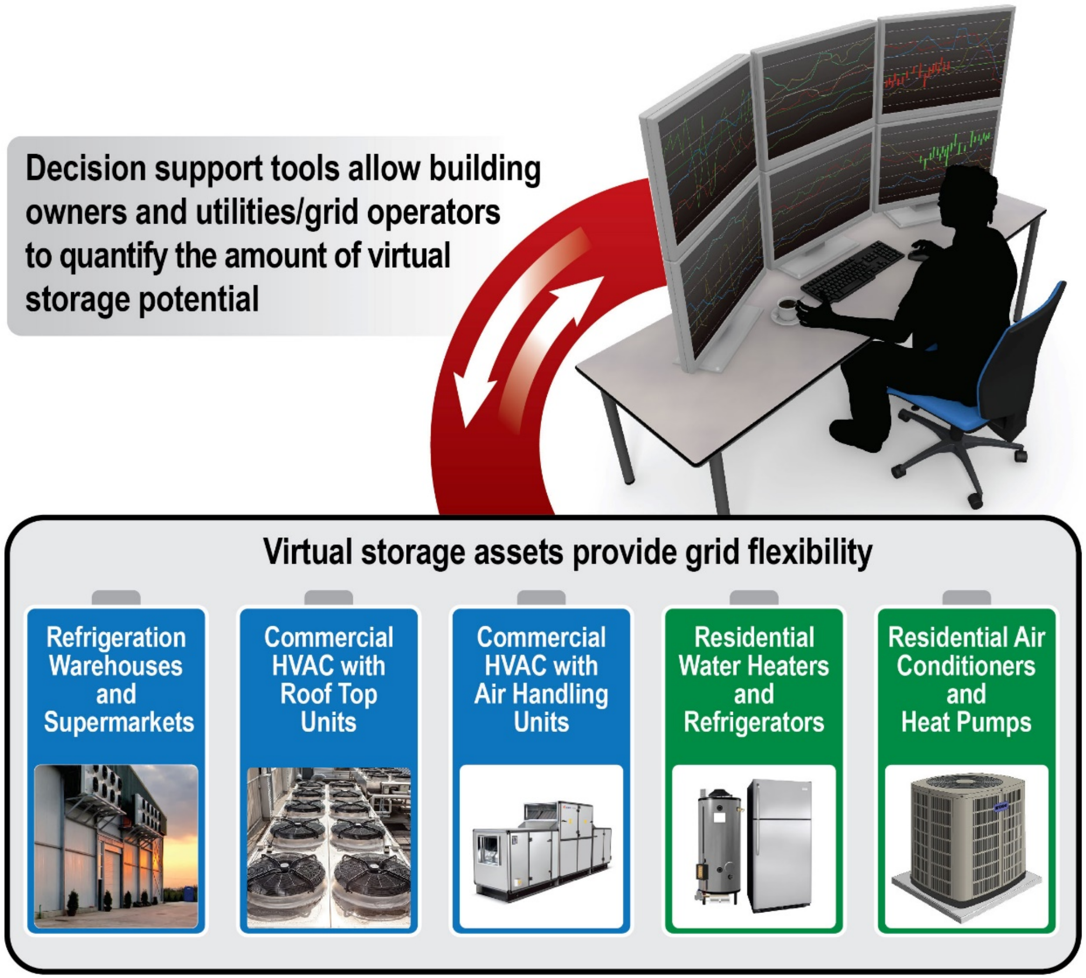
Virtual Batteries

2017 Building Technologies Office Peer Review



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Karan Kalsi, Karanjit.kalsi@pnnl.gov
Pacific Northwest National Lab

Project Summary

Timeline:

Start date: April 2016

Planned end date: March 2018

Key Milestones

1. Flexibility characterization for residential and commercial buildings; 2/28/17
2. Techno-economic assessment of virtual building and dedicated grid storage systems; 2/28/18
3. Develop dispatch and control apps and deploy VOLTTRON apps in at least one test site; 12/31/17

Budget:

Total Project $ to Date:

- DOE: $1,000K
- Cost Share: $0K

Total Project $:

- DOE: $3,550K
- Cost Share: $0K

Key Partners:

