Introduction and Vision[1]

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Introduction

The introduction of smart sensing, metering, and control technology is transforming the nature of our power system from end to end. Enabled by the proliferation of information technology, decision makers—such as utilities and building owners—can see and understand the operation of their systems with unprecedented levels of granularity and detail. Technological advances such as smart thermostats and Phasor Measurement Units, which grant grid operators increased situational awareness, promise tremendous gains in the efficiency and grid-responsiveness of commercial and residential buildings, as well as the overall power system's reliability and efficiency.

The installation of smart sensors and meters has substantially changed the energy system throughout the country by, for example, providing insight into system performance. Yet these technologies have not yet been fully integrated and/or made available to outside parties, new pools of investors, or the consumers that they measure, communicate from, and connect to, even though the benefits of integrating such technology are significant. For example, the National Energy Technology Laboratory (NETL) found that with only 10% customer participation, the potential nationwide value of demand dispatch could be several billion dollars per year in reduced energy costs.[2] NETL also found that more than one-fourth of the 713 GW of U.S. electricity demand in 2010 could be dispatchable, offsetting new generation and transmission build for years—if only loads such as homes and commercial buildings (hereafter called buildings) could respond to that dispatch.

As another example, McKinsey estimated that "smart grid" customer applications, largely in homes and buildings, could potentially be worth $59 billion annually, including packages of pricing, in-home displays, smart appliances and information portals that would serve to reduce both demand and overall use.[3] Estimates of the national benefits of a smarter grid by other entities are also significant.[4]

The current lack of dispatchablility is the fundamental disconnect between the current state in which buildings are passive, "sleeping" untapped assets for operators and building owners, and the future state, in which buildings could act as distributed energy assets, functioning as "shock absorbers" for the grid, opening up new value streams for owners and operators, and, in general, playing an essential role in enabling a more efficient, green, and secure energy system.

The current system does not exchange energy data information between assets in buildings and between buildings and the grid. It is comprised of legacy distribution management systems (DMS) that make up the backbone of the utility's grid control and optimization systems, installed distributed energy resources (DER), including PV, fuel cells, and combined heat and power systems, and the ultimate customer-side loads (i.e., the buildings and their equipment, appliances, and devices that ultimately "consume" the energy). The left side of Figure 1 (on the next page) illustrates the current DMS with its one-way flows, and also sporadic to variable interaction between distributed energy resources and customer-side loads. The balkanized nature of the system leads to lack of coordination and integration between participants and thus substantial efficiency and economic savings are left untapped. This disconnect is inherent and obviously visible within the scales across the parties involved—the grid generates electricity in megawatts (MW), while consumers "consume" that energy in watts and kilowatts (kW), yet they pay and ultimately understand their consumption in non-energy metrics: dollars.

1 This report is being disseminated by the U.S. Department of Energy (DOE). As such, this document was prepared in compliance with Section 515 of the Treasury and General Government Appropriations Act for Fiscal Year 2001 (Public Law 106-554) and information quality guidelines issued by the DOE.

2 National Energy Technology Laboratory. August 2011. *Demand Dispatch – Intelligent Demand for a More Efficient Grid*, NETL defines demand dispatch as "a possible end state that can optimize grid operations beyond what can be achieved with Supply Dispatch alone. Supply Dispatch relies on "generation following the load" while Demand Dispatch allows "load to follow the generation" enabling full optimization of both supply and demand." Accessed 4/20/13 from Smartgrid.gov at: http://www.smartgrid.gov/document/demand_dispatch_intelligent_demand_more_efficient_grid

3 See McKinsey & Co., *US Smart Grid Value at Stake: the $130 Billion Question*, website accessed 2/25/14 at: http://www.mckinsey.com/client_service/electric_power_and_natural_gas/latest_thinking/mckinsey_on_smart_grid

