Reference Guide for a Transaction-Based Building Controls Framework

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Executive Summary

Buildings consume over 40% of the total energy in the U.S. and over 70% of the nation's total electricity today. Since the mid-1970s, more concerted efforts to increase energy efficiency in commercial and residential buildings have led to substantial reductions in energy use per square foot. Yet while new buildings offer opportunities to builders and operators to take advantage of state-of-the-art energy efficient technologies and know-how, the existing building stock would require comprehensive, "deep" retrofits to achieve similar savings.

A new building diagnostic and controls revolution is underway within the buildings sector, primarily in the commercial buildings sector. In it, application-based systems are presenting an opportunity to implement strategies in which highly "optimized" control capable of constantly increasing efficiency levels while improving resource allocation (both local and global) is an inherent attribute of the strategy rather than an explicitly programmed feature. These building controls and algorithms can also be part of deep retrofits in existing buildings that result in energy savings not just today, but also ensure persistent energy savings over the life of the buildings through improved operation and maintenance. At the same time, the introduction of sensors and controls, as well as information technology and communication protocols between the buildings and the electric grid, has led to digitized sensing, metering, communication and controls. This "smart grid" revolution is adding intelligence to the energy ecosystem, allowing power generators and grid operators to see the system at unprecedented levels of granularity. Added to these developments is the proliferation of photovoltaic cells, small-scale natural gas generators, as well as other distributed generation sources; giving building owners additional opportunities to reduce their energy costs and increase the reliability of their supply.

Using these technological advances and careful coordination, buildings could provide valuable comfort and productivity services to building owners and occupants, such as automatically and continuously improving building operations and maintenance, while at the same time reducing energy costs. Ultimately, buildings could even act as dispatchable assets, providing services to the power system, such as absorbing the fluctuations of intermittent renewable energy.

This document proposes a framework concept to achieve the objectives of raising buildings' efficiency and energy savings potential benefitting building owners and operators. We call it a transaction-based framework, wherein mutually-beneficial and cost-effective market-based transactions can be enabled between multiple players across different domains. Transaction-based building controls are one part of the transactional energy framework. While these controls realize benefits by enabling automatic, market-based intra-building efficiency optimizations, the transactional energy framework provides similar benefits using the same market-based structure, yet on a larger scale and beyond just buildings, to the society at large.

The premise of transaction-based control is that interactions between various components in a complex energy system can be controlled by negotiating immediate and contingent contracts on a regular basis in lieu of or in addition to the conventional command and control pattern. In the buildings arena, transaction-based controls would bring an array of changes. Existing buildings would be retrofit with transaction-based automatic fault detection and diagnostics and controls technologies on various types of commercial equipment. They would provide insights into current and projected energy use, comfort preferences of tenants or owners, and generation capacity from distributed resources. The added

technology base would fulfill two main purposes. Owners and tenants could benefit from the diagnostics, commissioning and retuning capabilities in several ways. The sensing and metering technology could, for example, provide building-specific advice to owners, outlining return on investments and timescales for efficiency upgrades, such as new equipment or motors, or calculate and point to the amount of energy wasted per year. Transaction-based controls could also provide specific advice for occupants willing to trade their comfort and convenience levels against a monetary gain by, for example, adjusting their smart thermostat settings to let the temperature fluctuate within a pre-determined band and getting compensated for the potential change to their comfort level. Unlocking the vast resource of trading comfort levels at a certain cost is one of the key value propositions the transaction-based energy system engenders.

In general, using a transactional framework to coordinate currently disparate entities has the potential to provide substantial energy savings and new cash flow opportunities to buildings, effectively turning currently disparate and passive assets into coordinated engines of efficiency and productivity. The framework offers the opportunity to extract services out of loads and assets that previously did not exist; delivering building owners targeted benefits while enabling ancillary benefits, such as reduced energy costs, reduced energy use and reduced emissions to society as a whole.

This document discusses a non-exhaustive, but representative set of exchangeable products, services, and rights in the context of four major types of transactional interactions: 1) end-user services, 2) energy market services, 3) grid services, and 4) societal services. End-user services include building diagnostics and valuations, which support the operations and maintenance of end-use assets and enhance overall customer comfort and convenience. Energy market services support the efficient utilization of resources and assets by helping customers modify their energy consumption behavior through mechanisms such as time-of-use and real-time pricing. Grid services could include ancillary or regulatory services that buildings could provide using transactive mechanisms. Lastly, societal services could include participation in energy efficiency or emissions cap-and-trade markets using transactive mechanisms.