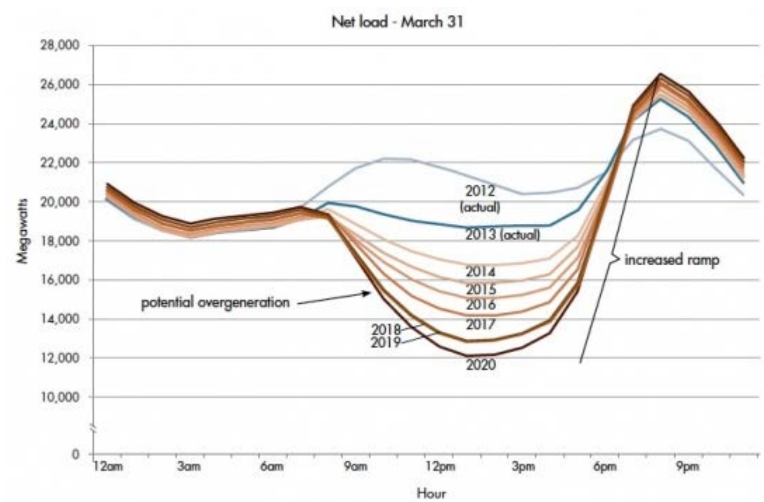
ORNL
UTRC
TVA
University of Florida

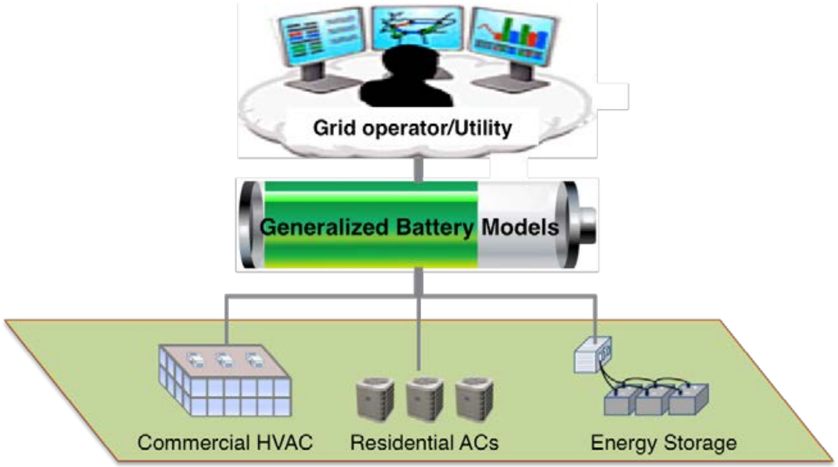
Project Outcome:

Enable utilities to use flexible building loads as virtual storage resources to provide grid services, integrate more renewable generation such as wind and photovoltaics (PV) into the grid, and improve building operational efficiency

Purpose and Objective: Problem Statement

- Growing need for more flexible grid assets with increasing wind and solar deployments
- Current grid-scale energy storage technologies have high capital investment
- Commercial/residential buildings can provide distributed ‘virtual’ storage capacity for the grid services and generate new value streams for building owners
- Virtual energy storage assets already exist but need to be:
  - Identified
  - Quantified
  - Controlled
- Complimentary to physical energy storage (thermal and electric) to provide grid services





Purpose and Objectives: Objectives

- Perform national opportunity assessment to quantify potential (GW/GWh) of virtual storage (VS) resources
- Develop flexibility screening tool to quantify regional potential of virtual storage resources
- Perform cost-benefit assessment for using virtual storage to provide grid services complimentary to physical storage
- Develop controls for virtual storage assets to provide grid services using VOLTTRON platform
- Test and validate virtual storage performance using realistic scenarios based on input from utilities and building owners

Purpose and Objectives: Target Market and Impact of Project

Target Market: Grid operators and behind-the meter asset owners/operators

Impact: Lower cost delivery of grid related services by using behind-the meter virtual storage assets enabled by

- Flexibility screening tool that provides building owners and utilities a means of quantifying potential of virtual storage resources to provide grid services
- Decision-support tools for grid operators and building owners to evaluate investments for using virtual storage resources
- Widely available control applications implemented in VOLTTRON available that enable virtual storage assets to provide grid services
- Testing and validation in realistic environments prove that virtual storage resources can complement physical storage