4 See for example the Federal Energy Regulatory Commission, 2009, *A National Assessment of Demand Response Potential*, accessed 2/24/14 from the FERC website at: https://www.ferc.gov/industries/electric/indus-act/demand-response/dr-potential/assessment.asp. Also see Pacific Northwest National Laboratory, 2010, *The Smart Grid: An Estimation of the Energy and CO_2 Benefits*, accessed 2/24/14 from PNNL at: http://www.pnl.gov/main/publications/external/technical_reports/PNNL-19112.pdf

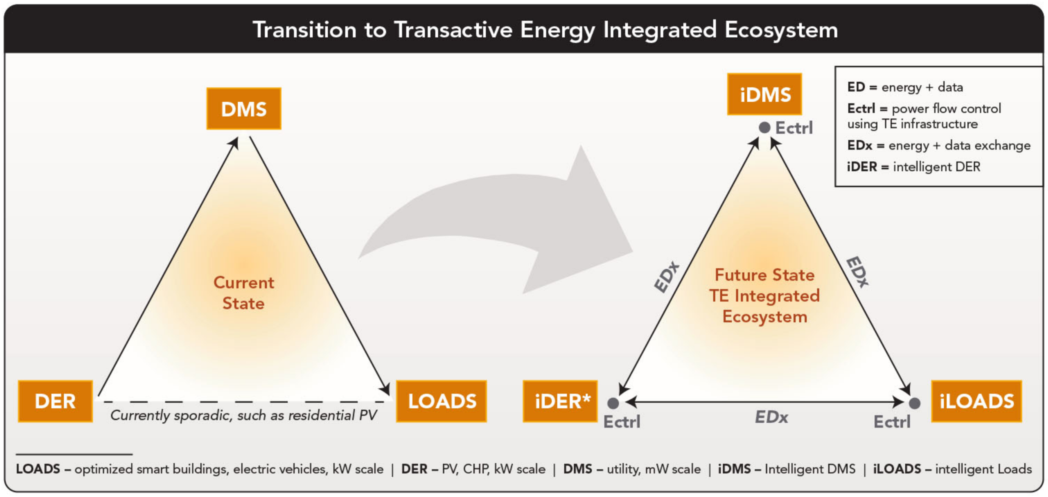

FIGURE 1. Transition to a Transactive Energy Integrated Ecosystem[5]

To unlock the true potential of buildings, a new, "transactive" approach to energy is needed that will allow the millions of sensors, meters, smart appliances, loads and distributed generation to seamlessly communicate and coordinate. Transactive energy, defined by the Gridwise Architecture Council, is "a set of economic and control mechanisms that allows the dynamic balance of supply and demand across the entire electrical infrastructure using value as a key operational parameter." It refers to the "combination of economic and control techniques to improve grid reliability and efficiency. These techniques may also be used to optimize operations within a customer's facility."[6]

The term "transactive" comes from considering that decisions are made based on a value. The value is allocated and can be based on a non-energy criteria expressed as price (such as the "green-ness" of the power, asset valuation, or comfort). These decisions may be analogous to or literally economic transactions."[7] The right side of Figure 1 illustrates the concept of a future "two-way" transactive energy-based system, which coordinates millions of small customer-side loads, such as air conditioners and lights and electric vehicles, and DER such as rooftop PV systems, to the benefit of the entire energy ecosystem.

This new transactive energy ecosystem is envisioned as a seamless, cost-effective electricity system, from generation (MW) to end-use (W), capable of meeting all clean energy demands and capacity requirements, with characteristics that span the scales and parties within the system, including significant scale-up of clean energy including variable generation renewables; consumer participation and choice with distributed generation, demand-side management, energy efficiency and electric vehicles; holistically designed solutions exhibiting regional diversity, AC-DC transmission and distribution solutions, micro-grids, energy storage, and centralized-decentralized control; and, reliability, resilience, and security throughout the cyber-physical environment.

One of the reasons why the current U.S. energy system has not yet realized the promise of transactive energy is the perceived complexity of such an energy system. Katz and Cazalet discuss this in some detail in their article "The Future of Transactive Energy."