The document then describes the services nodal network that will help researchers and private vendors develop solutions that can be deployed at a large scale across the various participating domains, and ensure that such solutions are compatible and interoperable. A general framework and set of communication protocols that support interoperability are outlined. Listing real-world examples, this reference guide describes the network topology of participating logical and physical nodes and the communication interfaces between them.

The document is complemented by four chapters corresponding to each of the four service categories described above. Each of the four chapters contain separate groups of comprehensive use cases of transactive energy, including the timescales of transactions, the needed equipment and technology, the benefits for buildings, the grid, efficiency gains and renewable energy integration, and outlines contracts and regulations and current examples of these transactions.

Acknowledgements

Terms and Definitions

Advanced Metering Infrastructure (AMI): typically refers to the full measurement and collection system that includes meters at the customer site, communication networks between the customer and a service provider, such as an electric, gas, or water utility, and data reception and management systems that make the information available to the service provider. Advanced metering systems are comprised of state-of-the-art electronic/digital hardware and software, which combine interval data measurement with continuously available remote communications. These systems enable measurement of detailed, time-based information and frequent collection and transmittal of such information to various parties.

Ancillary Services: Ancillary services are services necessary to support the reliable transmission of capacity and energy from generation resources to customers, while maintaining the reliable operation of a transmission system. Ancillary services can include: synchronized reserves, regulation and operating reserve, energy imbalance (using market-based pricing), and the cost-based services of scheduling, system control and dispatch, voltage control and black start.

Applications: Implementation of one or more use cases (enabling a transaction) and services (shared resources and functions among applications (e.g., libraries, drivers, etc.))

Architecture: Provides a conceptual structure describing the overall organization and inter-relation of significant components and systems for a particular problem space. The architecture embodies the higher-level principles and requirements that designs of applications and systems must satisfy.

Building Automation System (BAS): A distributed supervisory and control systems installed in commercial and industrial buildings that support optimal facility operation and performance. BASs are hard and software based and connect individual monitors, meters and sensors within the facility in one central location.

Building Energy Management Systems (BEMS): Similar to BAS, BEMS monitor and control services such as heating, ventilation and air-conditioning (HVAC) within commercial and industrial facilities. BEMS balance energy use, and operating and environmental conditions to increase a facility's efficiency.

Demand Response (DR): Changes in electric usage by end-use customers (including automatic responses) from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized.[1]

Distributed Energy Resource (DER): DERs are small, modular power-generators placed close to the point of energy consumption. DERs include wind turbines, photovoltaic (PV) solar installations, or gas turbines, among others, and can support local electricity supply and reliability and local energy autonomy (e.g., a microgrid, energy storage, and electric vehicles).

Exchange: A structured or unstructured market that enables the allocation of value among all parties involved (i.e. a settlement)

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[1] Per Federal Energy Regulatory Commission (FERC) definition.

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Framework: The description of a system at a broad, conceptual level, which can provide a context for more detailed technical aspects of the subject matter, including models and architectures that can guide the design of implemented solutions.

Interoperability: The capability of two or more networks, systems, devices, applications, or components to exchange and readily use information—securely, effectively, and with little or no effort by the user. That is, different systems will be able to exchange meaningful, actionable information. The systems will share a common meaning of the exchanged information, and this information will elicit agreed-upon types of response. The reliability, fidelity, and security of information exchanges between and among the energy ecosystems must achieve requisite performance levels.

Independent System Operator (ISO): ISO that originated out of FERC order 888/889 to help existing tight power pools satisfy the requirement of providing non-discriminatory access to transmission. ISOs are predecessors to Regional Transmission Organizations, voluntary formations of electric transmission grid operators within a multi-state system (including Canada).

Market: An area of economic activity in which buyers and sellers come together and the forces of supply and demand affect prices.

Market Participation/Access: The market participation/access refers to a qualitative characterization that considers:

- Ease of entry/exit into the market

- Size of transaction costs relative to the expected value of a transaction

- Number of buyers and sellers seeking to maximize their value.

Market Price: A price actually given in current market dealings.

Node: A communication or connection point able to send and receive information. Nodes could be physical, such as a modem, switch or other networked device, or virtual, such as ones based in the Cloud.

