Clean Energy and Transactive Campus Project (CETC)

2017 Building Technologies Office Peer Review

The Spokesman-Review

SUNDAY, APRIL 3, 2016

J Thomas Ranken: Innovative energy project could generate jobs

J. Thomas Ranken

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William Boeing incorporated the Boeing Airplane Co. in 1916. That moment sparked 100 years of Washington state leading the world in aviation innovation.

Multiple industries have experienced similar moments. In 1979, Bill Gates moved Microsoft from Albuquerque to Washington state. In 1984, Starbucks served its first Caffè Latte. In 1994, Jeff Bezos left New York to start Amazon.

Energy might well be the state's next Boeing moment. Companies like Avista, Itron and Schweitzer Engineering Laboratories have made significant strides in energy generation, transmission and efficiency over the past decade. Now, three research titans are working to advance the nexus where all three meet.

Pacific Northwest National Laboratory, Washington State University and the University of Washington have partnered on a two-year demonstration project to pilot transactive energy management across three campus locations.

Buildings in Pullman, Richland and Seattle will communicate seamlessly to manage energy production and consumption 300 miles apart. High energy generation on one campus will be used to offset high

MOST RECEN
GUEST OPINI

Views mixed on religion, rights

J Thomas Ranken: Innovative
project could generate jobs

Johnson: Caucus satisfies polit
craving

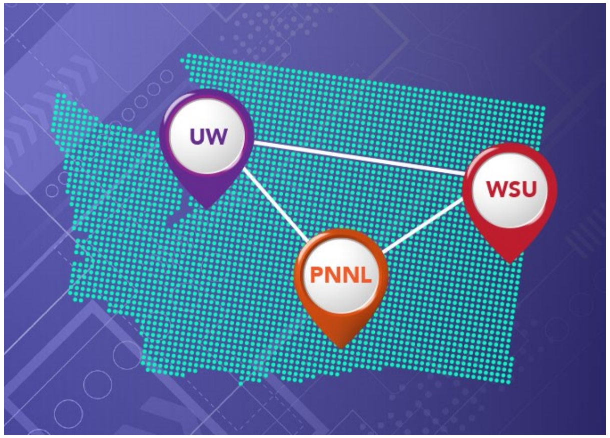
Michael Senske: TPP paves wa
growth at home

Regina Malveaux: Extreme risk
orders are crucial

Something wicked

MOST
COMMENTED
GUEST OPINI

Michael Senske: TPP paves wa
growth at home



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Project Summary

Timeline:

Start Date: August 2015

Planned End Date: 2018

Key Milestones:

1. Preliminary report of transactive controls on PNNL campus project (9/30/16)
2. Development and testing of "max-tech" controls complete (9/30/17)
3. Testing and validation of multiple-campus experiment complete (12/31/18)

Budget:

Total Project $ to Date (including cost-share): $2.885M (FY15/16); $6.707M (FY17)

Total Overall Project $ (including cost-share): $9.592M + TBD

Key Partners:

Pacific Northwest National Laboratory (PNNL)
University of Washington (UW)
Washington State University (WSU)

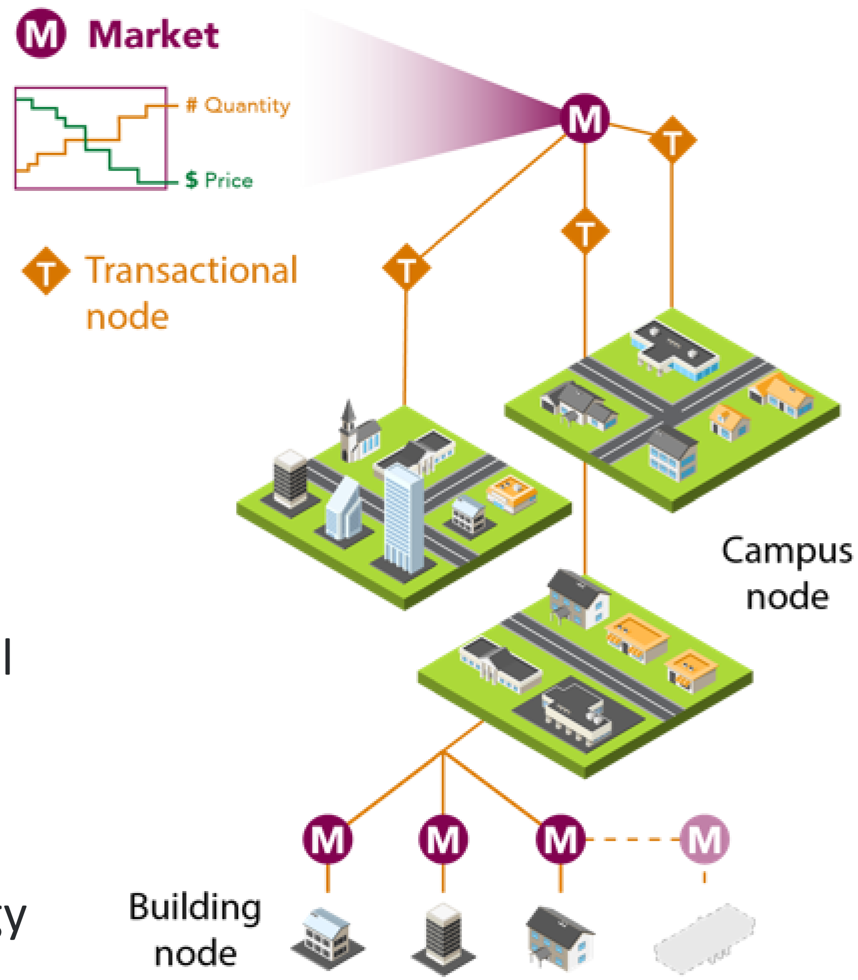
Project Goal:

- Create a "recipe" to replicate and scale up transactive control technologies 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

Purpose and Objectives

Problem Statement: Transactive control (TC) technologies provide a viable solution for coordinating responsive building loads and distributed energy resources, benefiting energy efficiency and power grid reliability objectives

- Must be tested in realistic situations
- Must develop approach that enables a single building, sets of buildings, or entire communities to readily adopt them



Target Market: All commercial and residential buildings ~40 Quads

Target Audience: Utilities considering deploying transactive energy concepts, energy service providers deploying TCs in buildings, any campus that wants to deploy TCs

Project Objective: Goals and Solution

- **The goals of the CETC span EERE programs, yet the common dominator is the buildings' role as outlined in the Transaction Based Controls Reference Guide (Volume 1 and 2)**
  - A. **BEYOND DEMAND RESPONSE** – enable buildings, fleets of equipment, and other building assets to deliver services to the grid while maximizing energy efficiency (EE)

    "How can we control equipment within a distribution feeder to deliver valuable services to the owners and operators of buildings and the grid simultaneously?"
  - B. **GRID SCALE, RIGHT SIZED STORAGE** – enable buildings to function as "virtual" storage devices to reduce the total capacity of grid storage needed to meet the needs of a utility

    "How can we utilize building loads and control of equipment to lessen the physical storage we need to maintain grid reliability?"
  - C. **BEHIND THE METER RESPONSE TO PV** – lessen, dampen, and otherwise minimize the effects of building and distributed PV as seen by the utility

    "How can we utilize groups of loads and buildings to make site installed PV appear as a non-variable generation source to the utility?"
- **First campus-scale demonstration in the nation in which ideas to address these goals are being deployed, measured, and tested, as well as exposing them to researchers, faculty, staff, and students**
  - *The project's outcome is to create a recipe for replication of transactive equipment, buildings, campuses, districts, and fleets in real-life as utilities, municipals, and building owners are facing larger deployments of clean energy technologies, aging infrastructure, and new regulations*

