Supporting a Thriving Transaction-Based Controls Ecosystem

DOE's role in creating a comprehensive controls program across DOE to support Buildings and Grid Modernization

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ABSTRACT

Tranaction based-controls are "a means of executing transactions through automatic control of the operating state of building equipment and other energy systems in response to data and value streams." Furthermore, Pacific Northwest National Laboratory and two other DOE national laboratories, through extensive modeling showed that proper use of transaction-based controls can achieve 20-30% energy efficiency savings in small office buildings through the deployment of controls, control strategies, and control applications/algorithms. Investing in applied R&D reduces the "Figure it out tax" for the industry which includes: a. Sensors , b. Plug and Play capabilities, c. Self configuration, start-up, and automatic fault detection and diagnostics, d. Complex Control Methods, and e. Others identified in the S&C Roadmap. Another promising concept, Complex Control Theory, is expanding through conversations about, research into, and implementations of transactive energy that can enable control aggregation to deliver the myriad of services that end use equipment can deliver for market based service solutions - for example, does the market prefer the aggregation of commercial RTUs across fleets of big box retailers to deliver end user and grid services or do owners and operators prefer to manage buildings within the property boundaries? Aggregation is but one important topic to complex control theory. By using an incentives-based approach, rather than direct utility "Command and Control", it respects customer choice in the use of their assets while enhancing their options for direct and remunerative participation, and offers them the satisfaction of helping to reduce the region's carbon footprint. Several campus testbeds will further be specialized as a platform upon which additional R&D will be conducted to advance the state of knowledge in three key areas of critical interest to the project's DOE team members: PNNL - transactive energy management systems for campuses and buildings UW - smart campus and building information systems that provide energy efficiency benefits and support the integration of PV system with distribution. WSU and UW will utilize the testbed and associated R&D activities to develop new, multi-disciplinary curricula that combine the disciplines of information and control technology, distribution systems engineering, building systems engineering, and energy economics. Transactive Controls research and development represents an opportunity for DOE's BTO program to fully realize the benefits that whole building system integration can provide to the grid at different scales and for different, yet regionally specific, economic drivers.

BACKGROUND

The Department of Energy's Building Technologies Office (BTO) has established a vision of transaction-based controls that first, and foremost, benefits the owners and operators of buildings through the delivery of energy efficiency[i]. Transaction based-controls are "a means of executing transactions through automatic control of the operating state of building equipment and other energy systems in response to data and value streams."[ii] Furthermore, Pacific Northwest National Laboratory (PNNL) and two other DOE national laboratories, through extensive modeling (following DOE's Codes Determination Methodology[iii]) showed that proper use of transaction-based controls can achieve 20-30% energy efficiency savings in small office buildings through the deployment of controls, control strategies, and control applications/algorithms[iv]. This important policy finding estimated through modeling has raised the awareness of building controls as a concentration area across DOE[v]. In addition to the energy efficiency savings, transaction-based controls can benefit the system efficiency of the electricity grid by delivering traditional grid services such as direct load control, ancillary services via an aggregator and others as outlined in the grid services use cases developed for BTO[vi]. In the market place, even commercial programs such as USGBC's LEED program recognizes and incents buildings that have installed DR-enabled control systems (but does not require those buildings to be enrolled in any DR utility program) [vii]. Therefore, the marketplace is beginning to recognize and value transaction-based controls[viii].

TRANSACTION BASED CONTROLS

In the publication, Transaction-Based Building Controls Framework, Volume 1: Reference Guide[ix], PNNL specified four service classes that transaction-based controls could deliver;

1) **user services** (e.g., energy efficiency measures, diagnostic and automated commissioning services),
2) **energy market services** (e.g., variable rate utility tariffs, real-time price (RTP); future tariffs for emerging technologies),
3) **grid services** (e.g., traditional Demand Response and, in the future, other ancillary services or load management), and
4) **societal services** (e.g., services society have deemed important through policies or regulations – such as those to reduce emissions of greenhouses gases or to improve air quality via reductions of smog-forming pollutants).