Reference Model (per above described architecture): A set of views (diagrams) and descriptions that are the basis for discussing the characteristics, uses, behavior, interfaces, requirements, and standards of the energy ecosystem. This model does not represent the final architecture of the energy ecosystem; rather it is a tool for describing, discussing, and developing that architecture.

Requirement: 1) A condition or capability needed by a user to solve a problem or achieve an objective. 2) A condition or capability that must be met or possessed by a system or system component to satisfy a contract, standard, specification, or other formally imposed documents.

Sensors and Controls: Mechanical and/or electric devices sensitive to light, temperature, humidity, etc. that transmit a signal to a measuring or control instrument, which can act independently, based on set parameters and the information available.

Services: Shared resources and functions among applications (e.g., libraries, drivers)

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Standards: Specifications that establish the explicit set of requirements for a product for a particular use, its function and performance. Standards are key facilitators of compatibility and interoperability. They define specifications for languages, communication protocols, data formats, linkages within and across systems, interfaces between software applications and between hardware devices, and much more. Standards must be robust so that they can be extended to accommodate future applications and technologies. An assortment of organizations develops voluntary standards and specifications, which are the results of processes that vary on the basis of the type of standards setting-organization and its purpose. Government regulations may incorporate or reference voluntary and required standards.

Transactional Energy Ecosystem: A construct that integrates the concepts of *transaction-based energy* and *transaction-based control* (described below), with a settlement (market) platform

- **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-based control:** 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.

- **Transaction-based control applications:** A type of application that has a set of capabilities, such as discovery, self-organization, agent mobility, secure communications, short and long lifetimes, autonomy and self-organization. Furthermore, these applications have characteristics, such as:
  - Belief propagation based on local data (which has a convergence concept associated with it)
  - Decentralization but no coordination
  - Dynamic and possibly short-lived associations of agent subsets
  - Flocking behavior (think stock market flash crash)
  - Self-relocation
  - Possible emergent behavior.

- **Transaction-based energy:** A structure that combines information, data and energy infrastructure to enable energy-based transactions.

- **Transaction-based energy services**: Transaction-based energy services for energy providers and customers balance all parties' energy needs against available resources, thereby making at least one individual better off without making any other individuals worse off.

Transaction-based Framework: The transaction-based framework describes the digital infrastructure, hardware and communications network that enables the trade of goods and services between participating parties, leading to a better use of available resources and a more efficient power system.

Value: The monetary worth of goods, services or rights, specifically capacity, energy, ancillary services, and O&M services.

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1.0   Unlocking the True Potential of Buildings: Transaction-Based Building Controls Framework

This document provides a contextual framework and the specifications of a descriptive model of nodes in a transactive network that would enable buildings and other assets to deliver services to building owners and occupants, as well as other participants in the energy ecosystem. Its purpose is to define the concept of the transactional building controls framework, including the transactional network model, illustrate the future transaction-based energy ecosystem, give examples of potential implementations, and outline the benefits of transactional energy to stakeholders in the energy ecosystem.   While it is not intended to prescribe specific technology solutions, the document contains an extensive list of "use cases" describing a range of possible applications of transaction-based energy services, technical requirements to fulfill these, as well as a qualitative description of benefits to participating stakeholders. These use cases are envisioned to define essential components that would enable transactions in the energy and energy-related domains and give practical examples to the broader community of electric power and buildings technology organizations, researchers, manufacturers, standards- and codes-developing organizations, and system and technology vendors.

1.1 Present State

Buildings consume over 40% of the total energy in the U.S. and over 70% of the nation's total electricity today. Residential buildings, by themselves, account for about half of the electricity use (37%), and require 291GW of peak electric generation capacity. Since the mid-1970s, more concerted efforts to increase energy efficiency (EE) in commercial and residential buildings have led to substantial reductions in energy use per square foot. Driven by building codes, prescriptive measures, energy audits, advances in efficient lighting, HVAC and energy management systems, the residential and commercial building sectors have lowered their energy intensity by over 30% [Nadel 2011]. Existing building codes apply only to new construction and major renovations of existing buildings in the U.S. and can lead to additional savings of between 10 and 20%.