Purpose and Objectives: Impact of Project

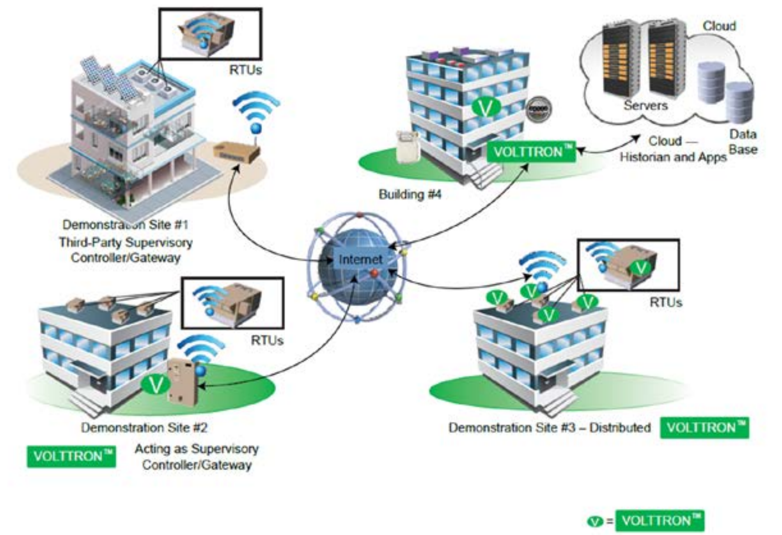
- CETC will provide tools that enable the buildings sector to replicate the project’s technology implementations and methods, leading to **improved energy efficiency**, **increased integration of renewable energy, and enhanced power grid reliability**
- **Outcomes of the project include**:
  - **Short-term (immediate)**: Development, validation, and release of open source energy efficiency and transactive control software tools compatible with VOLTTRON™; associated technical documentation and user guides that will comprise the “recipe” and enable replication
  - **Medium-term (<3 years)**: Two or more energy service providers deploying the software tools to benefit buildings and the grid
  - **Long-term (>3 years):** One or more utilities deploying transactive energy concepts at a distribution scale

Approach

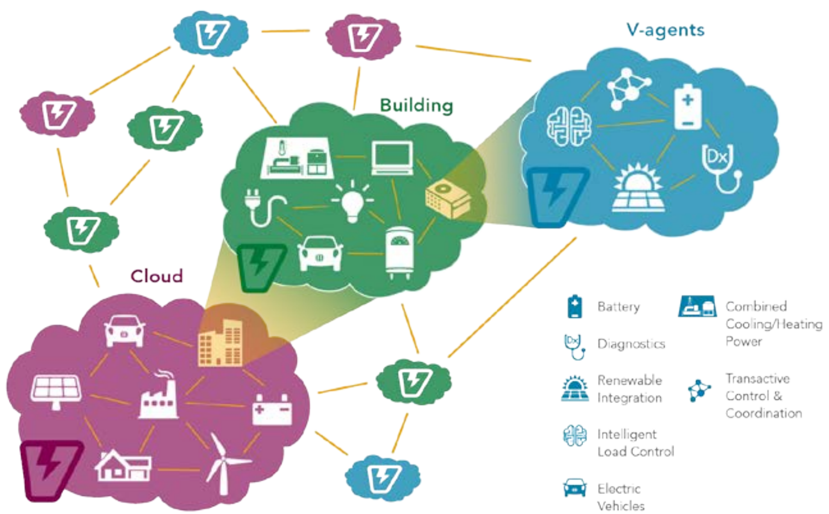
- PNNL:
  - tests and validates transactive methodologies via experiments on the PNNL campus in multiple buildings
  - produces user guides for broader implementation
- UW:
  - acquires battery energy storage system (BESS) and adds inverters to solar arrays to test the coordination of campus assets
  - develops methods to optimize charge/discharge cycles of BESS using transactive signals
  - develops methods for converting the project's building data to actionable information
- WSU:
  - develops a testbed to examine transactive control strategies for a campus-scale/city-scale micro-grid, incorporating new solar arrays and access to a utility's grid-scale battery
  - develops resiliency strategies
  - develops bilateral energy trading concept using block-chain technology

Approach: Key Issues

- Develop and demonstrate transactive control technologies that improve building performance, management of building power loads, renewable energy integration, grid operations, cost, and efficiency

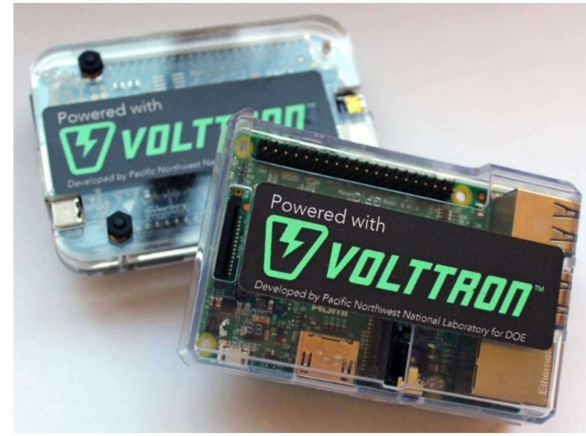


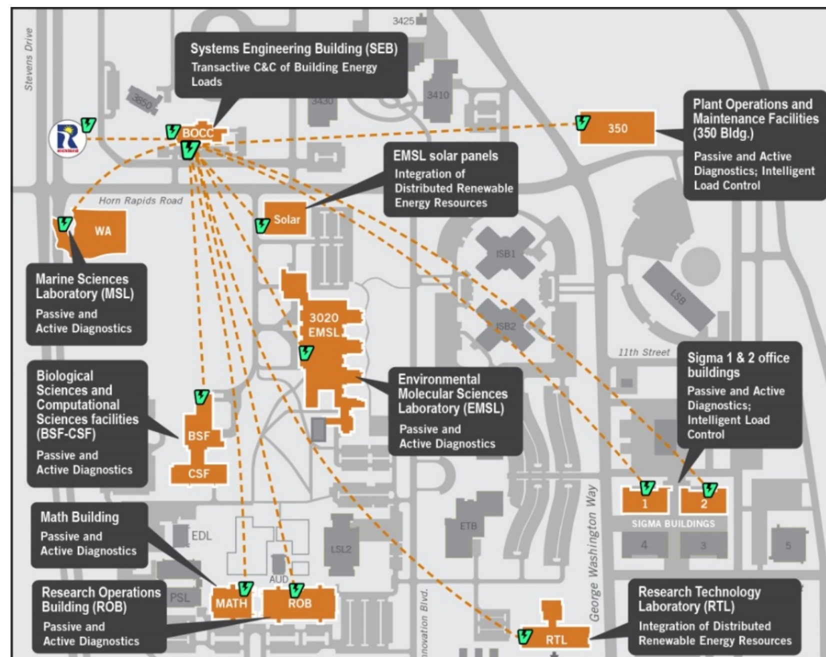
- Create methods that enable these approaches to be readily adopted and implemented in single buildings, sets of buildings, and communities at scale