Progress and Accomplishments

National Opportunity Assessment

- Identify
- Quantify
- Prioritize

Completed

Flexibility Characterization Tool

- State
- County

Developed Version 1.0

Testing and Validation

- VOLTTRON control app development
- Building site testing

Completed Preliminary Benefit Assessment Study for California

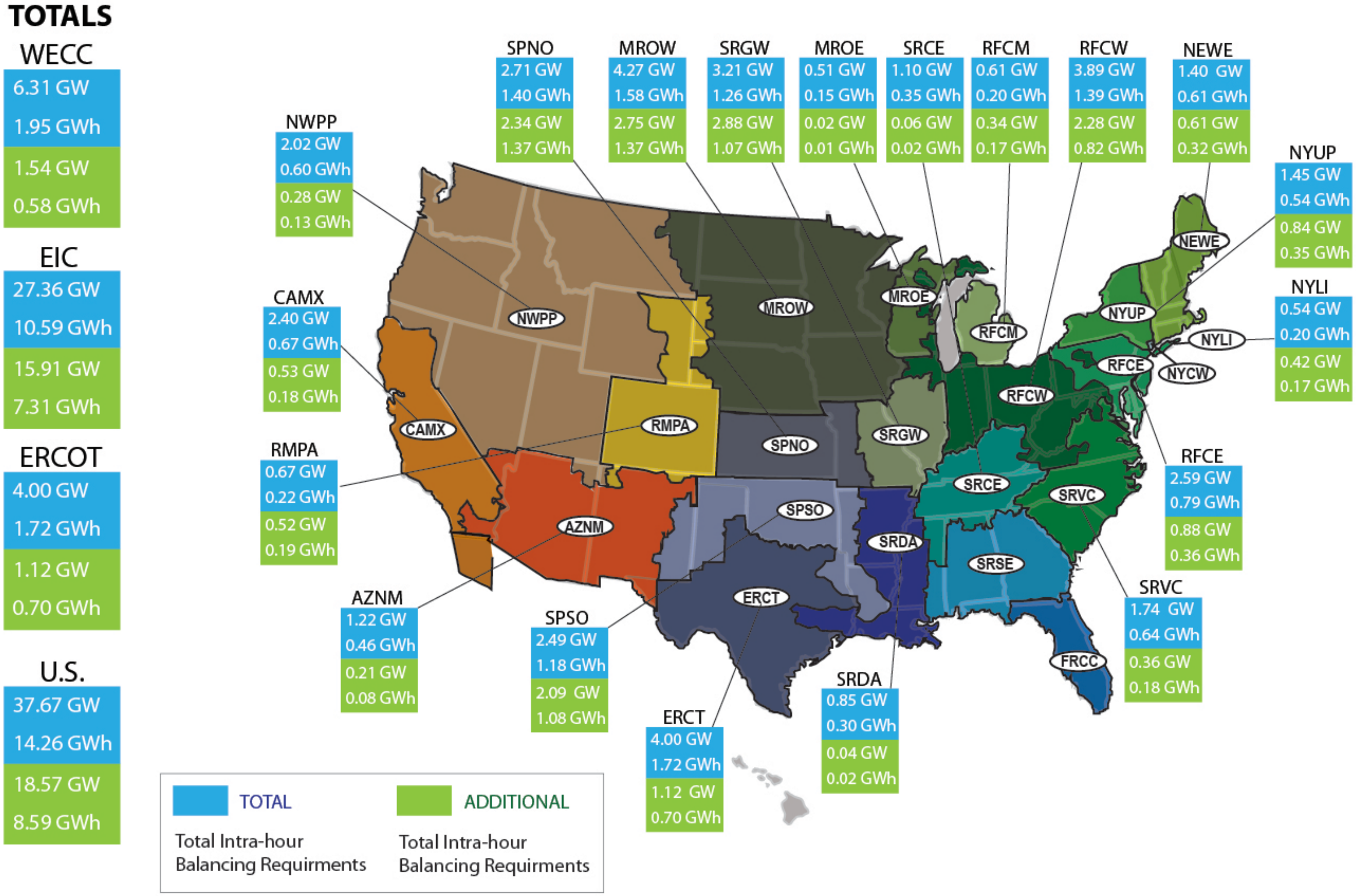
Not Yet Started

Cost-Benefit Analysis

- Revenue assessment
- Cost analysis
- Physical storage requirement

National Opportunity Assessment – Background

Total Intra-Hour Balancing Requirements (2020 Grid with 20% RPS)



M. Kintner-Meyer et.al. “National Assessment of Energy Storage for Grid Balancing and Arbitrage Phase II: WECC, ERCOT, EIC,”

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National Opportunity Assessment – Virtual Storage Max. Tech

