budget: $500k, Cost Share: $0

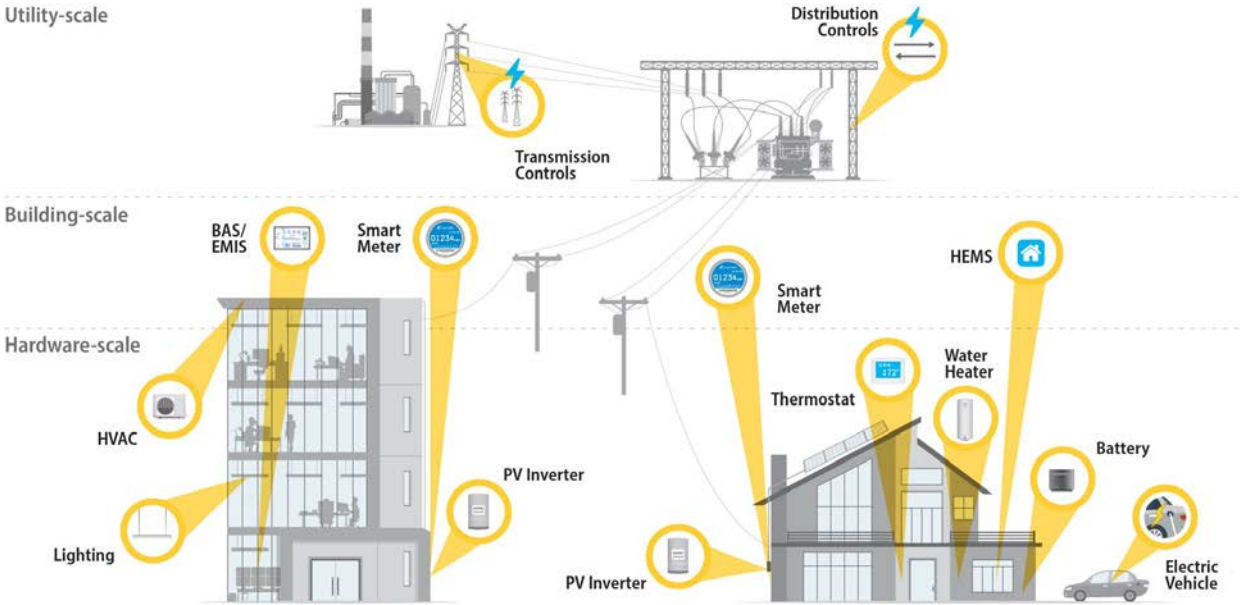
Milestone 1: Worker updates to abstract job types

Milestone 2: Alignment with BOPTEST

Milestone 3: Alfalfa Release (0.7.1)

Buildings Play an Increasingly Active Role in Complex Energy Systems

As energy delivery becomes increasingly **distributed**, **interconnected**, and **digitized**, building energy modeling (BEM) can be a powerful **stand-in for real buildings** to accelerate technology development, mitigate control integration risks, and train the workforce of the future.



Examples of BEM Standing In for Real Buildings

Controller Hardware-in-the-Loop (CHIL)

Control products can be deployed to **improve energy efficiency** and **avoid costly updates to grid infrastructure**. CHIL enables hands-on integration of third-party control products under realistic conditions to **surface and resolve technical challenges prior to field**.

Hardware-in-the-Loop (HIL)

Advancements in **refrigeration technology and thermal energy storage can reduce onsite carbon emissions in buildings.** Laboratory evaluation of equipment performance in varied installation and integration conditions **accelerates the market entry of products that commercialize these innovative technologies.**

Examples of BEM Standing In for Real Buildings

Workforce Training

The integration of distributed energy resources and control systems in buildings is **reshaping their operational and maintenance requirements**. BEM-supported training stations offer a cost-effective solution for workers to acquire hands-on experience, ensuring **equitable access to the skills required for these new jobs**.