Approach: Distinctive Characteristics

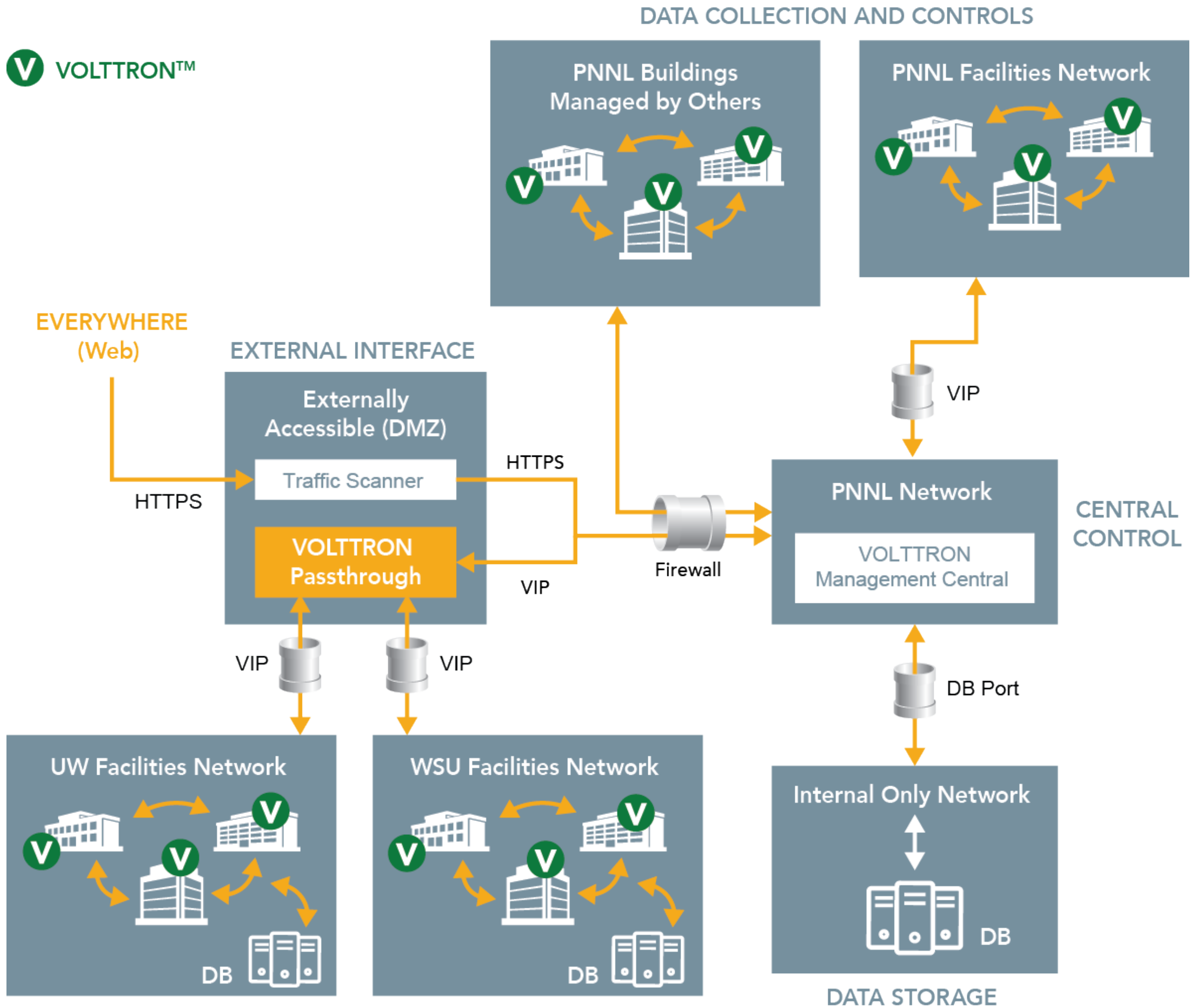
- First **behind-the-meter** implementation of transactive energy at this **scale**, involving multiple buildings and devices
- Innovative DOE-supported, PNNL-developed **VOLTTRON distributed control and sensing** platform provides a foundational tool for supporting individual CETC experiments and connecting the partners' research activities
  - VOLTTRON deploys "V-agents" (algorithms) in building and other systems to coordinate various actions
- Technology can be launched from **inexpensive computing** resources





Experiment deployment on the PNNL campus

Approach: Network Infrastructure



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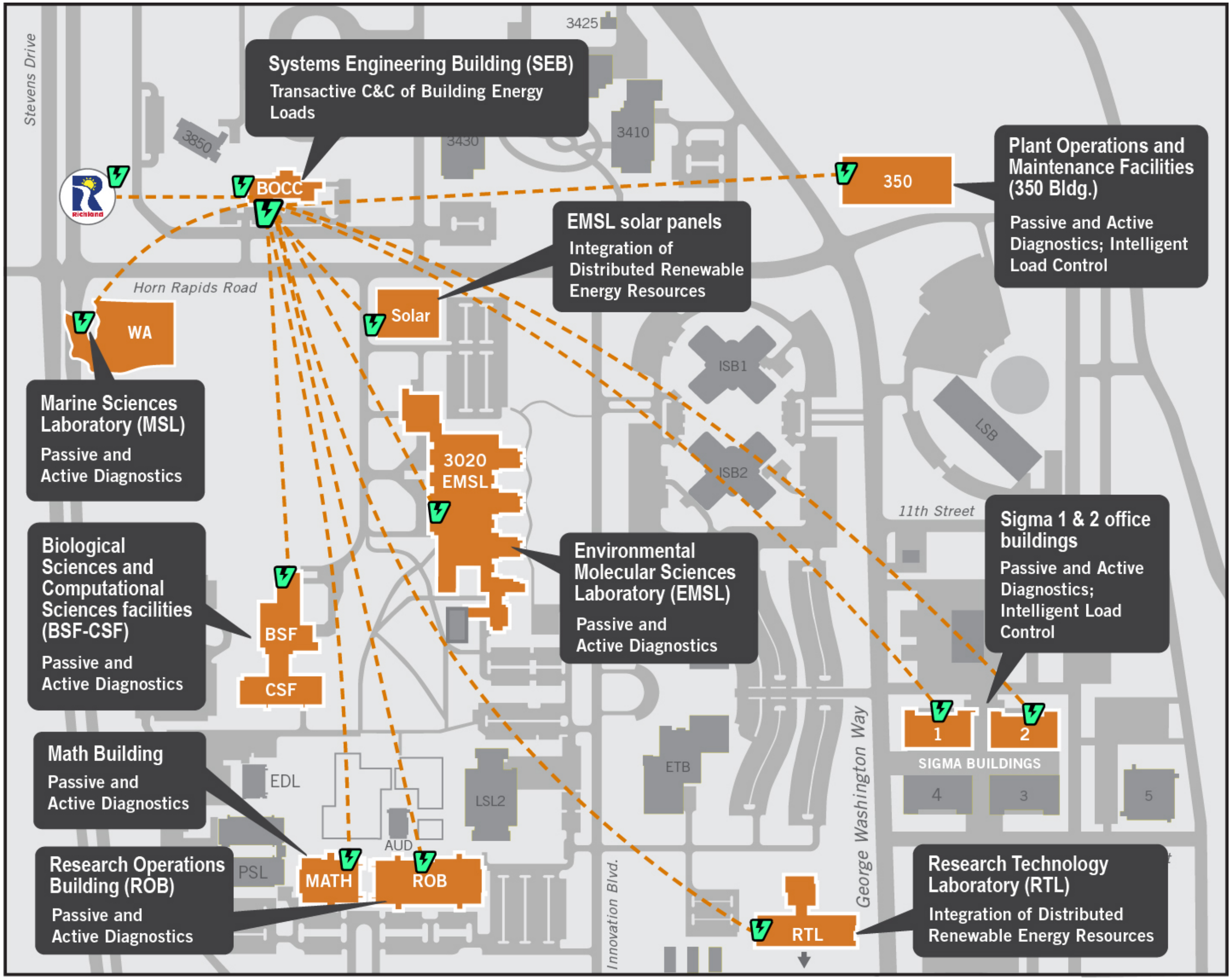
Approach: PNNL Campus Deployment



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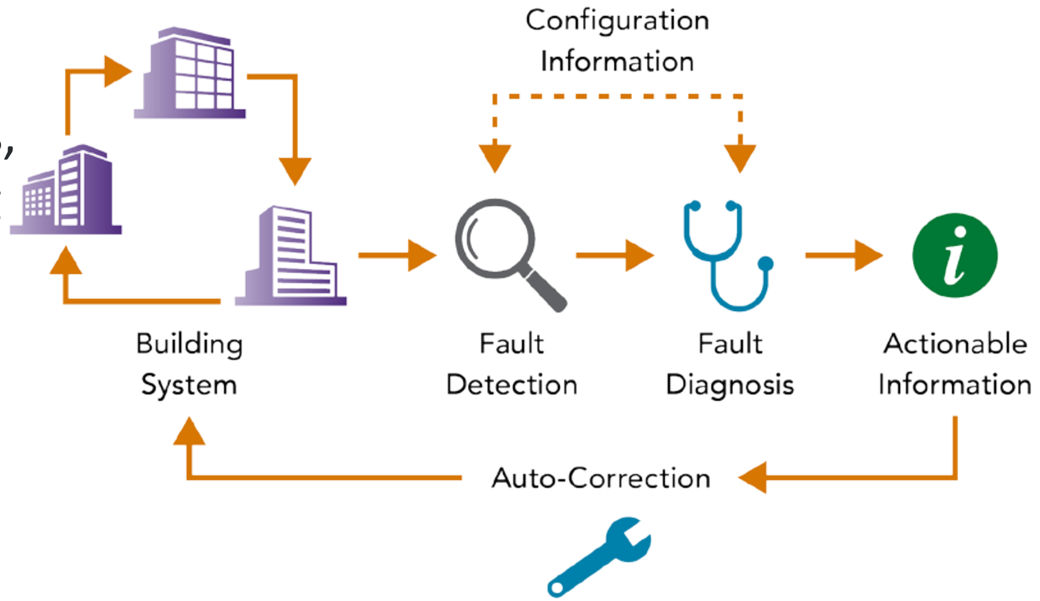
Progress and Accomplishments: PNNL