Yet while new buildings offer opportunities to builders and operators to take advantage of state-of-the-art EE technologies and know-how, the existing building stock would require comprehensive, "deep" retrofits to achieve similar savings. Burdened by badly performing equipment, appliances, walls and windows, the existing building stock faces cost barriers and several other obstacles to increased EE. Residential buildings, for example, overwhelmingly have analog electricity meters, manual lighting; plug loads and appliances; and no central control.

In the case of commercial buildings, even as buildings are made more energy efficient through codes, standards and beyond-code design processes, over $30 billion worth of consumed energy is wasted by the lack of controls or the inability to use existing building automation systems (BASs) properly. Over 90% of the commercial buildings are either small-sized (<5,000 sf) or medium-sized (between 5,000 sf and 50,000 sf), and most if not all these buildings lack the sensors and information systems needed to create the "self-awareness" required to continually tune and operate them at optimal efficiency with proper tradeoffs between cost and occupant service requirements (e.g., comfort) [Katipamula 2013].

The preferences, desires and flexibility of building occupants are also hardly ever considered in EE decision making. While building occupants could offer a large and tradable resource of exchanging comfort levels for energy savings (in exchange for some monetary gain, for example), the current state is leaving them out of the equation. The large expense of deep retrofits (and with it long payback times), as well as the lack of broad access to sensing and measuring technologies, and the current disregard for occupants willingness to trade comfort for savings are a few reasons why the outlook for greater gains in EE for the existing building stock is substantially less positive than in new buildings.

1.2   The Smart Buildings Revolution

A new revolution is underway within the buildings sector, primarily in the commercial buildings sector, where application-based systems are presenting an opportunity to implement strategies in which highly "optimized" control, capable of constantly increasing efficiency levels while improving resource allocation (both local and global) is an inherent attribute of the strategy rather than an explicitly programmed feature. The premise of transaction-based control is that interactions between various components in a complex energy system can be controlled by negotiating immediate and contingent contracts on a regular basis in lieu of or in addition to the conventional command and control. Figure 1.1 illustrates the connections between sensors, devices and controls in a small commercial building.
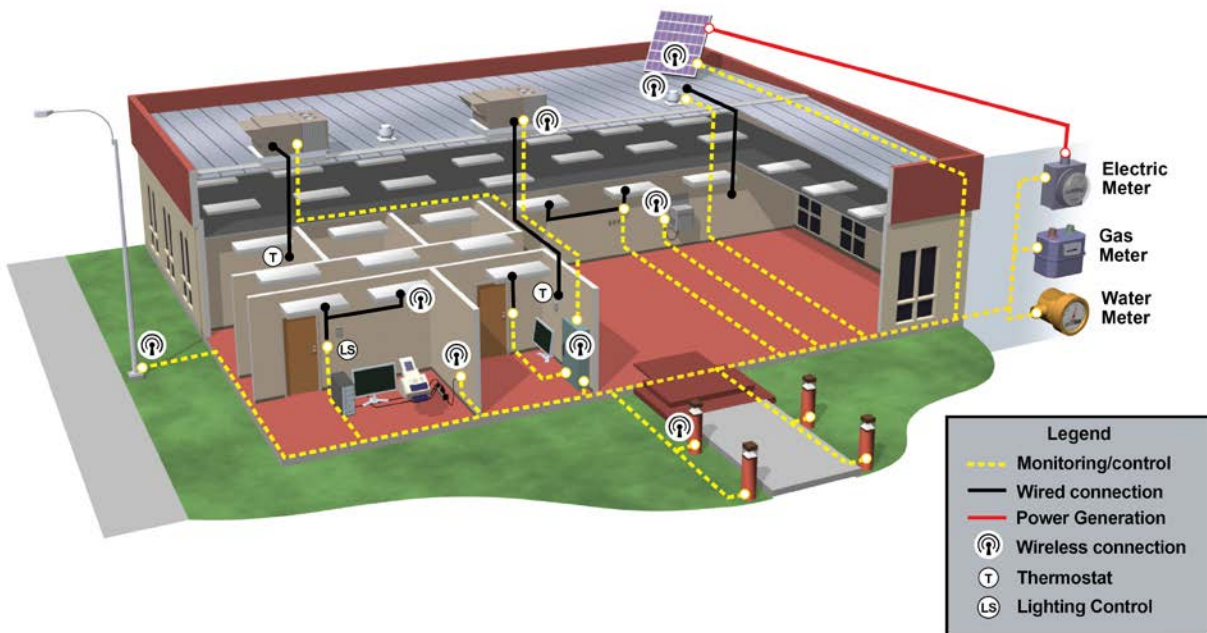
Figure 1.1. Illustration of Transaction-Based Controls in a Small Commercial Building