This spectrum of services detailed in Volume 1 includes a non-exhaustive list of use cases[x] for each of the four categories of services.

Fundamentally, transaction based controls require the commingling of energy data and information. In the 'controls' market today, there are several vendors who claim to provide this type of solution, but they are proprietary, expensive and narrowly focused on one or two systems (typically only HVAC or HVAC and lighting)[xi]. Because DOE is technology neutral in the selection or award of proprietary solutions and needs to support the larger discipline of transaction-based controls, in 2011 DOE adopted PNNL's innovative distributed control and sensing software 'platform' (VOLTTRON) as the flexible open source solution to accelerate the development of its controls program and simplify the technology transfer process. VOLTTRON[xii] was developed by PNNL as part of The Future Power Grid Initiative (FPGI) using Lab Directed Research and Development[xiii] funding, a five-year project established in 2011 that is designed to deliver next-generation concepts and tools for grid operation and planning and ensure a more secure, efficient and reliable future grid. However, the initial VOLTTRON platform was distribution grid focused, so in 2012 DOE began the enhancement of the solution to extend the functionality to include buildings specific control strategies and fully released the solution (and future solutions) as open source[xiv]. The solution has been tested at utility scale, being certified in PNNL's PowerNET Testbed[xv] and includes cyber security features that have been tested through various events[xvi]. Furthermore, to support other solutions (and continue to "not pick a winner"), BTO commissioned to PNNL to develop Volume 2 of the Transaction-Based Building Controls Framework which comprises a specification document defining the architecture of transaction- based control systems and related IT[xvii].

Transaction based controls allow buildings and connected equipment within the buildings to perform four **primary functions:**

- **SUPPLY** - generate power to avoid, minimize, or shift larger system distortions from renewable assets like PV, Wind, etc. Example solutions include economic dispatch of fuel cell technologies.

- **CONSUME –** regulate, change, or alternate operation to optimize or reduce large system distortions. Example solutions include the control of end use loads to manage the whole building site usage to a fixed amount or quantity.

- **REGULATE** - transfers loads between two or more devices to optimize the larger electricity system. Example solutions include load management to extend or reduce a transformers design capacity or lifetime.

- **STORE –** applications of those functions necessary to store or stage energy. Example solutions include physical storage like batteries or management of buildings and connected equipment to provide Virtual Battery "storage."

DOE's TC PROGRAM VISION

DOE's collection of controls projects and activities has garnered widespread industry support and collaboration through multiple public engagements because the comprehensive program was built on three key principles defining DOE's role:

1. DOE should invest in comprehensive applied R&D in the fundamentals of sensors and controls in areas like plug and play, large scale complex control methodologies, agent based control theory, etc, which encompasses multiple solution and cuts across many industry entities,
2. DOE should continue development of an open source transaction based controls platform and related tools (e.g. Volttron Core and Volttron EIS[xviii]) so everyone has equal access to the research, findings, and applications (whether or not industry participants ultimately adopt Volttron or simply incorporate features and code found in Volttron), and
3. DOE should continue to stimulate the market, fund the development of market based solutions, and promote market successes only after careful scoping studies are completed that describe the use cases, business case, and market justification with the industry through direct industry engagement.

In each of these areas, DOE programs (including BTO and other EERE offices) have key roles to play. For example, previous ARRA investments funded municipalities and cities to install and deploy clean energy technologies[xix]. However, in many of those communities the projects only deployed the technologies – such as EVs, smart meters, or building located PV. Therefore, integration opportunities remain to realize the full benefit of clean energy technologies at scale – which can help a utility increase and enhance their service offerings rather than impede their operations[xx].

