## PNNL RESULTS TO DATE

| Experiment | Progress (as of December 2016) |
|---|---|
| Passive and Active Diagnostics | Implemented in 10 PNNL buildings, results indicate the algorithms have been successful in identifying faults in building operations. Deployment of active algorithms and expansion of the tools are planned for additional buildings. |
| Intelligent Load Control | Implemented in three PNNL buildings, controlling the operation of multiple heat pumps serving offices and other work spaces. Test results demonstrate that when building energy consumption peaked at different times during the day—such as the first thing in the morning —ILC quickly prioritized heat pump operations, shutting down some units while running others. The approach successfully dropped demand to meet an established consumption limit while maintaining occupant comfort within an acceptable range. ILC will be expanded to three other buildings for testing. |
| Transactive Control and Coordination of Building Energy Loads | Deployed in a PNNL building's AHU; results have confirmed the ability of this method to achieve experiment objectives. Plans call for expanding this control to other buildings. |
| Integration of Distributed Renewable Energy Resources | Results show that control methods can command a supply fan to track solar production and adjust accordingly, while keeping occupant comfort levels within an acceptable range. |

## ABOUT PNNL

Interdisciplinary teams at Pacific Northwest National Laboratory address many of America's most pressing issues in energy, the environment and national security through advances in basic and applied science. Founded in 1965, PNNL employs more than 4,000 staff and has an annual budget of approximately $1 billion. It is managed by Battelle for the U.S. Department of Energy's Office of Science.

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U.S. DEPARTMENT OF ENERGY

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PNNL RESEARCH FOR A TRANSACTIVE ENERGY FUTURE

# Clean Energy and Transactive Campus Project

Pacific Northwest National Laboratory, through its involvement in the Clean Energy and Transactive Campus Project (CETC), is helping the U.S. Department of Energy drive a new energy vision for the nation. In this vision, leading-edge control technologies seamlessly engage America's buildings, power system and renewable energy resources. The result is improved "transactive" coordination and control of energy supply and demand that will:

- deliver improved energy efficiency
- increase the capacity of buildings to host distributed energy resources and provide flexibility for the grid
- reduce building operating costs.

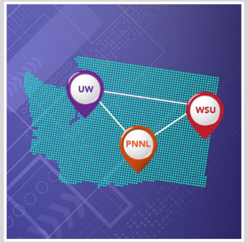
A key CETC enabling technology is the VOLTTRON™ distributed sensing and control software platform. Developed by researchers at PNNL, VOLTTRON™ securely collects, analyzes and converts growing data streams from energy-related devices and systems in today's buildings into actionable information. This leads to new control and management methods for buildings and the grid.

The CETC partners are pursuing unique but interconnected experiments focused on achieving outcomes in two primary areas: building efficiency and grid reliability. PNNL's four experiments and their focuses are:

- Passive and Active Diagnostics - building efficiency
- Intelligent Load Control - grid reliability
- Transactive Control and Coordination of Building Energy Loads - grid reliability
- Integration of Distributed Renewable Energy Resources - grid reliability.

Additionally, PNNL is providing overall project coordination and establishing a network infrastructure to connect the three participating campuses. PNNL's experiments and results are described in more detail on pages 2-4.

## CETC: A SNAPSHOT




- **Key Objectives:** Create a blueprint to replicate and scale up transactive control methodologies for application in buildings, campuses and communities across the nation; establish a clean energy and responsive building load research and development infrastructure in Washington State.
- **Participants:** Pacific Northwest National Laboratory, the University of Washington (UW) and Washington State University (WSU)
  - PNNL focus: Implementation and testing of control technologies in multiple PNNL buildings; development of a network to connect the three partner sites and experiments
  - UW focus: Control of campus solar panels and onsite energy storage, and application of data analytics to enhance transactive control of building loads
  - WSU focus: Integration of solar energy and storage with Pullman, Wash., and WSU microgrid; development of strategies to share energy between WSU building loads and solar modules
- Funded jointly by the U.S. Department of Energy and Washington State Department of Commerce
- Project started in 2016

U.S. DEPARTMENT OF ENERGY

# PNNL EXPERIMENTS

## Passive and Active Diagnostics for Building Efficiency

Buildings consume a significant portion of the nation's energy, and in many cases do so inefficiently. This experiment tests and validates the effectiveness of automated passive and active diagnostic algorithms that initiate and run tests in buildings. These actions are intended to identify equipment issues, correct problems and ultimately improve building operations and energy efficiency. The algorithms are being deployed, via VOLTTRON™, in PNNL buildings.