> *"Demand response using traditional direct load control approaches is an effective utility tool to access simple sheddable loads to shave demand peaks. The problem is that direct load control cannot make use of the potential demand response of more complex systems. System complexity and inter-dependencies are opaque to the utility."*[8]

In this vision, and in the associated papers examining buildings-to-grid opportunities from the three perspectives of buildings, the grid and enabling information and communications technology, the Building Technologies Office (BTO) within the U.S. Department of Energy's (DOE's) Office of Energy Efficiency and Renewable Energy outlines the technical opportunities for building assets seamlessly to integrate and transact with grid operations, and defines the characteristics that are inherent in transaction based controls,[9] which are necessary to control those assets and operations utilizing transactive energy. BTO aims to incubate both transactive energy and transaction-based controls within its research portfolio and thereby reduce some of the market-limiting complexities that currently exist.

5 Adapted from a forthcoming report, commissioned by DOE's Building Technologies Office, due Spring 2014 from Pacific Northwest National Laboratory, *A Framework for Transactional Building Energy Services.*

6 The GridWise Architecture Council. 2013. GridWise Transactive Energy Framework: Draft Version. GWAC website accessed 11/30/13 at: *http://www.gridwiseac.org/pdfs/te_framework_report_pnnl-22946.pdf*

7 Gridwise Architecture Council website, website accessed 9/25/13: *http://www.gridwiseac.org/about/transactive_energy.aspx*

8 David Katz and Edward Cazalet. June 2013. *The Future of Transactive Energy* Electricity Today, Volume 26, No. 5. Digital version accessed 8/19/13: *http://online.electricity-today.com/doc/electricity-today/et_june_2013_digital/2013062101/#72*

9 Transaction based controls, a key element of transactive energy, are simply control solutions that allow operational decisions to be based on market signals (i.e. commodity, service, , etc.) whether it is a direct (i.e. time of day electricity price) or indirect (i.e. price given the fuel and carbon impact of the existing electricity mix) financially based indicator of the energy system.

Past and Present Approaches

Several of the foundational technological advancements enabling a future transactive-based energy system were made possible by the large scale investments into grid modernization in recent years. In 2009, the U.S. government started making $4.5 billion in federal funds available to utilities, research organizations, private companies, manufacturers, and cities to boost a smarter electric power grid with awards of American Recovery and Reinvestment Act (ARRA) grants and demonstrations.[10] Many of these grid investments were enabled by the foundational work of DOE's Office of Electric Delivery and Reliability (OE), which focused on the deployment of enabling infrastructure for automated metering, substation automation, and grid modernization. Even before the ARRA investments, utilities had begun to make significant investments at unprecedented rates in clean energy technologies, such as solar power and wind turbines.

Concurrently with OE's efforts, DOE's Office of Office of Energy Efficiency and Renewable Energy has been conducting leading-edge research, development, and demonstration projects to make new energy technologies such as solar, wind, EVs, and advanced building technologies in cooling, windows, lighting and others more commercially viable in the marketplace. However, cost reductions 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 these technologies into the electrical grid is a critical role the transactive energy-based system needs to play to ensure that utilities can continue to operate the grid in a safe, reliable, and cost-effective manner. Herein lies a challenge and an opportunity. *Without a holistic approach to integrating these technologies into distribution systems, utilities or the marketplace will not adopt them at the scale necessary to provide energy, economic, and environmental benefits nationwide.* The investment into a transactive energy-based ecosystem is thus essential to demonstrate that "grid integration barriers" associated with renewable resources, energy efficiency, and emerging technologies can be overcome so that utilities, public utility commissions, and other stakeholders will have confidence that clean energy technologies can be installed at a relevant scale while maintaining or improving grid reliability.

In past demonstrations, and even ongoing demonstrations funded by ARRA, transactive energy shows promise and demonstrates value as a more economically efficient method of managing complex energy systems. This is because end use control with connectivity is less expensive and faster to deploy than investments in new transmission capacity and traditional, stationary storage solutions (or other ancillary service solutions).