DOE has a clear and present role across EERE to help these communities realize these projects full potential by lessening any transmission and distribution power quality issues caused in whole or in part by clean energy technologies and more importantly to sustain or create opportunities for continued investment in the energy and information sectors. DOE's roles are best characterized by:

1. **Investing in applied R&D** that reduces the "figure it out tax" for the industry which includes:
    a. Sensors[xxi],
    b. Plug and Play[xxii] capabilities,
    c. Self configuration, start-up, and automatic fault detection and diagnostics (FDD),
    d. Complex Control Methods, and
    e. Others identified in the S&C Roadmap.
2. **Convening the industry** to discuss and work out institutional issues that benefit the greater good which includes:
    a. Interoperability[xxiii],
    b. Cyber Security[xxiv], and
    c. Characterization of Assets[xxv].
3. **Developing an open source software solution** that is easily adoptable (by all of DOE) and contains proof-of-concept, bench top examples, and extensible solutions of transaction based controls at the scale of:
    a. User services (Energy Efficiency),
    b. Energy market services,
    c. Grid services, and
    d. Societal services.
4. **Stimulating the market** through the development of demonstrations that are small-scale implementations of real market solutions (based on carefully constructed reference documents with deep industry input and comment).
    a. Residential Solutions
        i. Whole Home Energy Management, and
        ii. Fully integrated solutions for traditional (water heater, A/C, etc) and emerging (heat pump water heater, PV, EV, battery,etc) equipment as well as sensors for 'quality of life'
    b. Commercial Solutions
        i. Sector Based
            1. Small and medium buildings controls platform[xxvi], and
            2. Other sector solutions (convenience stores, supermarkets, etc).

ii. Equipment and Component based
   1. Building to vehicle integration[xxvii],
   2. Municipal pumps and water control solutions, and
   3. Other market based solutions.

RELATED CONTROLS CONCEPTS

Another promising concept, Complex Control Theory, is expanding through conversations about, research into, and implementations of transactive energy (and related transaction based controls) that can enable control aggregation to deliver the myriad of services that end use equipment can deliver for market based service solutions – for example, does the market prefer the aggregation of commercial RTUs across fleets of big box retailers to deliver end user and grid services or do owners and operators prefer to manage buildings within the property boundaries? Aggregation is but one important topic to complex control theory[xxviii]. As these fundamental issues and market opportunities are explored, DOE must continue and track the maturity of controls[xxix] versus the services that can be delivered. This is particularly relevant as more building located devices and assets are becoming "connected" thanks in part to the Internet of Things (IoT) movement (and the trivial cost of adding connected features and capabilities during the manufacturing of these devices).

This "mapping" of the equipment's ability to deliver each or multiple services type (or the lack of the ability) is a key goal of characterization[xxx]. Whereas DOE has explicitly stated that the it won't label or rate products[xxxi], it is recognized that other groups may need ratings and labels to satisfy their constituents, as a means of educating consumers/buyers, or to more narrowly specify the performance required in a specification of bid (thereby, supporting competitive markets rather than vendor driven solutions). Utilizing its convening abilities, DOE has recognized that characterization is one of the important pillars for success. Internally to DOE, EERE may consider rating or mapping project activities to insure the department is diverse in its investment in opportunities.

Specific to buildings, EERE's BTO specified the following needed efforts to scale controls:

- "Common definitions[xxxii] and data formats to facilitate scalable, lower-cost solutions that will enable building and building-to-grid optimization;" (responding to the interoperability needs)

- "Smart building solutions including automated controls to provide faster response and support greater penetration of end use solutions to U.S. energy, demand, and grid regulation needs (i.e. <50msec response to better enable ride-through capabilities);" (responding to the outstanding core, foundational RD needs)

- "Greater utilization of smart meter data[xxxiii] to enable and appropriately value energy savings and building/component response; and" (responding to the outstanding needs to leverage data and to commingle that data with the electricity itself to enable transaction based controls and the larger, emerging field of transactive energy)

- "Further U.S. innovation and leadership focused on new innovations and solutions to support greater cost-effective energy efficiency and energy demand savings, renewable penetration, and grid support from the end use and building level." (responding to the need to stimulate the market through programs with clear reference documents specifying the characteristics of market solutions, the business case, and use case).