Cybersecurity and Resilience

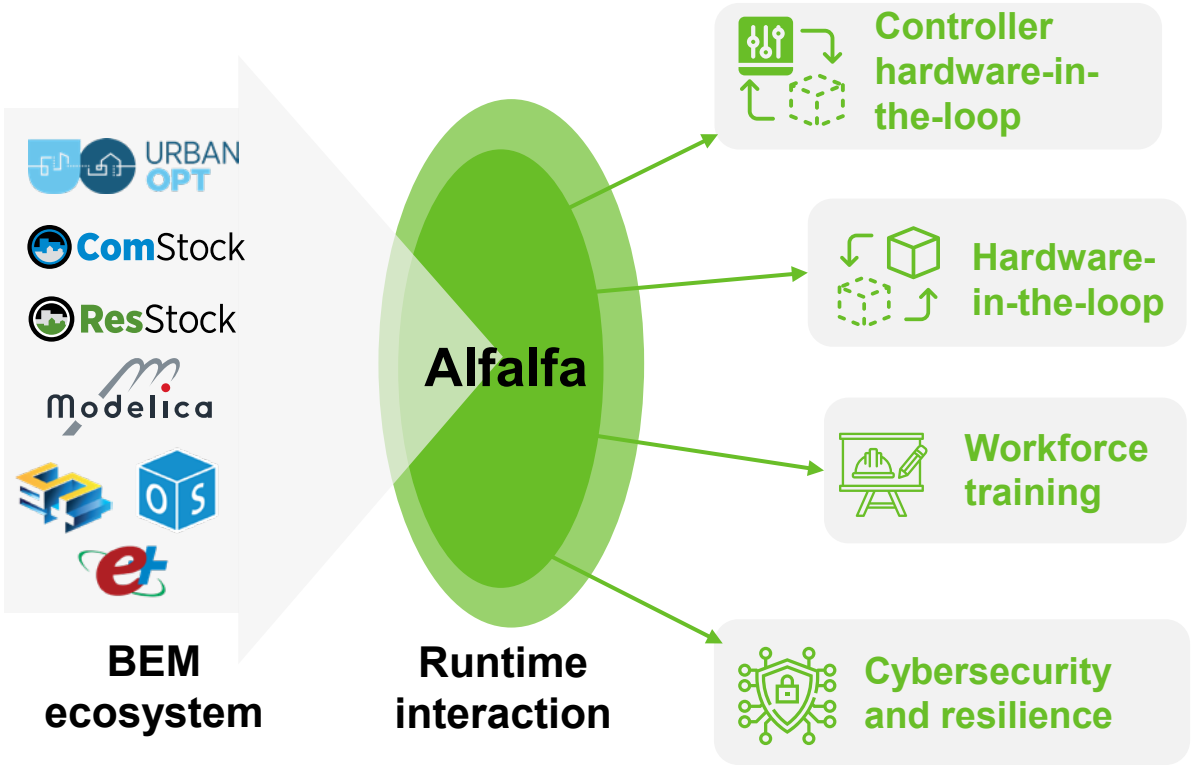
The deployment of **connected devices and controls increases the attack surface for cyber threats**. By evaluating device- and system-level vulnerabilities across various cyberattack scenarios, we can **enhance the security, privacy, and resilience of our communities** through improved solutions.

New Applications of BEM Bring New Integration Requirements

Traditionally, BEM has focused on offline analysis: run the simulation for x years, then analyze results.

Dynamic runtime interaction is a core requirement of many potential applications of BEM to the energy transition.

By making it easy to run and interact with BEM, we can **reduce cost and technical barriers** to utilizing BEM for these new applications.



Project Delivery and Impact

The Alfalfa project maintains the **open-source** components necessary to **cost-effectively** utilize the BEM ecosystem for **hardware integrations**, **control test beds** and **operator training tools:**

- Scalable **virtual building web service** that runs multiple modeling engines behind a unified API.
- Configuration files for automated deployment to **on-premise** and **cloud compute** providers.
- Modular integration code, including **BACnet** and Apache Kafka.
- Workflows to integrate **community-** and **urban-scale** modeling tools.

National Buildings Blueprint Alignment

Alfalfa enables the testing of **hardware** and **control system integration** under **realistic dynamic scenarios** prior to deployment to a site, **reducing project delays and costs**.

This testing is critical path to **cost-effective deployment of controls** to meet BTO's blueprint goal of "50% of all homes and businesses have automated control platforms that reduce energy waste and enable flexibility."

Testbeds built on Alfalfa support blueprint strategic objectives to **increase building energy efficiency** and **transform the grid edge at buildings** by enabling hardware-in-the-loop (HIL) and controller-hardware-in-the-loop (CHIL) approaches to the development and evaluation of technologies that improve efficiency and/or coordinate participation of building devices to provide grid services.