For example, the Gridwise Olympic Peninsula Test Bed Demonstration, funded by OE and several utilities in 2005, evaluated whether automated two-way communication between the grid and distributed resources could enable resources to be dispatched based on energy and price signals that they receive—which is both an example of transactive energy and transaction-based controls. Specifically, the demonstration involved the control of residential electric water heaters and thermostats, commercial building space conditioning, municipal water pump loads, and several distributed generators that were coordinated to manage constrained feeder electrical distribution through the two-way communication of load status and electric price signals. The coordination and management was achieved simply by utilizing transaction based controls and transactive energy concepts that augmented the physical energy with information regarding its current price and future price. Significant project results included 15% reduction of peak load, up to 50% reduction in total load during shoulder periods, and the potential to provide regulation and other ancillary services.[11]

In the Olympic Peninsula Test Bed Demonstration, price was the transactive signal for the system, but in the future prices may not be the most appropriate trigger for building end uses—as the desire for comfort or the revenue of the operations within the buildings, in some instances, may dwarf the cost of the energy used in the building. In "Smart Power," author Peter Fox-Penner also identified that this 2005 Demonstration tried "something that had never been tried before" and "foreshadowed both the Smart Grid's tremendous promise and its regulatory pitfalls."[12]

One relevant ongoing demonstration, funded by ARRA and AEP-Ohio, involves the first real-time market at the distribution feeder level, with a tariff approved by the PUC of Ohio. AEP-Ohio is using market bidding mechanisms to perform distributed optimization (a form of transactive energy) with 400–500 homes on 4 feeders, involving a double-auction retail market where the market accepts demand bids and clears on 5-minute intervals. The demonstration includes a smart thermostat and home energy manager, which acts as agent to offer bids and accept clearing price and controls local resources, e.g., thermostat, based on a cleared price. Homeowners set (and change) their comfort/economy preferences with the smart thermostat.[13]

10 Smart Grid.Gov Website, accessed 12/30/13: *http://www.smartgrid.gov/recovery_act/overview*

11 DR Hammerstrom, R Ambrosio, TE Oliver et al. 2008. *Pacific Northwest GridWise™ Testbed Demonstration Projects*; Part I. Olympic Peninsula Project. PNNL-17167. Pacific Northwest National Laboratory, Richland WA. PNNL website accessed 10/1/13 at: *http://www.pnl.gov/main/publications/external/technical_reports/PNNL-17079.pdf*

12 Peter Fox-Penner. 2010. Smart power: *Climate Change, the Smart Grid, and the Future of Electric Utilities*. Island Press, Washington, DC.

13 Smart Grid.Gov website, accessed 12/30/13: *http://www.smartgrid.gov/project/aep_ohio_gridsmartsm_demonstration_project*

The Benefits of a National Solution

The mission of BTO is to develop and promote efficient, environmentally friendly, and affordable technologies, systems, and practices for our nation's residential and commercial buildings that will lower energy use and greenhouse gas (GHG) emissions, spur economic growth and continue America's role as a global innovator while providing the energy-related services and performance expected from our buildings. The overarching long-term goal of BTO is to reduce building-related energy use 50% by supporting the development and deployment of energy-efficient technologies and systems.

Buildings will need to play a critical role in the realization of any smart grid solution for a number of reasons. First, buildings consume 73% of the nation's electricity—today's power system largely exists to serve human needs in buildings.[14] Moreover, buildings will also drive nearly 70 percent of the projected electricity use growth through 2040.[15] Second, buildings' demand for air conditioning services, in particular, drives summer system peak demands.[16] Third, buildings are the main efficiency testbed for the millions of smart technologies, such as controls, diagnostics and appliances that are being deployed, and will play a key role in mobilizing the electrification of transportation by hosting EV charging locations. Fourth, owners of both residential and commercial buildings are adding hundreds of megawatts of distributed generation to their structures every year, effectively challenging the current paradigm of one way delivery of power.[17] And finally, gains in the energy efficiency of buildings, equipment and appliances can transform them into recognizable, bankable assets, acting as the lowest cost virtual storage that is already at scale and deployed in the market today.[18]