DEMONSTRATIONS

Concurrently, a demonstration of a Transactive Controls environment is currently being funded by DOE in the Pacific Northwest. In this project, one Transactive Controls concept, Transactive Energy, is being executed at a campus of buildings. Transactive energy refers to the combination of economic and control techniques to improve grid reliability and efficiency, according to the GridWise Architecture Council.[xxxiv] The fundamental purpose of transactive energy management is to seamlessly coordinate the operation of large numbers of new intelligent assets—such as distributed solar, energy storage and demand response—to provide the flexibility needed to operate the power grid reliably and at minimum cost, particularly one filled with intermittent renewable generation such as the Pacific Northwest. It addresses the key challenge of providing smooth, stable, and predictable "control" of these assets, despite the fact that most are neither owned nor controlled by the power grid. By using an incentives-based approach, rather than direct utility "command and control", it respects customer choice in the use of their assets while enhancing their options for direct and remunerative participation, and offers them the satisfaction of helping to reduce the region's carbon footprint. By adding a feedback signal indicating their assets' ability and willingness to respond to the incentives offered, transactive energy management allows the grid to acquire and direct the precise amount of flexibility when and where it is needed. The much higher resolution data streams and granularity of control from transactive energy information systems at the campus and buildings level offers the opportunity to address novel energy efficiency opportunities, as well.

The Project Team (PNNL, WSU, and UW**),** in cooperation with Washington State technology partner Alstom Grid, is proposing to connect the PNNL, UW, and WSU campuses to form a multi-campus testbed for transactive energy management solutions. Building on the foundational transactive energy management system established by the Pacific Northwest Smart Grid Demonstration (PNWSGD), it is proposing to construct and operate the testbed as both a regional flexibility resource and as a platform for R&D for buildings/grid integration. The testbed will support the integration of renewables and other regional needs, using the flexibility provided by loads, energy storage, and smart inverters for batteries and photovoltaic (PV) solar systems, at four physical scales: multi-campus, campus, microgrid, and building.

The needs of the region will be served by the resource represented by the aggregate of the three campuses, while that of the local utility is served by the campus it supplies. The multi-campus testbed forms an R&D platform for how:

1) campus resources can be aggregated and operated to balance fluctuations in the region's renewable generation
2) each campus can be utilized to support the needs of the serving utility by helping it manage its peak loads.

Each campus testbed will further be specialized as a platform upon which additional R&D will be conducted to advance the state of knowledge in three key areas of critical interest to the project's DOE team members:

- PNNL – transactive energy management systems for campuses and buildings
- UW – smart campus and building information systems that provide energy efficiency benefits and support the integration of PV system with distribution.
- WSU – operation of campus-scale microgrids to provide services to the bulk grid and their extension to planning and operation of resilient distribution systems.

In addition, WSU and UW will utilize the testbed and associated R&D activities to develop new, multi-disciplinary curricula that combine the disciplines of information and control technology, distribution systems engineering, building systems engineering, and energy economics. This will provide the pipeline of skilled science and technology professionals required to develop the clean energy industry for the region and the nation.

The technical aim of this joint activity is to streamline the interactions between clean energy supply, efficient buildings and the smart grid to enhance the impact of renewable generation, energy storage, and advanced energy efficiency —while simultaneously improving the reliability and resilience of the electric grid. Moreover, through the proposed series of linked investments state-wide, and upfront collaboration with resident industry, it is the intention of the Project Team to create a testbed for advanced clean technology integration that differentiates Washington State as a leader in the growing global market for energy management products and services.