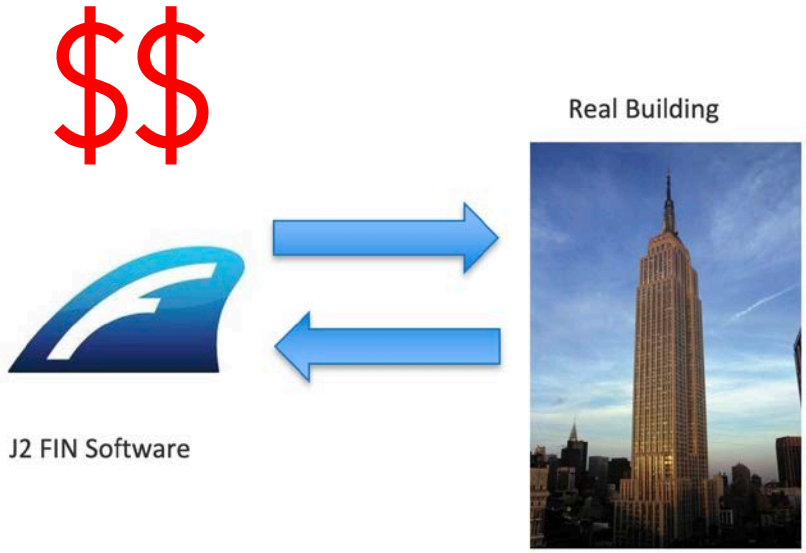
In **resilience** evaluations of communities under threat scenarios, Alfalfa is being used to identify **vulnerabilities** in device and system performance and to assess potential **social consequences** of outages, an important lens into the **equity** impacts of the energy transition.

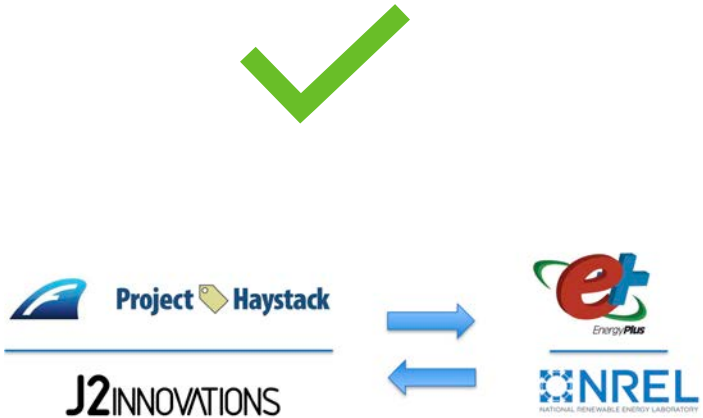
Alfalfa Makes it Easy To Run and Interact With BEMs as Virtual Buildings

- **Models run interactively in real time or faster—**virtual buildings should seamlessly replace real buildings for control and hardware interaction or quickly run multiple scenarios to inform operation.
- **Machine and automation friendly—**to simplify integration and automation, all interaction with BEMs should be over web APIs, with the messy details, including multiple modeling engines, handled “under the hood.”
- **Easy to deploy on most compute platforms—**AWS, Azure, Google Compute, Linux, Mac OS and Windows.
- **Unified API for many modeling engines—**for example, switch between OpenStudio and Modelica models without updating your integrations.
- **Scalable—**architecture and workflows should be designed to scale to thousands of parallel buildings.
- **Operational interfaces—**the mapping from model variables to the sensors and actuators of real-world operations should be automated where possible.

Alfalfa Origin #1 – Control Integration

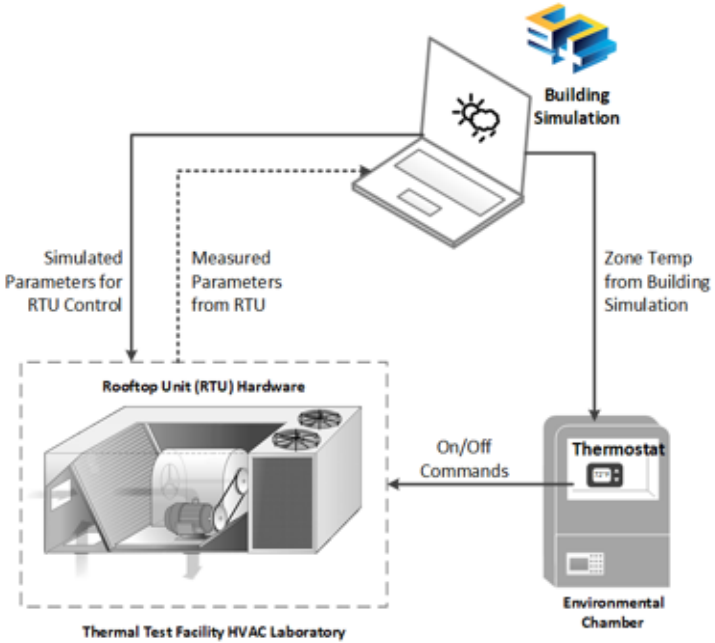
2018: NREL Evaluates Haystack-Based Command and Control Product for Startup J2 Innovations as Part of the Wells Fargo IN2 Incubator Program