The experiment involves use of

» PNNL's passive—"detection only"—diagnostic algorithm that identifies operational faults; this capability will be deployed in buildings with automation systems that manage many different devices, such as lights and heating/cooling.

» An active diagnostic algorithm that seeks out operational issues and implements control actions to correct problems. The algorithm will be used in buildings with either minimal control infrastructure or automation systems.

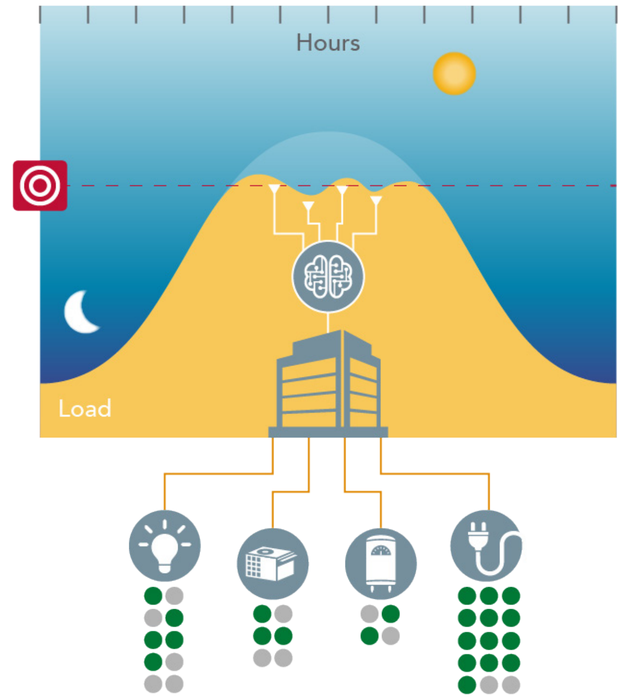
» A unique set of passive automated diagnostics that will be deployed in a single PNNL building that does not possess an automation system.

Both real-time and historical data will be used to validate and quantify the impact of these diagnostic tools. The research will inform efforts to scale this approach for broader deployment.

## Intelligent Load Control (ILC)

ILC involves the use of VOLTTRON™ with PNNL-developed algorithms to manage peak electricity loads in buildings, while concurrently maintaining occupant comfort. To accomplish this, ILC draws upon a method known as the Analytic Hierarchy Process (AHP), which prioritizes control actions for optimal results, applying both qualitative and quantitative rules. Use of AHP, for example, can help determine whether shutting down or turning on heat pumps in a certain sequence will achieve optimum energy efficiency.

Researchers believe ILC can be a key transactive energy resource. Their goal is to make the approach easy to configure and scale to other buildings with different types of end uses and, ultimately, to enable management of large numbers of buildings using this methodology.