Each device is given the ability to negotiate deals with its peers, suppliers and customers to maximize revenues while minimizing costs. This is best illustrated by an example. A typical commercial building might have several chillers that supply a number of air-handling units (AHU) or air handlers with chilled water on demand. If several air handlers require the full output of one chiller, and another air handler

suddenly also requires cooling, traditional building control algorithms simply start up a second chiller to meet the demand and the building's electrical load ratchets upward accordingly. A transaction–based building control system behaves differently. Figure 1.2 illustrates building components. Instead of honoring an absolute demand for more chilled water, the air handler requests such service in the form of a bid (expressed in dollars), increasing its bid in proportion to its "need" (divergence of the zone or supply air temperature from its set point) [Katipamula et al 2006]. The chiller controls, with knowledge of the electric rate structure, can easily express the cost of service as the cost of the kWh to run the additional chiller plus the incremental kW demand charge (if it applies). If the zone served by this air handler just began to require cooling, its "need" is not very great at first, so it places a low value on its bid for service and the additional chiller stays off until the level of need increases.
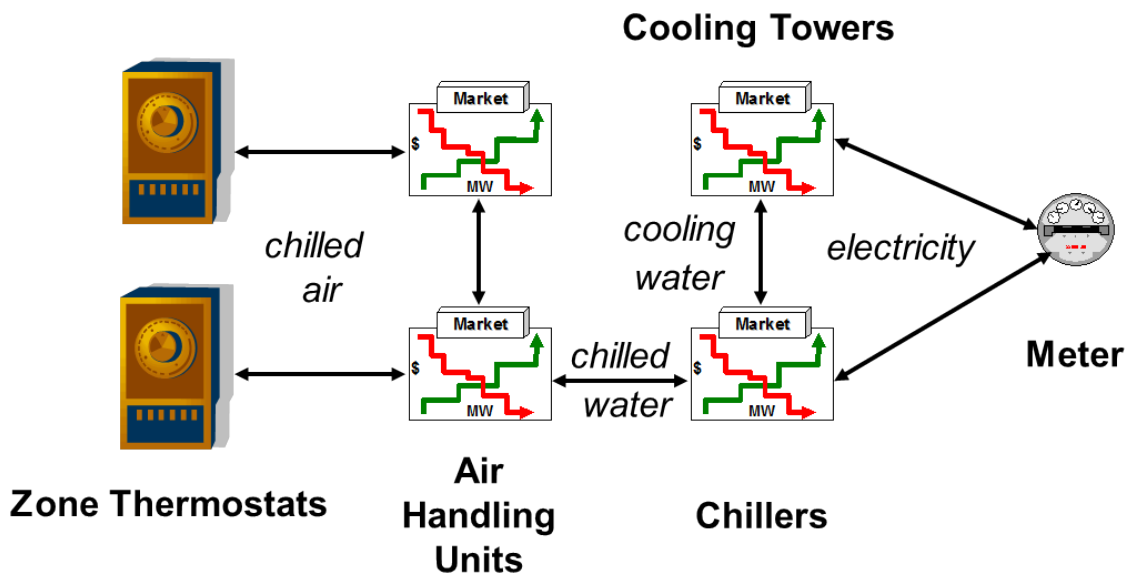
Figure 1.2. Conceptual Overview of Transaction-Based Building Control System

Meanwhile, if another air handler satisfies its need for cooling, the cost of chilled water immediately drops below the bid price because a second chiller is no longer required, and the air handler awaiting service receives chilled water. Alternatively, a peer-to-peer transaction can take place in which an air handler with greater need for service displaces (literally outbids) another whose thermostat is nearly satisfied.

In this way, the contract-based control system accomplishes several things. First, it inherently limits demand by providing the most "cost-effective" service. In doing this, it inherently prioritizes service to the most important needs before serving less important ones. Second, it decreases energy demand and consumption by preventing the operation of an entire chiller to meet a small load (assuming that no AHU is willing to pay the additional cost of service to start the second chiller), where it operates inefficiently.