The proposed project includes three distinct, innovative clean energy solutions that demonstrate the technical and societal benefits of deploying smart grid technology to help integrate renewable resources using energy storage and flexible building loads as a resource: smart buildings, smart campuses, and microgrids/smart cities. To realize and incentivize further development of clean energy solutions, this proposal also introduces a layered Network Operations Center solution (NOC) that manages the collection of smart buildings, smart campuses, smart cities/microgrids, both locally and globally. Each of BTO's transaction based controls projects, no matter which Transactive Controls concept (like Transactive Energy) is being focused upon, the intent is to understand, evaluate, & unlock the characteristics of whole buildings & connected equipment that provide all services, benefits, and functionalities; balance these characteristics with other energy efficient & renewable technologies; and are mindful that Connected Equipment can impact ongoing regulatory issues.

CONCLUSION

It is envisioned that Transactive Controls is beyond one building and that the solutions must be replicable and scalable for economic efficiency else each building implementation will be custom and costly. Fundamental Sensor & Control (S&C) solution development -- such as plug-n-play, auto-mapping, auto-tuning, auto-Cx, auto-etc and enabling technology solutions like Volttron will allow for this enhanced utilization of buildings to deliver key services. Transactive Controls research and development, therefore, represents an opportunity for BTO's program to fully realize the benefits that whole building system integration can provide to the grid at different scales and for different, yet regionally specific, economic drivers. In this way, the Transaction Based Controls Ecosystem enables a "no regrets," BTO program that delivers on the core mission (energy efficiency and reduced carbon footprint) while simultaneously delivering valuable consumer and utility grid benefits.

It is clear that the value of a Transaction Based Controls Ecosystem is staggering. Even if the only implemetation of TC were interoperable 'connecting' the IoT systems and devices, this would unloack 40% of the potential value attributed to IoT. For homes, the total IoT economic impact is estimated at $200 billion to $350 billion and for Offices at $70 billion to $150 billion by the year 2025[xxxv]

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[i] see DOE BTO Buildings-to-Grid website, accessed 10 March 2016; see http://energy.gov/eere/buildings/downloads/buildings-grid-technical-opportunities-introduction-and-vision

[ii] definition from Somasundaram S, RG Pratt et al. 2014. Transaction-Based Building Controls Framework, Volume 1: Reference Guide. PNNL-23302, Pacific Northwest National Laboratory, Richland, WA. See: http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-23302.pdf and figure 1 of Technical Opportunities Report, http://energy.gov/sites/prod/files/2014/03/f14/B2G_Tech_Opps--Intro_and_Vision.pdf

[iii] see https://www.energycodes.gov/determinations

[iv] see Katipamula S, RM Underhill, JK Goddard, DJ Taasevigen, MA Piette, J Granderson, RE Brown, SM Lanzisera, and T Kuruganti. 2012. Small- and Medium-Sized Commercial Building Monitoring and Controls Needs: A Scoping Study. PNNL-22169, Pacific Northwest National Laboratory, Richland, WA. http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-22169.pdf

[v] see DOE BTO's Multi-Year Program Plan (MYPP) for Fiscal Years 2016-2020, accessible at http://energy.gov/eere/buildings/downloads/multi-year-program-plan

[vi] see grid services use cases in section 6.0 of Somasundaram S, RG Pratt et al. 2014. Transaction-Based Building Controls Framework, Volume 1: Reference Guide . PNNL-23302, Pacific Northwest National Laboratory, Richland, WA.

[vii] US Green Buildings Program Demand Response Partnership Program, website accessed 10 March 2016: http://www.usgbc.org/leed/tools/pilot-credits/demand-response

[viii] Note needed which explains DOE's valuation activities for transactive energy and transaction based controls (e.g. BTO-OE valuation project). BTO and the Office of Electricity and Energy Reliability (OE) are supporting research at PNNL to formulate and test a methodology for valuation of systems where transaction-based mechanisms coordinate the exchange of value between the system's actors. The principal commodity being exchanged is electrical energy, and such mechanisms are called transactive energy systems. A report, forthcoming spring 2016, will lay a foundation for meaningful valuations of transactive systems in general, and transactive energy systems as a special case.