	Virtual Storage Assets	Power Potential (GW)*	Energy Potential (GWh)*	Current Investigation
1	Residential Air Conditioners and Heat Pumps	26.3	6.6	√
2	Commercial HVAC with Roof Top Units	17.6	25.9	√
3	Commercial HVAC with Air Handling Units	12.9	38.7	√
4	Residential Water Heaters	10.6	10.6	√
5	Refrigerators	4.3	2.2	
6	Residential Pool Pumps	4.7	4.7	
7	Commercial Water Heaters	1.0	1.0	
8	Electric Vehicles	0.8	1.6	
9	Super Markets and Grocery Stores	1.4	7.0	
10	Refrigerated Warehouses	0.3	0.6	
11	Data Centers	0.5	2.0	
12	Municipal Water Pumping	0.7	1.4	
	Total	**81.1**	**129.2**	

*peak load reduction study

- Virtual storage resources could provide a maximum capacity of 81GW
- 20% of max capacity enough to meet additional 18GW intra-hour balancing requirements in 2020 scenario

Commercial HVAC with Roof Top Units

National Opportunity Assessment for Commercial HVAC with Roof Top Units	
Total floor space (million square feet), 2012 [1]	**45,153**
Median peak demand intensity (W/ft^2) [2]	**5.4**
Cooling/Ventilation percentage of the WBE [1]	**32%**
Total peak power	45,153×5.4×32% ≈ 39.0 GW
Power reduction potential from peak demand [3]	**15-30%** *
Total power reduction capacity	78.0×(15%+30%)/2 ≈ 17.6 GW
Annual electricity energy consumption (billion kWh) [1]	**727**
Duration of power reduction (hours) [1]	**1.5** *
Total "daily" energy consumption	17.6×1.5 ≈ 25.9 GWh
Energy reduction capacity	727×32%/365 ≈ 637.4 GWh

[1] EIA, "2012 Commercial Buildings Energy Consumption Survey," 2012. URL: 2012 Commercial Buildings Energy Consumption Survey
[2] S. Kiliccote,, M. A. Piette, and D. Hansen, "Advanced Control and Communication Technologies for Energy Efficiency and Demand Response," in Proceedings of Second Carnegie Mellon Conference in Electric Power Systems: Monitoring, Sensing, Software and Its Valuation for the Changing Electric Power Industry, Pittsburgh PA. January 2006.
[3] Xu, Yin, Brown, and Kim, "Demand Shifting With Thermal Mass in a Large Commercial Building in a California Hot Climate Zone," technical report, LBNL-61172, 2008.

Residential Air Conditioning Units (including Heat Pumps)

National Opportunity Assessment for Residential HVAC Units	
Number of households using AC units (million) [4]	**94**
Average rated power (kW) [10]	**5.6**
AC units that are running at the same time	**20%**
Total peak power:	94×5.6×20% ≈ 105.3 GW
Power reduction potential from peak demand	**25%** *
Total power reduction capacity:	105.3×25% ≈ 26.3 GW
Total annual energy consumption (quadrillion Btu) [5]	**0.635**
Duration of power reduction (minutes)	**15**
Total "daily" energy consumption:	0.635 × 293,000/365 ≈ 509.7 GWh
Energy reduction capacity:	26.3×15/60 ≈ 6.6 GWh

[4] U.S. Energy Information Administration, "Residential Energy Consumption Survey (RECS), " 2009. URL: http://www.eia.gov/consumption/residential/
[5] He Hao, Borhan Sanandaji, Kameshwar Poolla, and Tyrone L. Vincent, "Potentials and Economics of Residential Thermal Loads Providing Regulation Reserve," Energy Policy, 79, 115–126, January 2015.