Passive and Active Diagnostics for Building Efficiency

- Involves deployment of algorithms in buildings to identify energy efficiency opportunities, correct problems, and ultimately improve building operations
- Experiment conducted in 10 PNNL buildings during 2016; results indicate the algorithms have been highly successful in consistently identifying faults in building operations



A. BEYOND DEMAND RESPONSE

Passive and Active Diagnostics for Building Efficiency

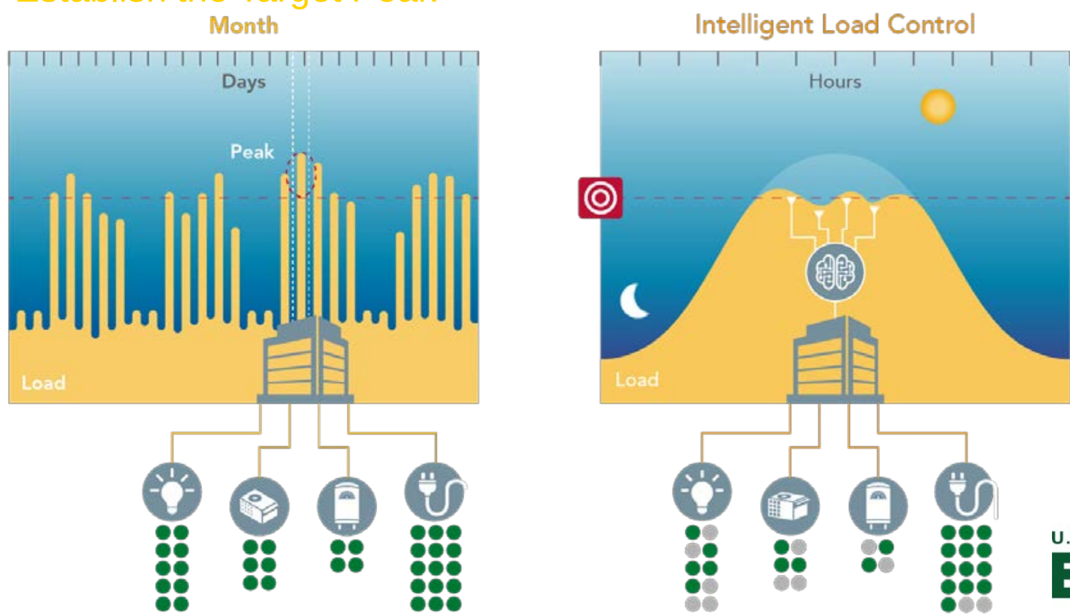
- **Experiment Status**: Designed, scripted in Python, validated through simulation, and deployed on 10 buildings on the PNNL campus
- **Documentation**: Technical report completed and a draft of the user guide is pending
- **Code**: Two main Python scripts represent this experiment
  - A set of proactive diagnostics to detect economizer controls can be found in economizer_RCxAgent.py and
  - A set of proactive automated re-tuning opportunities can be found in airside_retuning_rcx.py
- Example configuration files, required for both scripts, are also included in the repository. The v-agents also use a number of platform services, including *driver, scheduler, actuator, weather, etc.*

Progress and Accomplishments: PNNL

Intelligent Load Control (ILC)

- Automated management of building electricity peak, energy consumption, or energy budget
- Deployed in three PNNL buildings, primarily to control 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, ILC quickly prioritized heat pump operations, maintaining building comfort at acceptable levels and reducing load to the desired target

Establish the Target Peak



A. BEYOND DEMAND RESPONSE

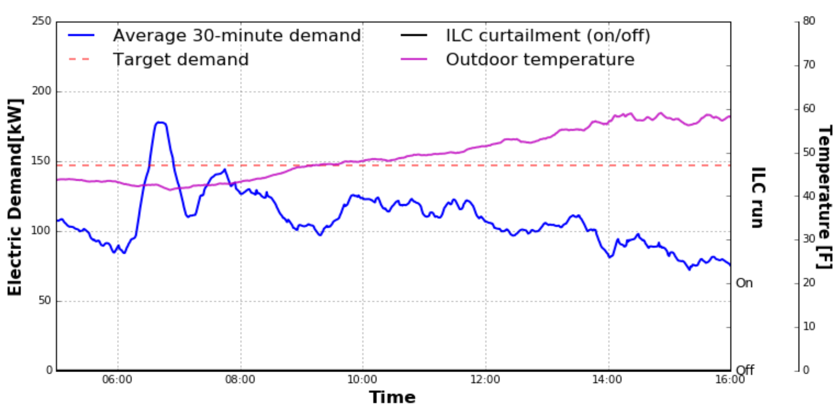
B. GRID SCALE, RIGHT SIZED STORAGE

Progress and Accomplishments: PNNL

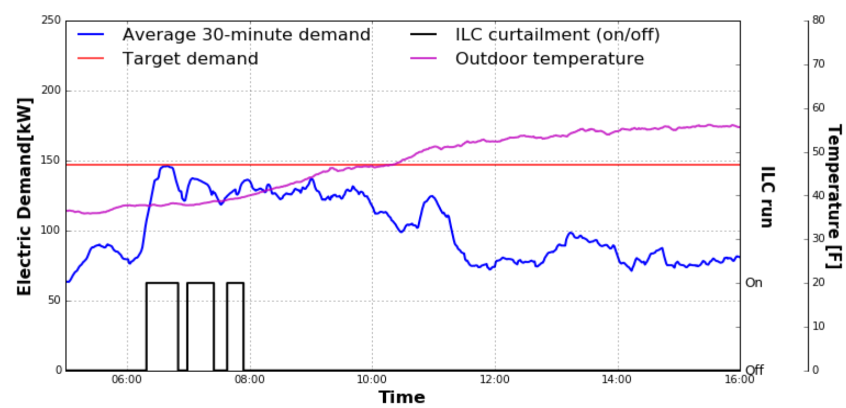
Intelligent Load Control (ILC)

- **Experiment Status**: Designed, scripted in Python, validated through simulation, and deployed on three buildings on the PNNL campus
- **Documentation**: Technical report completed along with the user guide
- **Code**: Two main Python scripts required to run ILC
  - Peak electricity forecasting script (wbe.py)
  - The main ILC script (agent.py) for prioritizing and controlling loads
- Example configuration files are also included in the repository. These v-agents use a number of platform services, including *driver*, *scheduler*, *actuator*, etc.