Alfalfa Origin #2 - Hardware Integration

2019: NREL Expands Experimentation in Energy Systems Integration Facility (ESIF) With Commercial Buildings Research Infrastructure



Hardware-in-the-Loop (HIL): A technique that combines hardware and simulation in a continuous feedback loop to explore complex scenarios in a controlled environment.

Famous HIL example: Flight simulator.

HVAC HIL example: RTU hardware operated in a realistic fashion without the need for physical building and real climate.

Alfalfa is Simple and Intuitive

Abstracts the Repetitive, Error-Prone Tasks of Model Interaction

Example Usage

```
client = AlfalfaClient("https://alfalfa.nrel.gov")

run_id = client.submit("model_directory")

client.start(run_id,
             start_datetime=datetime(2020,1,1),
             end_datetime=datetime(2020,1,2),
             external_clock=False,
             timescale=1
             )

inputs = client.get_inputs(run_id)
outputs = client.get_outputs(run_id)

client.set_inputs(run_id,
                  {
                    "Heating Setpoint": 18,
                    "Cooling Setpoint": 24
                  })

client.stop(run_id)
```

1. Initialize Alfalfa Client
2. Submit model to Alfalfa
3. Start run
4. Get control points
5. Override setpoints
6. Stop run

Under the Hood

- A clean container image with dependencies pre-installed provides a stable platform for repeatable simulation results.
- Model interaction using open libraries
  - BCVTB/MLEP for EnergyPlus (moving to Python).
  - PyFMI for FMUs.
- A suite of tools to help modelers debug their models.
- Deployments can be scaled from a single researcher's computer running a couple workers to a cluster running hundreds.

Relationship to BOPTEST

Both Projects Offer Web APIs for Live Interaction With Simulation

Key **differences:**

- Alfalfa is a **foundational component** for BEM-interactive tools and not itself a user-facing application
  - No built-in models or performance benchmarking.
  - User community is smaller set of platform developers with DevOps and modeling expertise.
- Alfalfa supports **multiple modeling engines** that can be interchanged “under the hood”, without updating integrated systems.

The project teams are **collaborating:**

- Aligning on a **common API** for interoperable integrations.
- **Sharing** the Alfalfa **service architecture/approach.**
- **Sharing code** and experience.

Challenge: Choosing Models and Interpreting Results

Alfalfa makes the mechanics of BEM interaction easy, **but it does NOT offload energy modeling expertise** for application developers building on top of Alfalfa:

- The accuracy of any analysis is constrained by the accuracy of the underlying models.
- Mapping between simulation inputs and outputs and the sensors and actuators of operational interfaces can be time consuming.
- Other considerations include:
  - Supported time resolution
  - Realism of built-in control modeling
  - Supported sectors (residential, commercial, multifamily)
  - Availability of pre-built models
  - Learning curve