Flexibility Assessment Screening Tool –DEMO

Daily Virtual Storage of Residential AC – County Level

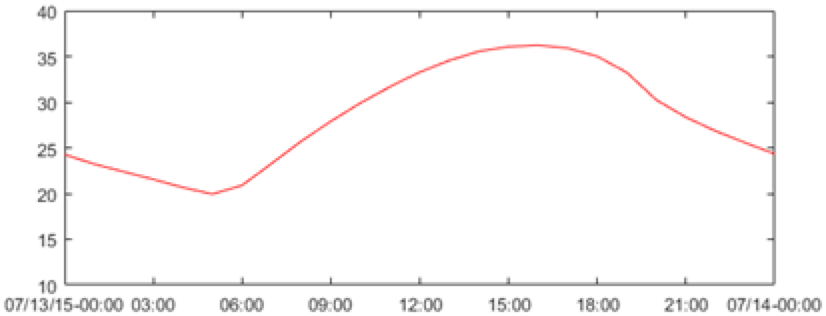
Siskiyou

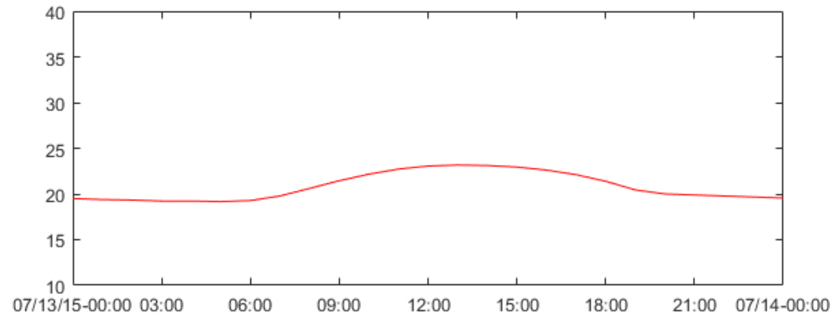
Total # of ACs = 8000

San Diego

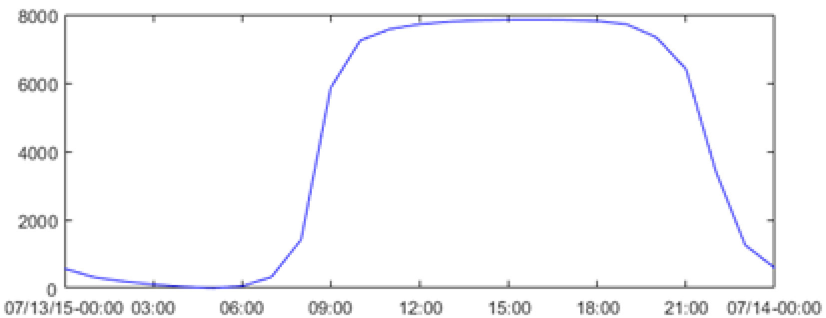
Total # of ACs = 280,000

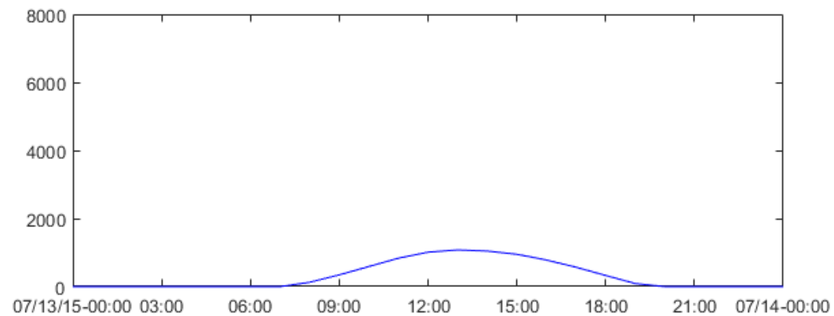
Ambient Temp. (°C)





No. of active ACs





- Virtual storage potential varies based on outside temp
- # of ACs available to participate in grid services varies based on outside air temp
- Greater # of houses does not mean greater potential to provide grid services

Initial Benefit Assessment – County Level

- Case Study
  - Prices: 2015 CAISO average LMP and regulation prices
  - Objective: Maximize total revenue from energy arbitrage, regulation up/down, and spinning reserve
  - Constraints: Virtual storage power and energy limits, power limits for regulation and spinning reserve, hourly regulation reserve, etc.

	Energy Arbitrage $/year	Regulation Up $/year	Regulation Down $/year	Spinning Reserve $/year	Total $/year
Siskiyou	10,983	150,501	25,651	2,559	189,696
San Diego	1,534	11,764	42,447	0	55,746

- Key Observations
  - Total revenue in Siskiyou higher → greater number of AC units available
  - Regulation up and down accounts for most of total benefits
  - Increased benefits in Siskiyou are from regulation up

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Benefits from Virtual Storage and Real Storage

- CPUC state level storage procurement targets of 1.3 GW*
  – Physical storage: 500MW/1000MWh
  – Virtual storage: 800MW/560MWh (20% residential loads aggregated peak capacity)

	Energy Arbitrage $M/year	Regulation Up $M/year	Regulation Down $M/year	Spinning Reserve $M/year	Total $M/year
Physical Storage	3.21	19.14	13.48	0.01	35.83
Virtual Storage	4.32	11.85	22.19	0.07	38.43

- Key Observations
  – Virtual storage can complement physical storage to meet procurement targets
  – Revenue for providing regulation down greater for virtual storage resources
  – Revenue for providing regulation up greater for physical storage
  – Comparable revenue streams for providing energy arbitrage