Example No ILC: March 14



Example with ILC: March 15



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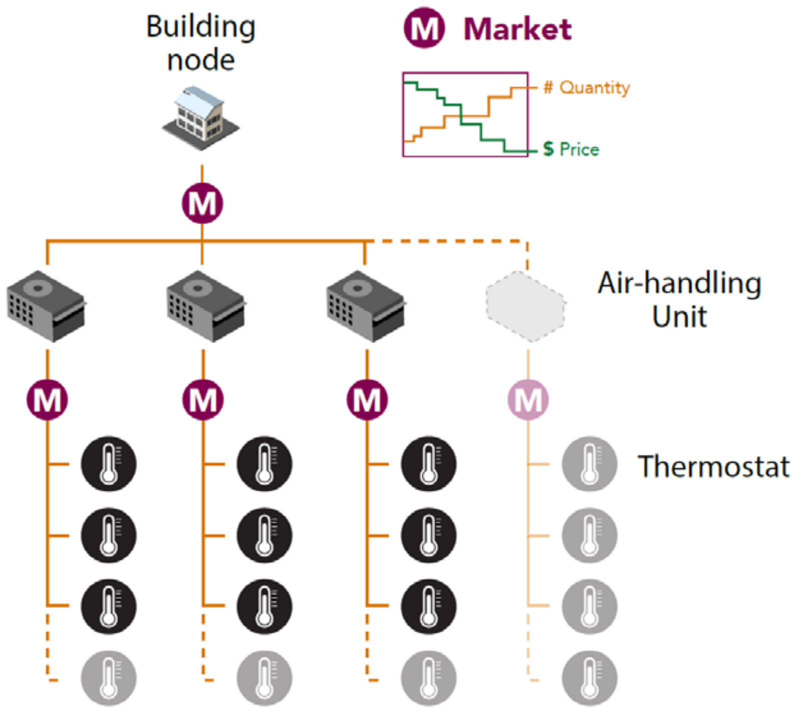
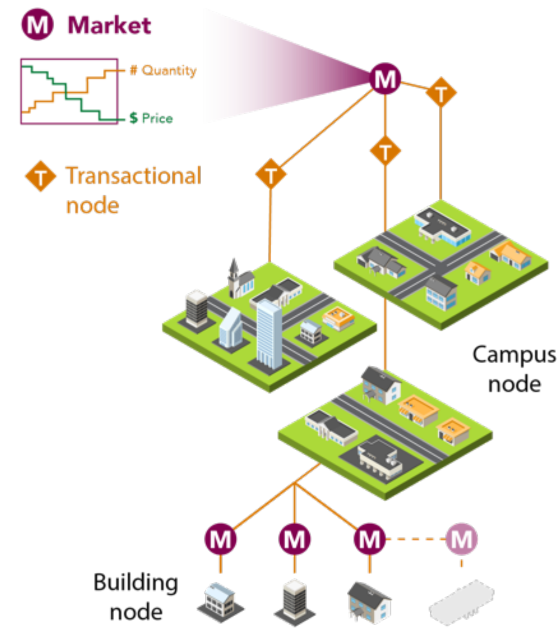
Progress and Accomplishments: PNNL

Transactive Control and Coordination of Building Energy Loads

- Creates markets within different building zones and devices as part of an automated, real-time process
- Deployed in a PNNL building's AHU, results have confirmed the ability of this method to achieve experiment objectives





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Progress and Accomplishments: PNNL

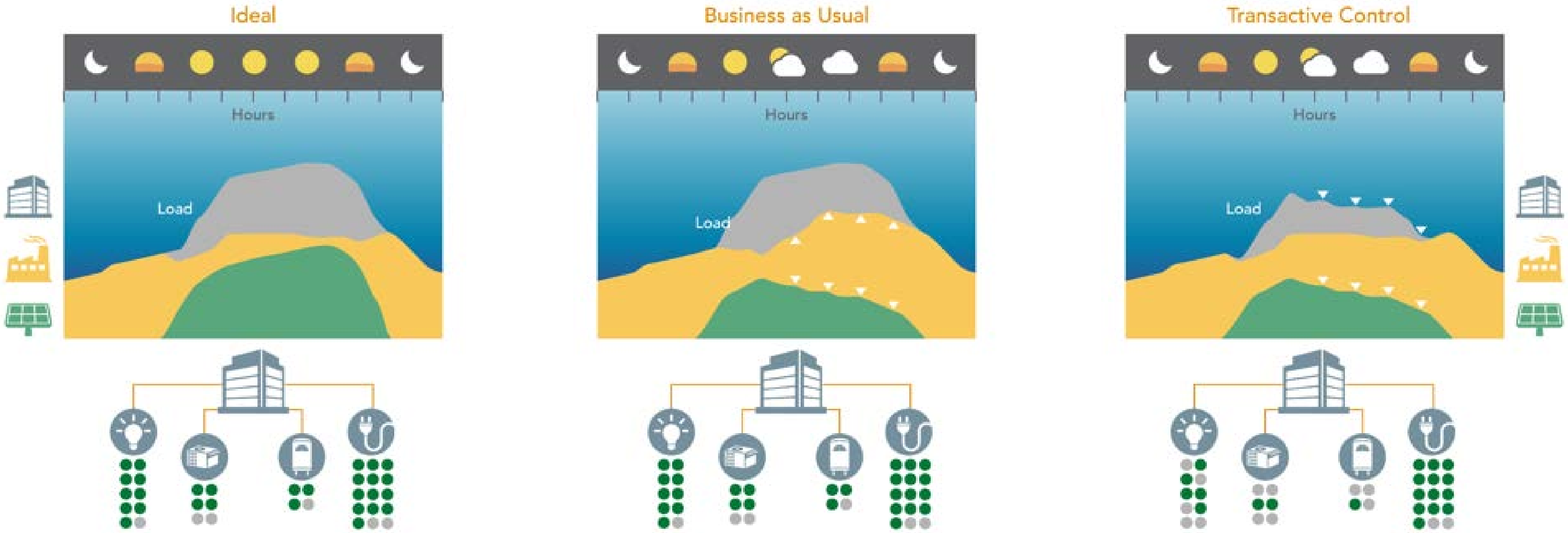
Transactive Control and Coordination of Building Energy Loads

- **Experiment Status**: Designed, scripted in Python, tested using simulation, and deployed in one building on PNNL campus
- **Documentation**: Technical report is complete a draft user guide is complete
- **Code Packages**: Code is significantly more complex than existing v-agents:
  - **vpubsub**: package that provides functions for defining topic subscriptions and message handlers through a configuration file
  - **venergyplus**: package containing the classes used for connecting VOLTTRON to an EnergyPlus model for co-simulation
  - **vmarket**: package containing the classes for creating transactive agents and markets. These classes are very generic in nature and can be used to create multi-layer markets of arbitrary complexity
  - **Vmodels**: package containing physical models of zones and equipment
  - **vtrxhvac**: package containing transactive market agents used in physical experiments on the PNNL building with built-up air-handling units, and those created for two other buildings on PNNL campus with RTUs

Progress and Accomplishments: PNNL

Integration of Distributed Renewable Energy Resources

- Monitors solar production and its intermittency, including fluctuations that challenge grid operations, and concurrently engages variable-frequency-drives on fans, hot water heaters and other fast acting loads to adjust a building's power consumption to balance loads
- Laboratory testing successful in achieving experiment objectives



Control building loads such as variable-frequency-drives on fans in AHUs and packaged rooftop units to absorb renewables generation losses and reduce grid fluctuations

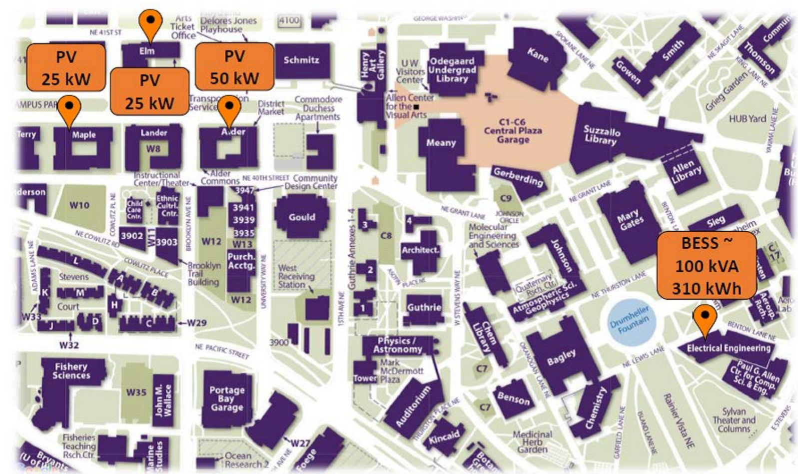
Progress and Accomplishments: PNNL

Integration of Distributed Renewable Energy Resources

- **Experiment Status**: Designed, scripted in Python, tested using simulation and in the laboratory, and ready for testing on PNNL campus buildings
- **Documentation**: Technical report completed; draft of the user guide is pending
- **Code**: Four main Python and/or MATLAB scripts were developed
  - Fan system identification agent (IDAgent.py) identifies relationship among fan power, fan speed, and supply air flow, etc.
  - Indirect fan speed controller (FanICAgent.py) that indirectly controls the fan speed via changing the duct static pressure set point using PID loop; applies to the supply fan in AHUs
  - Direct fan speed controller (FanDCAgent.py) that directly controls the fan speed using the identified fan power-fan speed model; applies to a variable speed fan in a roof top unit
  - A MATLAB script that determines the ON/OFF status of a population of water heaters, and a MATLAB-VOLTTRON interface written in MATLAB and Python to use VOLTTRON to turn ON/OFF of physical water heaters