Third, contract-based controls inherently propagate cost impacts up and down through successive hierarchical levels of the system being controlled (in this example, a chiller or a boiler that provides cooling or heating, air handler that provides air circulation, and the zone). The impacts on the utility bill, which are easily estimated for the chiller operation, are used as the basis for expressing the costs of air handler and zone services. Using cost as a common denominator for control makes expression of what is

effectively a multi-level optimization much simpler to express than an engineered solution would be. It allows controls to be expressed in local, modular terms while accounting for their global impact on the entire system. In effect, the engineering decision-making process is subsumed by a market value-based decision-making process that indirectly injects global information conveyed by market activity into the local engineering parameters that govern the behavior of individual systems over multiple time scales.

Many HVAC systems are controlled by thermostats. The desired temperature is set by the customer and the thermostat uses current space temperature sensor information to control the damper position that controls the air flow (or turns the compressor on or off), thereby satisfying the heating and cooling needs of the zone. In a conventional control system, indoor temperature and indoor set point temperature are the only information required to control the amount of heating and cooling to the zone. However, in a transactive based control system, the thermostat uses price information to make control decisions. Although much of the discussion so far has been for thermostatically controlled HVAC systems, transactive-based controls can be applied to non-thermostatically controlled systems as well (such as distributed generation, other load resources).

With appropriate technology and coordination, buildings could provide valuable services to owners and occupants, such as automatically and continuously improving building operations. On a larger scale, groups of buildings could transact with each other in a cap-and-trade type of arrangement, where one building could reduce energy or increase efficiency measures more easily than another, and then trade energy savings or efficiency gains for payments. Ultimately, buildings could even act as dispatchable assets, providing services to the power system, such as absorbing the fluctuations of intermittent renewable energy.

How could buildings be smarter? In the area of residential buildings, expanded penetration of smart controls scheduling appliances, automatically adjusting thermostat set points, dimming lights, and delaying water heater standby electric heating, are some of the technological changes needed. Some of these transaction-based controls may reduce total annual electricity consumption from the residential building sector (for example, dimming lights reduces total electricity consumption, rather than just shifting the load), so there is a potential for even greater energy cost savings.

One of the greatest obstacles for the penetration of transaction-based controls at the commercial building level is the lack of standardized, simple control interface hardware and software. The installation of automation and control systems tends to be unique to each building and, therefore, exhibits no economies-of-scale for later installations. Another important theme during the implementation of the transaction-based framework should be "flexibility." Transaction-based control will be accepted better if it can be flexibly tailored to the needs and capabilities of each building, the building owner, and the building's occupants.

Enabling the demonstrations of the transaction-based controls in individual buildings and then in a cluster of buildings to be flexible and portable across various BASs protocols and systems, should significantly reduce the cost of implementation compared to conventional approaches. But for 85% of the commercial buildings, which lack BASs, other delivery options, including using inexpensive gateways have to be explored.

Many new Internet-protocol-based controls provide a rudimentary ability to integrate individual appliances and assets within the building to allow the building to automatically and continuously raise its

efficiency. For example, automated lighting controls systems ranging from simple scheduling to sensor-based systems can actuate electric lights according to occupancy or ambient light levels – incorporating a variety of occupant personal control options.

Similarly, there have been several advances in the area of BASs. Their automatic programming strategies make them the preferred way to implement many energy efficiency strategies in commercial buildings. Yet the penetration of these systems into small-sized commercial buildings is low. This is mainly because they are perceived as expensive and because the building owners are not fully aware of the benefits.

Lastly, the introduction of information technology to the electric grid has led to digitized sensing, metering, communication and controls adding intelligence to the power system all the way from the point of generation to the final consumption of power. The new, "smart grid," technology allows grid operators and planners to see the system at unprecedented levels of granularity. Phasor measurement units (PMU), for example, deliver GPS synchronized snapshots of the bulk power system's status at time intervals as short as 60 times per second, leading to better understanding of the system and opportunities to more quickly react to changes, ensuring high levels of system reliability. Advance metering infrastructure (AMI), or "smart meters," are supporting utilities with deep insights into the status of the distribution system, including detecting outages, electricity theft, and detailed (up to every 15 minutes) use data for billing purposes and consumption inquiries, while reducing meter reading and truck roll costs, especially for commercial and industrial customers .