The future energy economy that BTO envisions will include an open, interoperable transaction-based system that facilitates physical transactions of energy, energy-related services, and the financial settlements associated with these transactions. This transactive energy system will directly and indirectly deliver national benefits, including:

- Enabling the BTO goal of achieving 50% energy savings in buildings by unlocking new value streams and business models for building owners and homeowners from investments in energy efficiency
- Increasing the share of clean-energy sources in the generation of our electricity and thereby reducing greenhouse gas emissions
- Creating clean energy jobs in several industries, such as operations and management, control technologies and applications, software development, and energy management services
- Improving asset utilization by relieving peak loads on generation, transmission, and local distribution systems
- Reducing investments in new generation, transmission and distribution capacity
- Reducing the cost of providing balancing (ancillary) services needed to keep the grid stable, thus reducing operating costs and mitigating future costs for capacity to manage the increasing penetration of variable renewable energy sources
- Integrating utility-owned assets with increasing penetration of customer owned, operated, and deployed distributed generation solutions, including photovoltaic systems and EVs, with efficiency and operational services

For building owners and operators, the benefits will include: gaining an in-depth understanding of the energy usage of their buildings; seeing additional cash flow opportunities from intra- and inter-building energy transactions, as well as advanced DR opportunities between the building and the grid; and, realizing efficiency gains from advanced load and asset control mechanisms.

These benefits will result from the system unlocking efficiency gains and creating new markets in the grid and buildings sector, as well as ancillary industries. Opening up the energy market to new participants is a critical step towards realizing these benefits. *Participants in open markets should be able to reconcile the cost and benefits of these complementary transactions among all interested parties to support value streams (new or existing) in energy efficiency, cost reduction, customer specific service needs, and enhanced reliability of the electricity infrastructure.* This optimization can be facilitated with a common integrated approach to the exchange of energy related data, and any associated financial data.

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[14] DOE/EIA. 2014. *Annual Energy Outlook 2014: Early Release*. Reference Case. EIA website accessed 1/06/14: *http://www.eia.gov/oiaf/aeo/tablebrowser/*

[15] Ibid.

[16] For example, see FERC Chairman Wellinghoff's "A Day in the Life of the Grid" and its discussion of system challenges to the hottest day of the summer in the Midwest. See "Green Tech Media", accessed 8/19/13: *http://www.greentechmedia.com/articles/read/A-Day-in-the-Life-of-the-Grid-with-Jon-Wellinghoff-Chairman-of-FERC/*

[17] See for example the PV growth in commercial buildings at DOE/EIA, 2012, *Utility Scale Installations Lead PV Growth*. EIA website accessed 1/06/14: *http://www.eia.gov/todayinenergy/detail.cfm?id=8570*

[18] Previous research by Katz and Cazalet has calculated that the cost for purchasing on kilowatt-hour of battery storage is approximately 10 times the cost of configuring a facility for one kilowatt-hour of demand response. See: David Katz and Edward Cazalet. June 2013. *The Future of Transactive Energy*, Electricity Today, Volume 26, No. 5. Digital version accessed 8/19/13: *http://online.electricity-today.com/doc/electricity-today/et_june_2013_digital/2013062101/#72*

The Path Forward

Presently, most energy-related components and systems within residential and commercial buildings are controlled with methodologies that are not designed for two-way communication with either the grid or other buildings, and often deliver suboptimal energy operations. These systems are generally unaware of perturbations and potential opportunities both within and outside the building envelope. Control and dispatch of loads and onsite generation are often rudimentary with heavy human interaction and extensive customization, which is neither cost effective nor scalable.

BTO's long-term vision for buildings is that they will actively support the integration of renewable and other variable, distributed generation resources while simultaneously providing building owners with enhanced comfort, amenity and economic and other opportunities. Buildings will furthermore provide cost-effective resiliency and robustness to the grid, offset expensive new generation and transmission investments, and enable several ancillary benefits, such as supporting the deployment of EVs.

The primary building-level issue that limits the scale and penetration of response is a deficiency in the ability to share performance information or transact load and energy services within the building and with other surrounding facilities or electric distribution systems. Building loads can serve as a resource to mitigate supply and demand imbalances in addition to other ancillary services. Further U.S. leadership is needed, 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.