[ix] see Somasundaram S, RG Pratt et al. 2014. Transaction-Based Building Controls Framework, Volume 1: Reference Guide . PNNL-23302, Pacific Northwest National Laboratory, Richland, WA. See: http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-23302.pdf

[x] For the use cases for the four service categories, see Sections 4 to 7 of Somasundaram S, RG Pratt et al. 2014. Transaction-Based Building Controls Framework, Volume 1: Reference Guide.

[xi] Note that transactive energy, requires the utilization of transaction based controls when signals pass across the meter to transact with building load assets. The term transactive energy is defined by the Gridwise Architecture Council (GWAC) as “techniques for managing the generation, consumption or flow of electric power within an electric power system through the use of economic or market based constructs while considering grid reliability constraints. The term "transactive" comes from considering that decisions are made based on a value. These decisions may be analogous to or literally economic transactions.” See the GWAC URL: http://www.gridwiseac.org/about/transactive_energy.aspx

[xii] see PNNL Website, What is the VOLTTRON platform? http://transactionalnetwork.pnnl.gov/volttron.stm.

[xiii] The Atomic Energy Act of 1954, as amended (42 U.S.C. 2011 et Seq., in Section 31) directs DOE to ensue the continued conduct of R&D and to assist in the acquisition of an ever-expanding body of knowledge in the fields of energy, its production, handlings, uses and effects. This mission, initially the responsibility of the Atomic Energy Commission, and subsequently the Energy Research and Development Authority and then DOE, has been and continues to be carried out in government-owned facilities. From its inception, the AEC and its successor agencies recognized made allowable certain amounts of research derived from the ideas of national laboratory researchers themselves. All LDRD activities are governed by a standard DOE policy, DOE Order 413.2B, Laboratory Directe Research and Development. See pages 4-5 of the *FY15 Lab Directed R&D Report to Congress*: http://energy.gov/cfo/reports/laboratory-directed-research-and-development-annual-reports

[xiv] see https://github.com/VOLTTRON/volttron/wiki/Volttron-Restricted and http://transactionalnetwork.pnnl.gov/documents/VOLTTRON_NERF_20150526.pdf

[xv] see http://gridoptics.pnnl.gov/powernet/

[xvi] for more information, contact the authors or volttron@pnnl.gov for details.

[xvii] see Akyol BA, JN Haack, BJ Carpenter, S Katipamula, RG Lutes, and G Hernandez. 2015. Transaction-Based Building Controls Framework, Volume 2: Platform Descriptive Model and Requirements . PNNL-24395, Pacific Northwest National Laboratory, Richland, WA. http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-24395.pdf

[xviii] VOLTTRON™ Central is a “sandbox” tool that combines algorithms and diagnostics tools assessing building energy use. It provides users a low-risk opportunity to explore known, but not yet widely deployed building analysis applications for improving building operational efficiency. http://transactionalnetwork.pnnl.gov/central.stm

[xix] The Quadrennial Energy Review, 2015, states on page 1-14 that “First term actions include $80 billion of investments in a cleaner, more efficient U.S. energy future through the American Recovery and Reinvestment Act of 2009, as well as additional funding through subsequent Presidential budgets…”

[xx] Programs within EERE are working diligently with industry to make clean energy technologies such as solar, wind, electric vehicles, and building energy technologies more commercially viable in the marketplace. However, cost reduction alone will not enable large-scale deployment. As clean energy and energy efficient technologies become more prevalent on the customer side of the meter, the distribution system must evolve to accommodate these technologies. Seamlessly integrating the many EERE technologies into the electrical grid is critical to ensure that utilities can continue to operate the grid in a safe, reliable and cost-effective manner. If we do not develop a holistic approach to integrate these technologies into distribution systems, they will not be adopted by utilities or the marketplace at the scale necessary to achieve significant energy, economic and environmental benefits. DOE’s

Office of Electricity and EERE introduce this topic and the associated opportunities in, Can we cite the GLMC MYPP here?