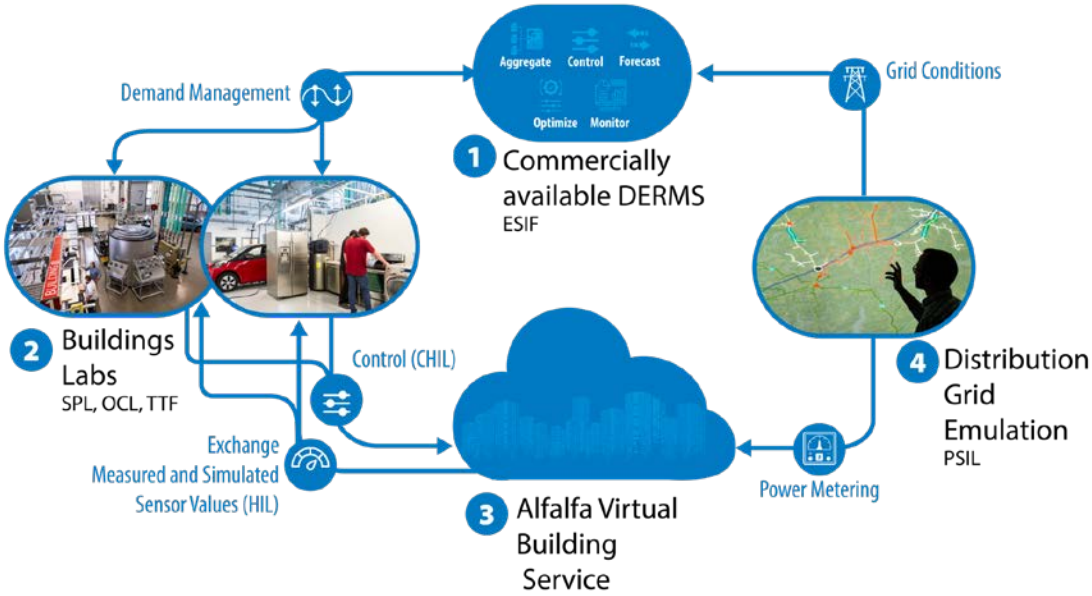
The Alfalfa project is developing resources to educate potential users and connect them with the best fit modeling resources for their application.

Challenge: Designing Control Testbeds for Nascent Space

There is **considerable variability** in the specifics—software, hardware, and communication protocols—of potential control toolchains **between utilities and building equipment**.

Alfalfa is designed as an ecosystem of **modular**, light weight components that can be combined as needed to de-risk realistic control toolchains prior to field deployment.

Example of Modular Alfalfa-Based Control Integration Testbed at NREL

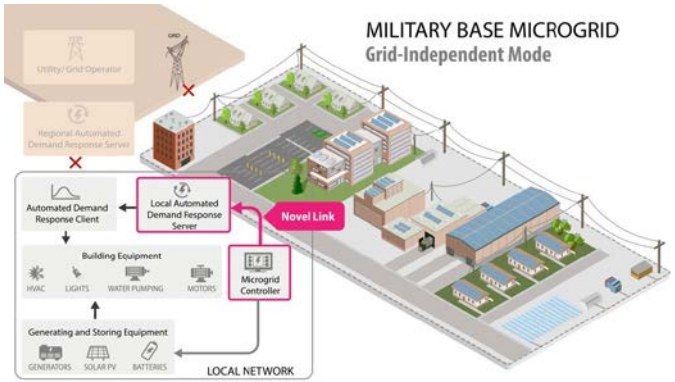


Delivered Software

2022-Present

- Updates to core Alfalfa web service (https://github.com/NREL/alfalfa)
  - Established ***continuous delivery***-based release process GitHub.com, used for 8 releases to date.
  - Significant updates to worker containers to support testbed-specific customization.
  - Dependency updates, improved error handling, performance tuning.
  - Documentation including usage tutorials and guides.
- Updated Python client (https://github.com/NREL/alfalfa-client) as preferred integration pathway.
- Kubernetes-based deployment resources (https://github.com/NREL/alfalfa-helm)
  - Supports deployment on premise and to AWS, Azure, and Google clouds.
  - Performance updates and benchmarking for 100 parallel buildings.
- BACnet support (https://github.com/nrel/alfalfa-bacnet-bridge)