Progress and Accomplishments: UW

- Solar panels, totaling 100 kW, and microinverters installed and commissioned
- 100 kW/325 kWh BESS procured; installation and integration in early 2017
- Studying via simulations how BESS can be used to optimize energy cost
- Studying conversion of building data into actionable information



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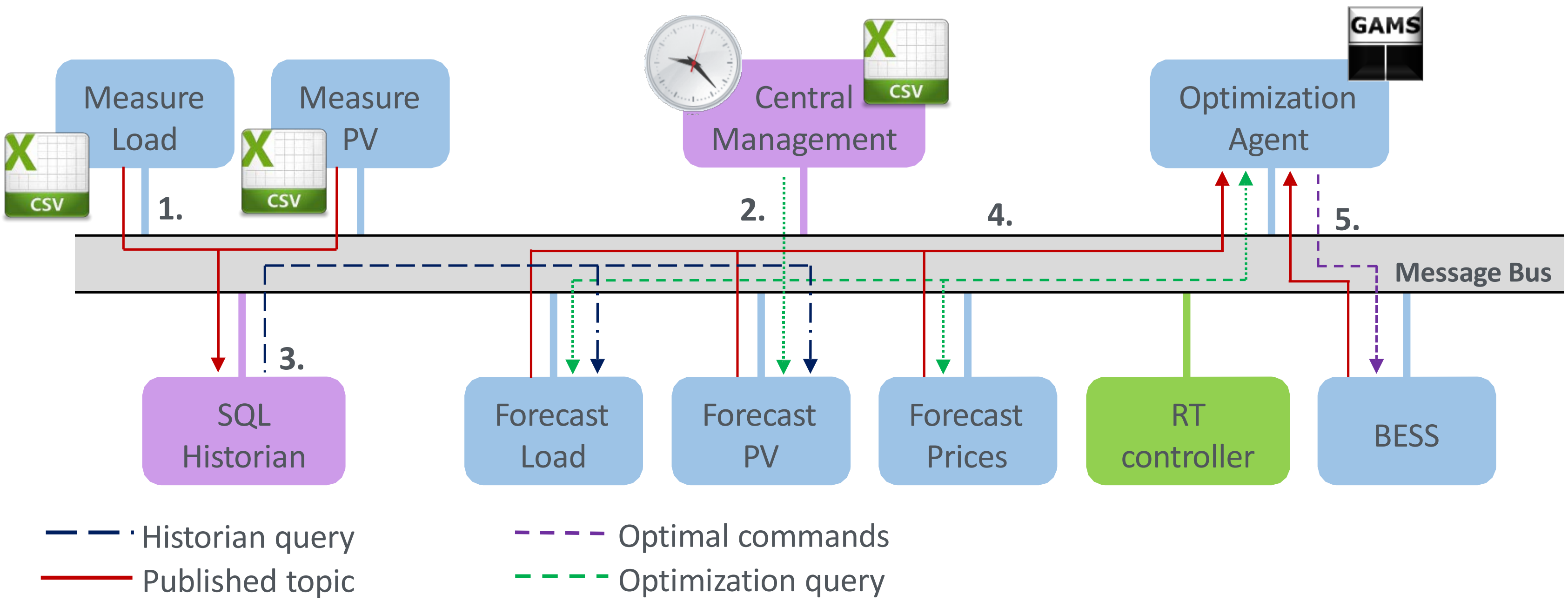
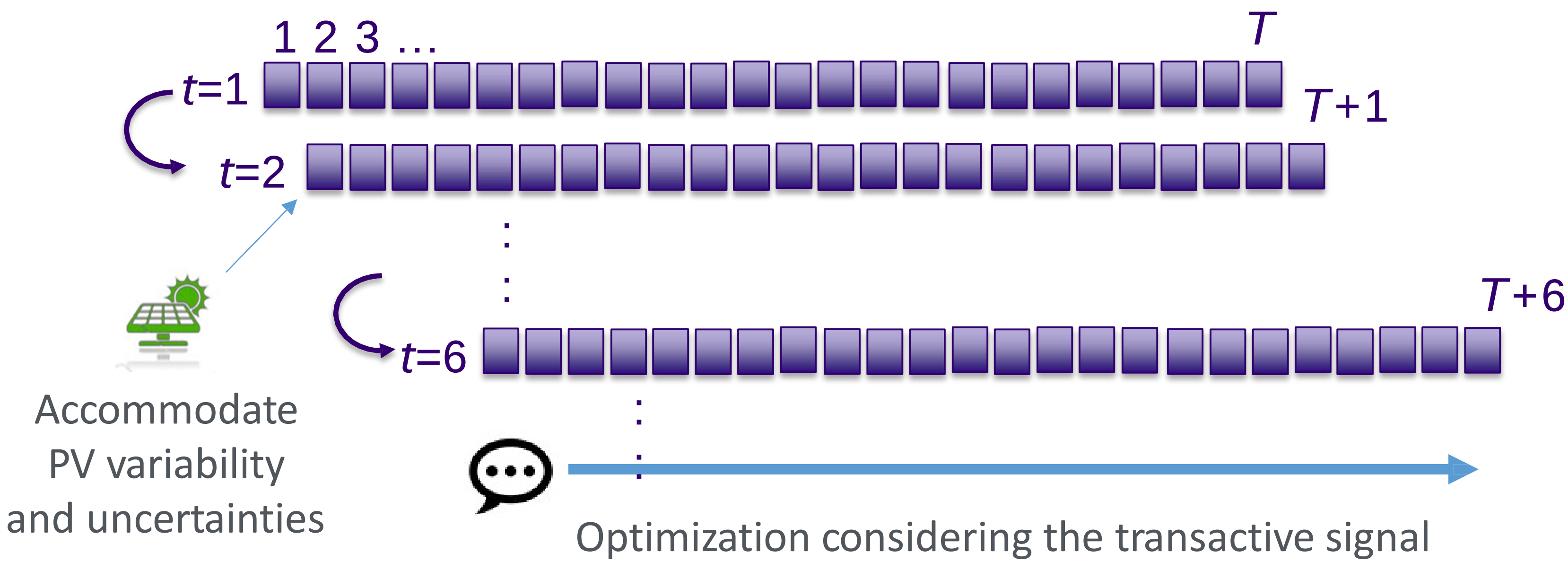
UW: BESS Optimization using VOLTTRON Architecture



1. Simulation data published
2. Gather information and send the optimization query
3. Request the measured values to generate the forecast
4. Send the forecast to the optimizer
5. Send the refreshed power schedule for the BESS