* https://www.reedsmith.com/California-Public-Utilities-Commission-Adopts-Energy-Storage-Procurement-Targets-10-23-2013/

Project Integration and Coordination

- PNNL (lead)
  - Develop flexibility characterization screening tool
  - Perform cost-benefit analysis
- ORNL
  - Provide experimental data from test sites used in flexibility screening tool
- University of Florida
  - Develop models used in flexibility screening tool
- TVA, BPA, and UTRC
  - Testing and deployment

Next Steps and Future Plans

- Continue development of flexibility screening tool
  - Perform assessment for different regions
  - Extend asset catalog
- Extend cost-benefit analysis to include all revenue streams and cost projections
- Estimate dedicated physical storage capacity needed to complement virtual storage
- Specify and document VOLTTRON control app development and testing process
- Develop and field test VOLTTRON control apps at selected test sites

REFERENCE SLIDES

Project Budget

Project Budget: $1,000K received in FY16. Planned funding for FY17 is $1,050K.

Variances: None

Cost to Date: Of Year 1 funding (FY16), expenditures total $612K. Year 1 funding was received in Spring 2016.

Additional Funding: ORNL received funding directly from DOE for this effort in FY16, which is not reflected in the table below. Funding was also provided to University of Florida ($100K – $60K from PNNL and $40K from ORNL) in FY16.

Budget History					
FY 2016 (past)		FY 2017 (current)		FY 2018 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$1,000K	$0K	$1,050K	$0K	$1,500K	$0K

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Project Plan and Schedule

Project Schedule												
Project Start: April 2016	Completed Work											
Projected End: March 2018	Active Task (in progress work)											
	◆ (red) 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												
Q4 Milestone: Identify flexible building load candidates to be represented as virtual storage resources				◆								
Q1 Milestone: Develop flexibility characterization methodology for various classes of building loads					◆							
Q1 Milestone: Perform techno-economic assessment of virtual and dedicated storage systems					◆							
Q2 Milestone: Initial benefits evaluation of flexibility from building loads						◆						
Q2 Milestone: Characterization method developed shows sufficient potential in quantifying the flexibility of building loads to justify performing economic assessment						◆						
Q2 Milestone: Flexibility characterization for residential buildings and commercial buildings						◆						
Q2 Milestone: VOLTTRON app development and testing process specified and documented						◆						
Current/Future Work				◆								
Q3 Milestone: Report documenting a method for characterizing the virtual battery							◆					
Q3 Milestone: Report completed on the metrics, how to apply them, and results of using them to assess the potential impacts and benefits of using virtual storage							◆					
Q3 Milestone: Field testing and validation Plan for deployment of VOLTTRON apps at selected test sites developed							◆					
Q3 Milestone: Coordinate effort with ORNL and other BTO programs and identify target climates for HPWH adoption and identify and solidify partnerships with high priority program implementers, utilities, and other collaborators							◆					
Q3 Milestone: Work plan based on coordinated effort with ORNL and other BTO programs that will identify specific milestones and deliverables							◆					
Q4 Milestone: Initial testing of VOLTTRON apps for flexibility evaluation and monitoring/visualization								◆				
Q4 Milestone: Investigate retailer, installer, and manufacturer potential involvement in a national initiative that incorporates demand response into project design, implementation, and evaluation								◆				
Q1 Milestone: VOLTTRON apps for flexibility evaluation and monitoring/visualization developed									◆			
Q1 Milestone: Developing dispatch and control applications in VOLTTRON for virtual storage systems to provide grid services									◆			
Q1 Milestone: Complete deployment of VOLTTRON apps in at least one test site									◆			
Q1 Milestone: Identify target markets and partners and designs for large scale deployment									◆			
Q1 Milestone: HPWH Deployment Plan, including presentation of findings and recommended next steps for FY2018-2019									◆			
Q2 Milestone: VOLTTRON apps for flexibility monitoring and visualization and accompanying user manual										◆		
Q2 Milestone: A report will be completed describing the performance and cost comparison studies between different types of virtual storage and dedicated physical battery storage systems										◆		
Q2 Milestone: Dispatch algorithms for coordinating virtual storage resources implemented and tested using GridLAB-D										◆		
Q2 Milestone: Report documenting optimal dispatch algorithms										◆		
Q2 Milestone: Document/report on testing of VOLTTRON apps										◆		
Q2 Milestone: Documentation of findings										◆		