[xxi] see BTO Multi-Year Program Plan (MYPP) for Fiscal Years 2016-2020, which includes Sensors and Controls: http://energy.gov/eere/buildings/downloads/multi-year-program-plan

[xxii] A plug and play device or computing bus is one with a specification that facilitates the discovery of a hardware component in a system without the need for physical device configuration or user intervention in resolving resource conflicts from https://en.wikipedia.org/wiki/Plug_and_play

[xxiii] The first installment of the Quadrennial Energy Review, released April 2015, strongly emphasizes the importance of interoperability, and includes the following key finding: "Enhancing the communication to customer devices that control demand or generate power will improve the efficiency and reliability of the electric grid. For example, open interoperability standards for customer devices and modified standards for inverters will improve the operation of the grid." http://energy.gov/epsa/downloads/quadrennial-energy-review-first-installment Also see the BTO commissioned report, "Buildings Interoperability Landscape" at http://energy.gov/eere/buildings/downloads/buildings-interoperability-landscape

[xxiv] Presentation by J. Hagerman to the Federal Facilities Council Building Control Systems Cyber Resilience Workshop, November 2015, on "Cyber Efforts for Federal Facilities", available at http://sites.nationalacademies.org/DEPS/FFC/DEPS_166792

[xxv] see A Framework for Characterizing Connected Buildings Equipment. Available at http://www.regulations.gov/#!documentDetail;D=EERE-2014-BT-NOA-0016-0047

[xxvi] Virginia Tech, with funding from DOE BTO, developed the Building Energy Management Open Source Software (BEMOSS™) operating system that is engineered to improve sensing and control of equipment in small- and medium-sized commercial buildings. See http://www.bemoss.org/

[xxvii] see R. Pratt, PNNL: http://energy.gov/eere/buildings/downloads/technical-meeting-software-framework-transactive-energy-volttron-2015

[xxviii] see J. Stoustrup, S. Rahnama at al. Power balancing aggregator design for industrial consumers using direct control. In *Proceedings of the 2015 European Control Conference*, Linz, Austria, July 2015. EUCA. R. Pedersen, J. Stoustrup et al. Aggregation and control of supermarket refrigeration systems in a smart grid. In *Proceedings of the 19th IFAC World Congress*, Cape Town, South Africa, August 2014. IFAC.

[xxix] In 2016, BTO and PNNL will work with industry to define an overarching maturity model for connected equipment, including HVAC controls, which then can be employed, on a voluntary basis, to evaluate the features and attiributes of connected equipment.

[xxx] Characterization is "the measurement or evaluation of physical or informational responses that are possible for connected equipment". Examples of physical measurements may include temperature, voltage, current, frequency, or time. Informational response evaluations may include validation of data file formats, status alerts, or sensor values. Characterization may include the evaluation of information oriented functions (e.g., forecasting, status, or diagnostics). DOE. 2015. http://www.regulations.gov/#!documentDetail;D=EERE-2014-BT-NOA-0016-0047

[xxxi] Presenation July 11, 2014 at the public meeting on the Physical Characterization of Grid-Connected Commercial and Residential Buildings End-Use Equipment and Appliances. Presentations and notes from the meeting at: http://energy.gov/eere/buildings/downloads/public-meeting-physical-characterization-grid-connected-commercial-and See the "Scope and Draft Framework" materials, slide 20; characterizaton is not label development, annual energy efficiency testing, test procedure development, etc.