Market Impact: Grid-Independent Military Microgrids



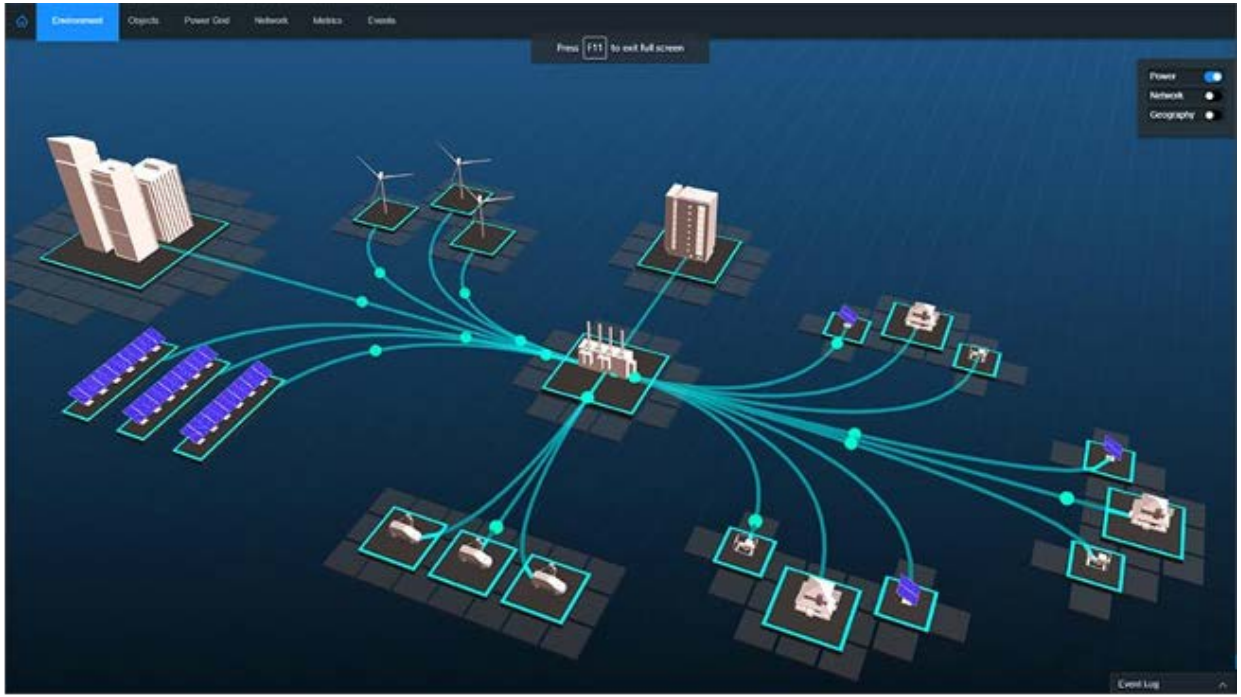
"S&C has collaborated with NREL on an ESTCP project that investigates the use of granular load shedding in islanded microgrids. This is one of several DOD-funded projects that S&C has done focusing on military microgrids.

"Before performing a site demonstration, we conducted laboratory tests to ensure all communications and system behavior were working as desired. These tests involved connecting the S&C GridMaster microgrid controller to virtual buildings running in Alfalfa and enabled us to run repeatable, interactive studies to validate our solution and to identify and fix issues before sending the equipment into the field.

"We believe this ability to test new technology prior to field deployment is a major benefit of Alfalfa and we hope to use it in the future for microgrid and smart grid projects..."