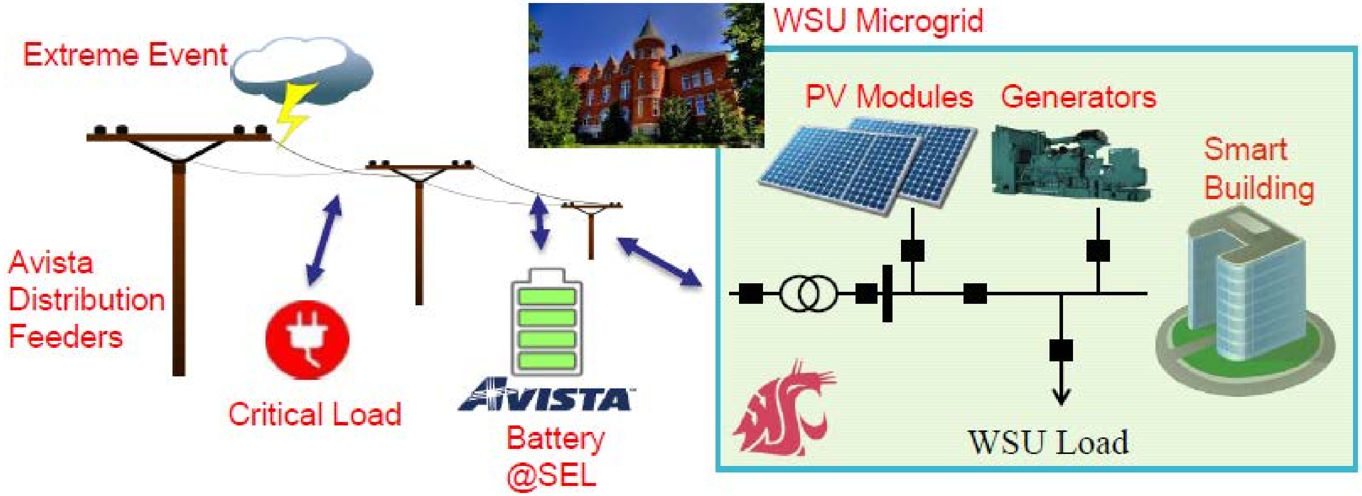
UW: BESS Optimization

Optimization on a rolling window basis (T) with refreshed forecasts for production and consumption



Progress and Accomplishments: WSU

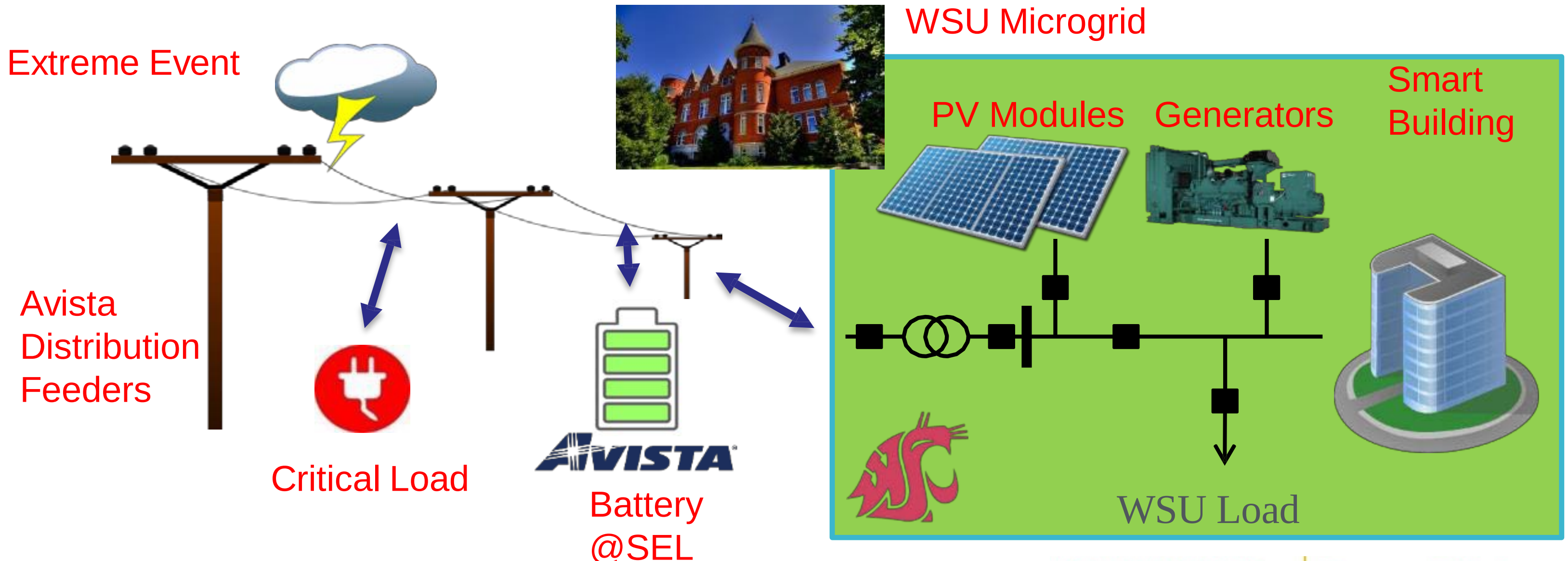
- 72 kW PV system and inverters procured, installed, and operational
- VOLTTRON nodes integrated into PVs
- Transactive energy strategies developed
- Optimization method for resiliency developed



WSU: Resiliency of Distribution Systems

PVs, Batteries, and Smart Buildings

- Define resiliency for an isolated distribution system with PVs, batteries, smart buildings, and WSU microgrid generators
- Optimal utilization of PVs, batteries, and WSU microgrid generators to serve critical load during system restoration
- Explore the role of smart buildings in resiliency enhancement
- Feasibility evaluation with the WSU testbed



WSU: Transactive Energy Demo

Progress and Accomplishments: Lessons Learned

- Facilities and operations (F&O) staff of buildings are concerned about cyber security of the controls infrastructure
  - Hesitant to introduce new hardware and software on to their networks
- Grid services that do not require fast response (>5 minutes) can be deployed easily using existing building control sequences to provide short-term (<30 minutes) and long-term (>30 minutes) grid services
- Grid services that require fast responses (in order of minutes) are harder to implement with existing control sequences
  - Some modifications and enhancements essential for fast response grid service
- F&O staff are willing to provide grid services, if there is a good business case

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Project Integration and Collaboration

Project Integration:

- An advisory committee made up of representatives of **Seattle City Light, Puget Sound Energy, Avista Corp, City of Richland, McKinstry and Transformative Wave Technologies;** other partners will be added as part of Phase II effort

Partners, Subcontractors, and Collaborators:

- Project partners are PNNL, UW, and WSU; Case Western Reserve University and University of Toledo will be added in Phase II

Communications:

Conferences:

"Regional Transactive Campus Testbed – Design and Initial Results," 2016 Transactive Energy Systems Conference and Workshop, May 17, 2016, Portland, Ore. Presented by Chad Corbin

"Transactive Campus Energy," the featured session of the Energy Systems Innovation Center's annual Energy Summit at the Power & Energy Automation Conference, March 10, 2016, Spokane, Washington

Brochures/Fliers:

"Clean Energy and Transactive Campus Project" (4-page brochure developed by PNNL, December 2016)

A Blueprint for the Nation's Transactive Energy (2-page flier developed by PNNL, March 2016)

Project Integration and Collaboration: Communications

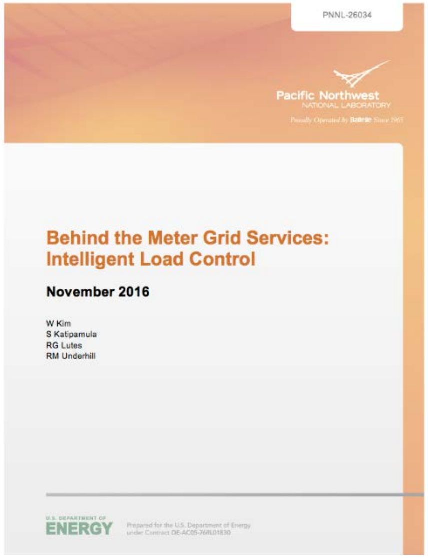
Publications to Date: Journal and Magazine Articles