[xxxii] Definitions. These B2G terms have been established in BTO's public meetings & reference documents (through review and comment):

- **Transaction** – The negotiated exchange of products, services, and rights within a structured or unstructured market that enables allocation of value among all parties involved (known as settlement).Transaction require the exchange of the …
    - Physical (in our case, Energy + Information)
    - Logical (in our case, controls or control systems that act on information)
    - Financial (in our case, a price to determine value to users)
- **Transaction Based Controls** – controls that exchange, negotiate, & respond to information through information and communication technologies (ICT).
    - Most common signal is economics based: "price."
    - Needs advancements in fundamental sensors & controls – like plug-n-play, FDD, auto-mapping, etc.
- **Transactional Platform** – a software platform (e.g. ICT & related physical hardware) that allow applications to be programmed and negotiate/act on the exchange of information.
    - VOLTTRON is fully supported throughout DOE (OE, EERE, others) & is open source.
- **Transactive Energy** - techniques for managing the generation, consumption or flow of electric power within an electric power system through the use of economic (or market-based) constructs while considering grid reliability constraints. (GWAC)
    - The term "transactive" comes from considering that decisions are made based on a value to the parties involved. The decisions may be analogous to (or literally) economic transactions.
- **Transactive Devices** or **Connected Equipment** – consumer products with ICT that enable them to be exercised through transactions – without boundaries.
    - Available technologies are typically proprietary (e.g. vendor specific ICT)
- **Transactive Buildings** – buildings that can dynamically respond to signals or messages from entities outside the building.
    - Can provide a measurable response to entities outside the building through the utilization of building located loads.
    - Self-aware (continuously aware of building state such that availability can be quantified) and continuously interacting with the larger systems they are a part (e.g. campuses, grid, etc.)
        - through ICT, negotiations, etc.
- **Transactive Campuses** are the physical locations of fully integrated collections of transactive equipment, buildings, and other EERE.
    - Transactive locations can deliver energy market and grid services through the management/ interactions of installed assets, devices, and loads.

[xxxiii] Under the American Recovery and Reinvestment Act of 2009 (Recovery Act), DOE has helped jumpstart nationwide grid modernization by partnering with the electric sector to deploy smart grid technologies across the transmission and distribution systems and into customer premises to improve efficiency, reliability, and control. New technologies such as in-home displays and programmable communicating thermostats, with advanced communications and controls coupled with various types of time-based rates, have given customers greater control over their electricity use, and paved the way for new electricity flows and markets.

The Recovery Act provided $3.4 billion in federal funding, and project recipients invested an additional $4.5 billion in private funding, for a total budget of $7.9 billion. While the Recovery Act projects are only partially completed, many important benefits have already been demonstrated:

- Reliability improvements from smart distribution technologies demonstrated shorter (up to 56%) and less frequent (11%–49%) outages, and fewer affected customers.
- Conservation voltage reduction technologies applied to distribution feeders have demonstrated energy efficiency improvements from 1% to 2.5% during peak periods.

- AMI and smart meters—in conjunction with time-based rate programs and customer systems—have demonstrated reductions in peak demand (over 30% in some cases) to improve asset utilization and defer new generation capacity. One utility rolled out demand response programs to 20% of customers, thereby deferring construction of a 170 MW peaking power plant.

While the DOE Recovery Act smart grid programs have made significant contributions to improving the reliability and resilience of the nation's electricity delivery systems, the $7.9 billion public-private investment is a relatively small down payment on the hundreds of billions of dollars the electric power industry will need to fully modernize the electric grid over the next several decades.

[xxxiv] see Melton RB. 2013. *GridWise Transactive Energy Framework*. PNNL-22946 Rev., Pacific Northwest National Laboratory, Richland, WA. http://www.gridwiseac.org/pdfs/te_framework_report_pnnl-22946.pdf

[xxxv] McKinsey Global Institute June 2015 - THE INTERNET OF THINGS: MAPPING THE VALUE BEYOND THE HYPE