- **Peter Curtiss, Principal Consulting Engineer, S&C Electric Company**

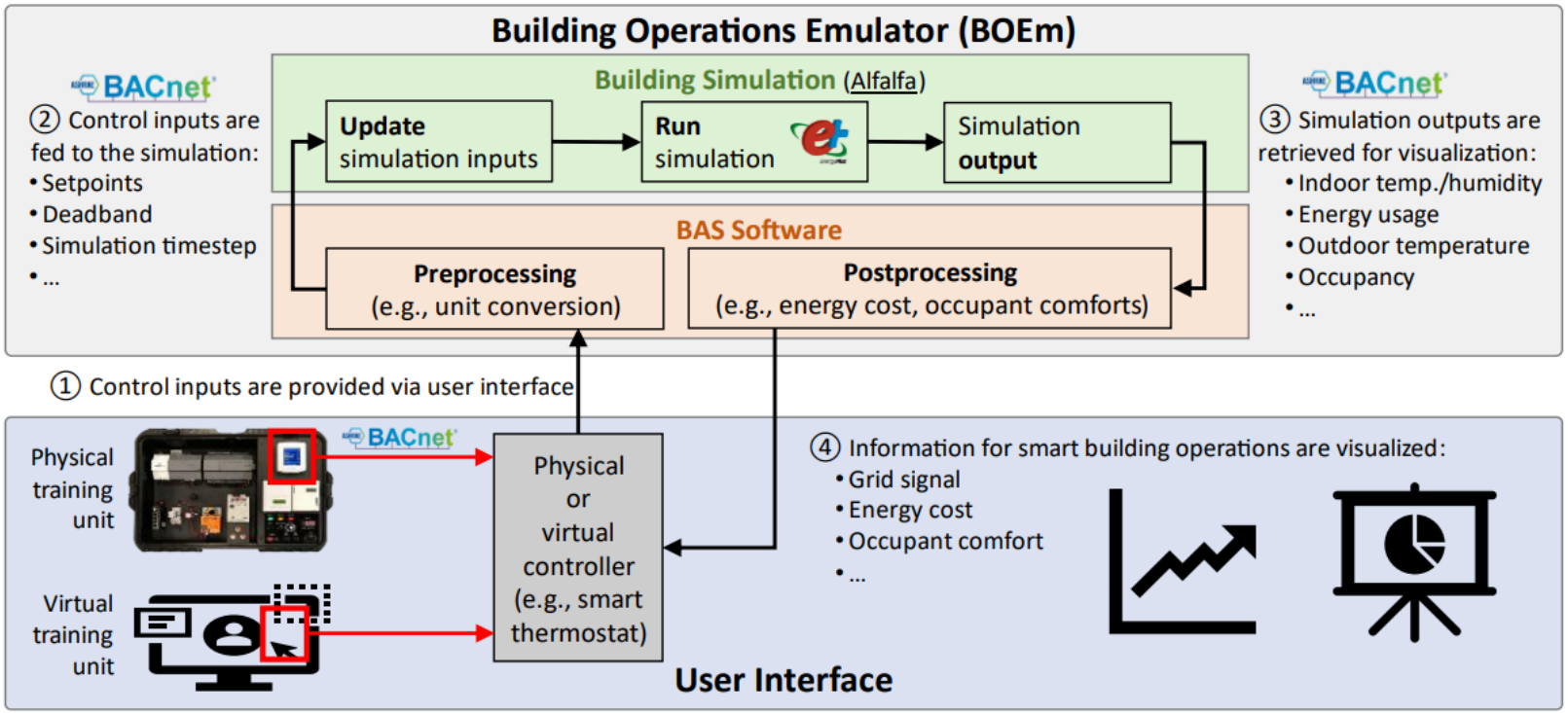
Market Impact: DER Cybersecurity



The DOE Office of Cybersecurity, Energy Security, and Emergency Response is leveraging BEM to understand the cyber risks and human impacts associated with behind-the-meter DER deployments.

Market Impact: Workforce Development

Alfalfa-Integrated Training stations—No NREL Performers



Northeastern University led development of BOEm, which recently won Best Research Paper at IBPSA-USA SimBuild 2024.
https://publications.ibpsa.org/proceedings/simbuild/2024/papers/simbuild2024_2126.pdf

Future Work

- 1.0.0 release of Alfalfa, including Python-based EnergyPlus interaction.
- Improved EnergyPlus/OpenStudio workflows for modelers developing Alfalfa measures.
- Maintain and improve alignment with BTO investments that include:
  - Controls Product Performance Evaluation and Reporting (CoPPER): expected to utilize Alfalfa.
  - BOPTEST: API, codebase, and experience sharing.
  - ResStock, ComStock, URBANopt: sources of representative communities of virtual buildings.
  - Standard Energy Efficiency Data (SEED) Platform: model calibration resource for specific commercial buildings.
- Continued stakeholder engagement and collaboration beyond BTO.

Thank you

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Reference Slides

Project Execution

Planned Budget	$190,000				$106,000				$225,000			
Spent Budget	$196,000				$105,000				FYTD Aug: $141,000			
	FY2022				FY2023				FY2024			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Past Work												
Worker updates to abstract job type example implementing BOPtest job type												
API updates to streamline integration and real-time communication												
Resources for deployment to cloud compute services and updates to support horizontal scaling												
Characterize the deployments including a comparison of Alfalfa 3.0 and 4.0.												
Progress Report												
Demonstrate scale of 100 buildings in real-time.												
Annual report of lab work that utilized Alfalfa.												
Current Work												
Alignment with BOPTEST												
Draft Publication												
Release of Alfalfa												
Annual report of lab work that utilized Alfalfa.												
Go / No-Go Decisions:												
Alfalfa successfully runs and captures experiment data for 100 buildings.												
Successful release of Alfalfa with at least one major improvement.												

Team

Alfalfa has a small core team and a much larger network of collaborators and stakeholders.

Anya Petersen

NREL

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Software Engineering Lead

Lauren Klun

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Project Manager

Kyle Benne

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