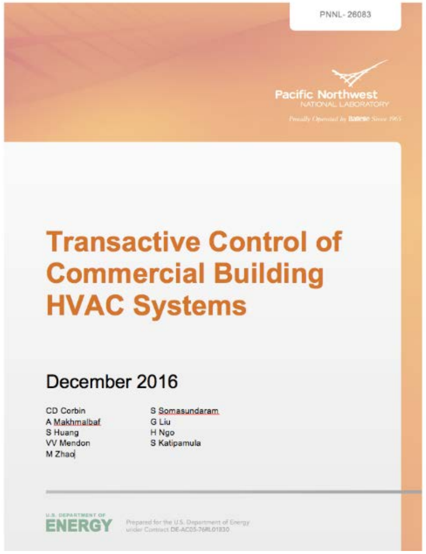
- Katipamula S, J. Haack, G. Hernandez, B. Akyol and J. Hagerman, "**VOLTTRON: An Open-Source Software Platform of the Future**," in IEEE Electrification Magazine, vol. 4, no. 4, pp. 15-22, Dec. 2016.
  doi: 10.1109/MELE.2016.2614178
  URL:http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7725895&isnumber=7725795
- Kim W, and S Katipamula. 2017. "**Development and Validation of an Intelligent Load Control Algorithm**." Energy and Buildings, 135 (2016), pp 62-73.
  http://dx.doi.org/10.1016/j.enbuild.2016.11.040
- Katipamula S, RG Lutes, G Hernandez, JN Haack, and BA Akyol. 2016. "**Transactional Network: Improving Efficiency and Enabling Grid Services for Building**." Science and Technology for the Built Environment (2016), 22(6), pp 643-654
  doi:10.1080/23744731.2016.1171628
- Katipamula S, K Gowri, and G Hernandez. 2016. "**An Open-source automated continuous condition-based maintenance platform for commercial buildings**. Science and Technology for the Built Environment (2016) 00, 1–11 doi: 10.1080/23744731.2016.1218236
- He Hao, Charles D. Corbin, Karanjit Kalsi, and Robert G. Pratt, "**Transactive Control of Commercial Buildings for Demand Response**," IEEE Transactions on Power Systems, 32(1), 774–783, January, 2017

Project Integration and Collaboration: Communications

Publications to Date: Technical Reports and User Guides

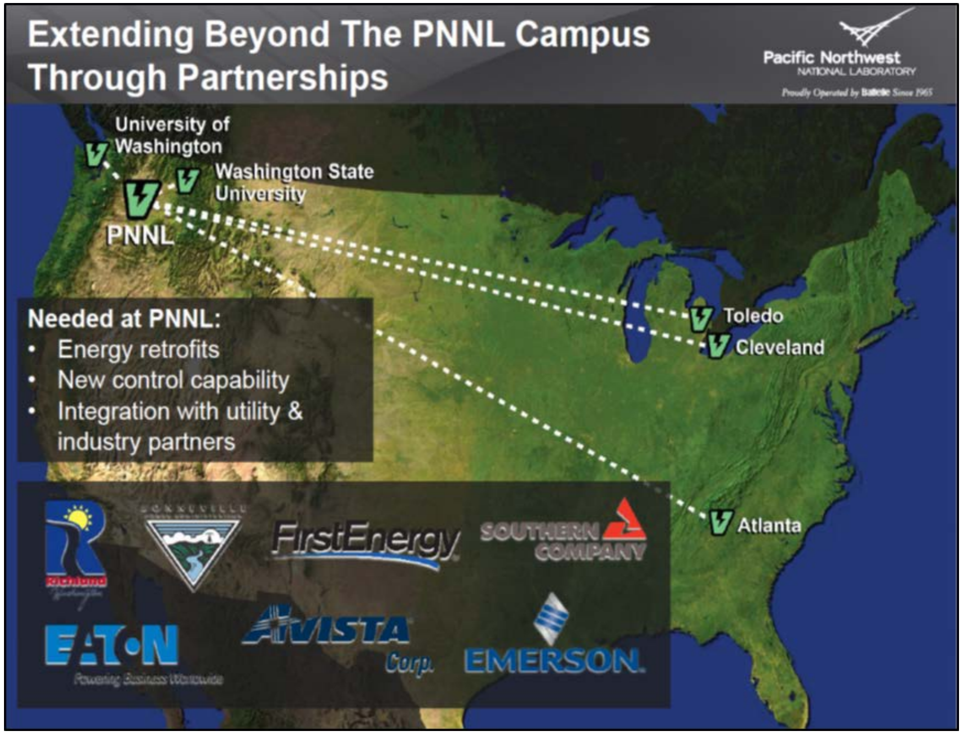
- Kim W, Katipamula S, Lutes RG, Underhill RM. 2016. "Behind the Meter Grid Services: Intelligent Load Control" PNNL-26034, Richland, WA.
- Hao H ,Liu G ,Huang S ,Katipamula S   2016. "Coordination and Control of Flexible Building Loads for Renewable Integration; Demonstrations using VOLTTRON" PNNL-26082, Richland, WA.
- Corbin CD, Makhmalbaf A, Liu G, Huang S, Mendon VV, Zhao M, Somasundaram S, Ngo H, Katipamula S. 2016. "Trnsactive Control of Commercial Building HVAC Systems." PNNL-26083, Richland, WA.
- Katipamula S, Lutes RG, Underhill RM, Kim W, Huang S. 2016. "Automated Identification of Retro-Commissioning Measures." PNNL-XXXXX, Richland, WA.





Next Steps and Future Plans: Phase I

- Largely completed
  - PNNL implemented and tested technologies in their buildings
  - UW and WSU acquired key assets that will serve as centerpieces of their future work
- User guides for the PNNL experiments are in development



Next Steps and Future Plans: Phase II

- Create network to connect the project partners and facilitate broader testing
- Expand experiments at PNNL
  - Includes extension of the experiments to the other partners
  - Create realistic transactive signal
  - Extend transactive experiments to multi-building and multi-campus scale
- UW and WSU begin testing assets they have acquired, in line with CETC objectives
- Case Western Reserve University and the University of Toledo join the project
  - Install BESS at both Case and Toledo
  - Enable building-grid integration on number of buildings on both campuses
  - Will conduct the PNNL-developed experiments in their facilities
- Potential opportunities to expand project activities to commercial buildings and neighborhoods

REFERENCE SLIDES

CETC I

Project Budget

Project Budget

Variances: No variances

FY2017 Cost to Date: All CETC I funds have been expended.

Additional Funding: Cost-share funds from OE and the State of Washington Department of Commerce - Clean Energy Funds

Budget History					
FY2015– FY2016 (past)		FY2017 (current)		FY2018 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$1,100K	$1,517K	$0K	$0K	$0K	$0K

Project Plan and Schedule

Project Schedule												
Project Start: Sept. 2015		Completed Work										
Projected End: Jan. 2017		Active Task (in progress work)										
		Milestone/Deliverable (Originally Planned)										
		Milestone/Deliverable (Actual)										
	FY2016				FY2017				FY2018			
Task	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Past Work												
Q1 Milestone: Experimental design and revised SOW approved by DOE												
Q2 Milestone: Report on transactive building control strategies												
Q3 Milestone: Preliminary report, transactive campus performance												

CETC II

Project Budget

Project Budget

Variances: No variances

FY2017 Cost to Date: Cost to date in FY2016 totaled $346K. Cost through February 2017, totals $672K. $309K of additional funds have been committed.

Additional Funding: Cost-share funds from OE in FY16 total $500K. Additional cost-share from OE not yet received for FY17 ($750K). The State of Washington Department of Commerce - Clean Energy Funds not yet received ($2,025K).

Budget History					
FY2016 (past)		FY2017 (current)		FY2018 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$2,700K	$500K	$1,000K	$2,775K	TBD	TBD

Project Plan and Schedule

Project Schedule													
Project Start: June 2016		Completed Work											
Projected End: Dec. 2018		Active Task (in progress work)											
	◆	Milestone/Deliverable (Originally Planned)											
	◆	Milestone/Deliverable (Actual)											
	FY2016				FY2017				FY2018				
Task	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	
Past Work													
Q1 Milestone: Design of "max-tech" controls complete													
Q2 Milestone: Design, Develop and Deploy CWRU-Campus Experiments													
Q2 Milestone: Design CWRU Campus Experimental Plan													
Q2 Milestone: Design, Develop and Deploy Infrastructure to Support Multi-Campus Experiments													
Current/Future Work													
Q2 Milestone: Design, Develop and Deploy Multi-Campus Experiments													
Q2 Milestone: Deployment and testing of "max-tech" controls on RTUs complete													
Q3 Milestone: Deployment of energy efficiency services complete													
Q3 Milestone: Generalization of the Solar integration experiments complete													
Q4 Milestone: Technical support to CWRU complete													
Q4 Milestone: Deployment and testing of "max-tech" controls on built-up unit complete													
Q4 Milestone: Multi-campus integration and testing complete													
Q4 Milestone: Testing and Validation of Multi-Campus Experiments													