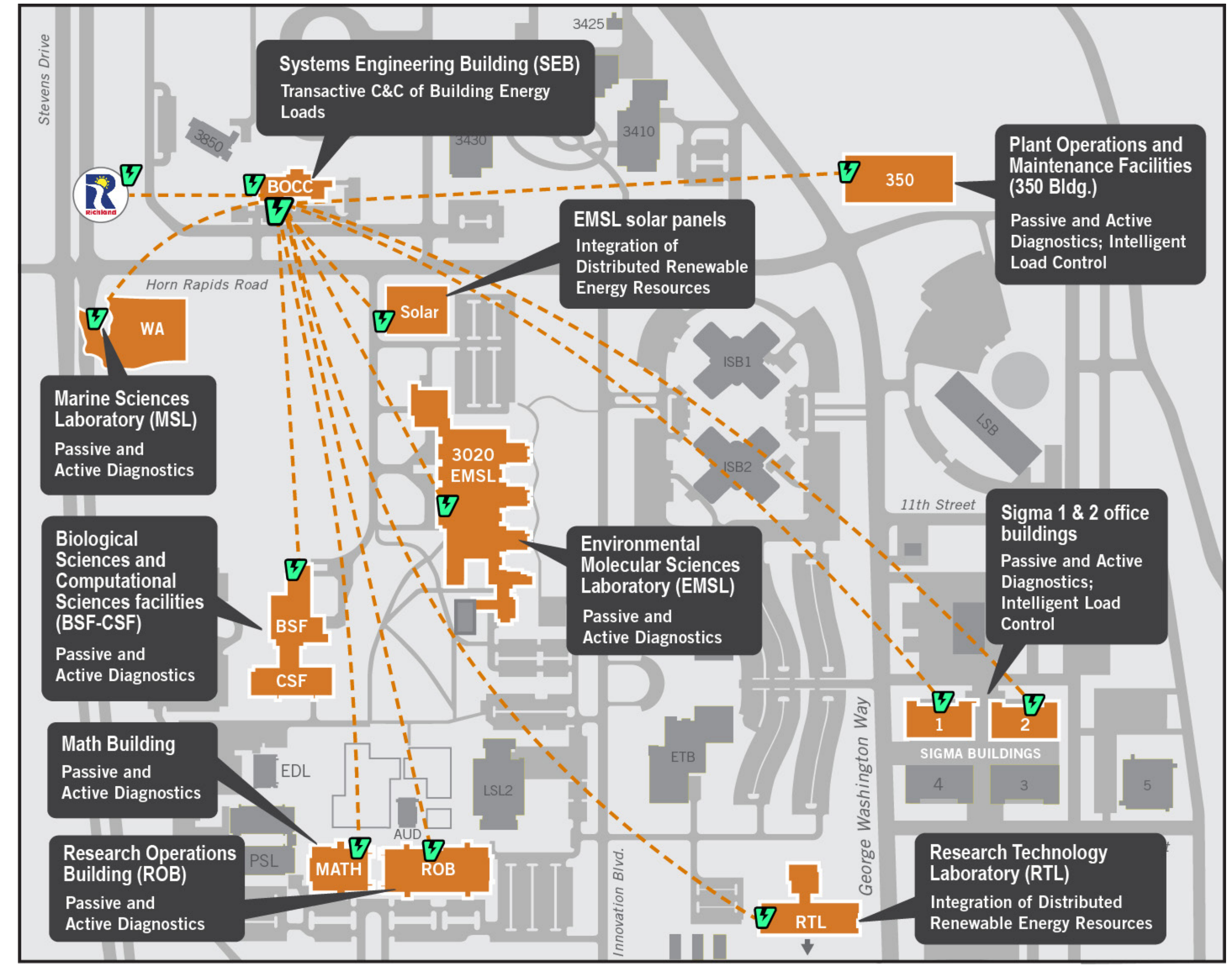

Intelligent Load Control is the "brain" behind coordination of building functions, such as lighting, heating and cooling, to adjust peak power loads and meet consumption targets. As illustrated in this graphic, ILC automatically prioritizes functions, turning them on (green dots) and off in a sequence that reduces power consumption, while concurrently making sure occupants remain comfortable.

## Transactive Control and Coordination of Building Energy Loads

This experiment uses the VOLTTRON™ platform to essentially create markets within different building zones and devices as part of an automated, real-time process. For example, an air handling unit (AHU) obtains electricity at a certain cost and then sells its product—cool air—to zones within the building that electronically "bid" on the cooling capacity based on price and desired occupant comfort levels.

Under this approach, the AHU or other controllable loads, such as water heaters, respond to a price-temperature curve that essentially relates the current energy price to the predetermined comfort expectations of building occupants. The curve influences AHUs to either reduce power load to balance cost and comfort objectives, or in cases of abundant, economical electricity, perhaps increase consumption to perform tasks in advance, such as pre-cooling a building.

For initial testing, researchers will use a utility-originated flat price to establish the transactive control energy price. Later, a dynamic signal will be used to simulate the price, supply and demand fluctuations one might expect in real-time interactions between buildings and the power grid in a transactive energy ecosystem.




At PNNL, CETC experiments are occurring in a number of buildings. VOLTTRON™, represented by the green "v" icons, gathers building data and sends it to the Building Operations Control Center (BOCC), where campus building operations are monitored. The BOCC is located in the Systems Engineering Building.

## Integration of Distributed Renewable Energy Resources

Large-scale use of clean, renewable energy is highly desirable, but the intermittent nature of these distributed energy resources can have a disruptive impact on the power grid.

One area of concern involves buildings that use photovoltaic (solar) panels for supplementary power. When clouds appear and solar generation drops, the grid must make up the subsequent power loss. PNNL's experiment initially looks at a short-term (several minutes) response to generation losses, but also may explore long-term (several hours or more) approaches. In both cases, the focus is on managing building power consumption to make up for reduced generation and ease fluctuation impacts on the grid.

The experiment specifically seeks to control building loads such as variable-frequency-drives on fans in AHUs and packaged rooftop units (RTUs) to absorb generation loss. In concert with VOLTTRON™, an algorithm tracks signals from solar generation and the power system, analyzes resulting data, and quickly adjusts fan speed to reduce or increase power consumption. In addition to fans, controllers could be developed for other types of loads, such as water heaters, pool pumps and electric vehicles.

The University of Washington and Washington State University will augment the knowledge gained from this experiment through their study and use of distributed renewable energy resources, including photovoltaic arrays, dynamically controlled inverters and onsite storage.