The path to achieving advanced automated buildings that cost effectively transact with the grid requires key opportunities for technological innovation be realized, including:

- *Open architecture control systems* that provide comprehensive solutions and capabilities that enable applications to run on various platforms from multiple vendors, interoperate with other systems applications, and present a consistent style of interaction with the user
- *Highly automated, cost-efficient sensors* for highly automated buildings that need additional sensors and metering for energy systems (e.g., plug load, lighting, and HVAC) or air quality, building occupancy, external lighting conditions, water consumption, and security; to be scalable, solutions need to be low cost (including both device and installation), accurate, reliable, wireless, and power harvesting
- *Data in standardized, open formats and taxonomy* that enable lower cost solutions to be developed (versus the situation today, where data is often locked in proprietary systems available only in batch forms using different formats and protocols)
- *High resolution data* that is relevant to the product or service that is being provided, enabling highly automated buildings to transact with the grid
- *Data analytics/tools*, such as data "mining" to improve performance or forecast the value of transactions and support a fluid and vibrant buildings-to-grid market. A critical component of any solution in building automation is predictive analytics that finds trends in how the building is performing or being used and then infers relationships between variables and creates rules to predict how the building performs under different scenarios.
- *Models* for power distribution system simulation and analysis, as well as industry standard grid modeling tools, to provide valuable information to users who design and operate distribution systems and to utilities that wish to take advantage of the latest energy technology solutions needed to incorporate the most advanced modeling techniques with high-performance algorithms to deliver the best results

Devices deployed on an open-architecture platform in the electric power system (on both sides of the revenue meter) will have to meet very strict requirements for availability, reliability, and security. Truly open-architecture controls systems will enable reduced transaction costs, thus ensuring competitive pricing and competition for business. Properly developed, these systems will deliver true 'plug-and-play' capability, similar to state-of-the-art software operating systems.

Conclusion

Our current energy systems does not value buildings appropriately, leading to billions of dollars in efficiency, energy, and infrastructure savings left untapped. National efforts, such as the Obama Administration's open data initiative, have started to highlight the importance and new opportunities for energy-data information that could support extracting the currently hidden value from buildings acting as distributed energy resources. With more understanding of the end-to-end nature of the data and related energy and energy related uses that the data describes, these energy-data opportunities could dwarf the economic benefit that other open data initiatives have realized (such as providing access to GPS-satellites and NOAA weather data) because of the sheer number of devices and installations across the country.

While transactive energy approaches are still being tested in demonstrations, their promise has led interested parties to already agree on several fundamental principles that will drive the transition towards a better energy future. For example, building owners, users and operators, and utilities and energy service providers, desire to realize more value in the foundational relationship between their buildings, devices, and the grid than exists today. They want to ensure that the smart devices that already have been installed provide additional value to both buildings and the grid by communicating in a true two-way fashion, so that the inter-dependencies are managed and become visible as a financial opportunity. They desire that the devices and buildings should know their state and the energy ramifications of changing their state so that buildings can respond when the grid needs it, and realize value for doing so. They are open to new business models, opportunities, and strategies that augment the group of energy stakeholders, allow new parties to engage in energy transactions and encourage research and development of energy efficient and renewable energy technologies.

The BTO effort in transaction based control technologies for buildings and building components will help realize the future of transactive energy. Enabling their ability to support the integration of intermittent, renewable energy in the form of, transactive energy will turn buildings into already deployed, low-cost storage for the grid, ready to balance both peaks and valleys of demand in a seamless, automated fashion. Empowering owners, operators and tenants by granting them access to currently inaccessible energy markets, transactive energy will open up new cash flow opportunities from energy savings and trades, efficiency gains, and in-depth understanding of buildings' energy use. Transforming the energy sector, BTO's effort will support the opening of new markets to new participants, leading to economic development, new American jobs, and homegrown technological leadership that will define our global competitiveness and energy independence.

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