The deeper potential of AMI, however, lies in its ability to transform the energy savings potential of buildings by providing building owners and tenants with insights into energy use, while, by relaying the combined energy usage patterns to grid operators, delivering transparency of consumption that turns demand into an actual tool of grid management. AMI is a key technology that could advance current levels of demand response (DR) from its current state of long time scales, manual interactions and heterogeneous applications to a close-to-real-time, automated system that applies to the majority of energy consuming devices. One example of the potential economic value of advanced DR comes from the National Energy Technology Laboratory (NETL), which found that with only 10% customer participation, the potential nationwide value of DR could be several billion dollars per year in reduced energy costs [NETL 2011]. 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 could respond to that dispatch.

In general, advances in building automation, control technology and the smart grid are supporting the transition to smarter buildings which will benefit the entire energy system by using less energy and being more energy efficient; leading to reduced operational expenses for building owners, but also less stress on the power system for system operators, and lower emissions for society as a whole. The transition to smarter buildings is thus a "no regrets" approach that will make everyone better off.

The requirements to make the building smarter are new communication, control and sensing technologies that

- make buildings capable of automatically receiving and acting upon signals from internal and external sensors and monitors;

- can characterize the magnitude of change in demand as a result of responding to the signals;

- function reliably, with a means of verifying operation through low-cost non-intrusive means;

- are capable of delivering continuous, automated operational improvements;

- provide smart grid related services;

- are cost-effective or economical; and

- are non-disruptive during operation and minimally disruptive during installation.

To enable this to occur, however, the building owners/operators must be able to utilize and provide information on the buildings' energy use and to make decisions at time scales that are largely unfamiliar to building operators today. While some buildings have embedded controls and some computing power, they lack a way of coordinating their responses to achieve these objectives listed above (at the building scale) and still maintain acceptable comfort and productivity to satisfy the building occupants. For this to happen there is a need for a transaction-based energy ecosystem to be established.

1.3 Transactional Energy Framework

This document proposes a framework concept to achieve the objectives of raising buildings' efficiency and energy savings potential benefitting building owners and operators. We call it a transaction-based framework, wherein mutually-beneficial and cost-effective market-based transactions can be enabled between multiple players across different domains. Figure 1.3 illustrates the concept of transactive energy. We define the framework as encompassing a broad, conceptual level and providing a context for more detailed technical aspects of the subject matter. Transaction-based building controls are one part of the transactional energy framework. While these controls realize benefits by enabling automatic, market-based intra-building efficiency optimizations, the transactive energy framework provides similar benefits using the same market-based structure, yet on a larger scale and beyond buildings.

The U.S. Department of Energy (DOE) aims to enable and promote the development of efficient, secure, and reliable transaction-based energy services, markets and operations that integrate energy supply, demand, and related services to promote a diverse, reliable, cost effective, and sustainable domestic energy economy. DOE believes that the future energy model will include an open, interoperable transaction-based system that facilitates physical transactions of energy, energy-related services and rights, and the financial

Figure 1.3. Merging of Markets and Control

settlements associated with these transactions. The key concept here is a construct that takes advantage of the market's efficient way of allocating resources, as well as unleashing the innovation and economic efficiencies of market participants. Figure 1.3 illustrates the merging of markets and control -- a central concept of the transaction-based system.

The term "transactive energy", defined by the GridWise™ Architecture Council, refers to "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" [GridWise 2013]. This document focuses on the application of transactive energy on intra- and inter-building applications, including distributed energy sources, such as PV or natural gas turbines, and new energy use in and around buildings, all interconnected with data.

In addition, the following definitions need to be introduced here:

- **Transactional Energy Ecosystem:** A construct that integrates the concepts of *transactional energy* and *transactional control* (described below), with a settlement (market) platform

    o **Transaction-based energy:** A structure that combines information, data and energy infrastructure to enable energy-based transactions.

    o **Transaction-based control:** 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

    o **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)

- **Exchange:** A structured or unstructured market that enables the allocation of value among all parties involved (i.e., a settlement)

Some additional terms and definitions are provided in the Terms and Definitions section of this report.

1.4 The Future State

A transactional energy framework defines the basic structure of the future energy integrated ecosystem. It will lay out the transition from today's static, one directional, and often times "manual" energy system ("current state") to a new "future state" of energy, characterized by highly automated, two-way (or even n-way) exchanges of information, data and energy between entities in the energy system, leading to a flexible, resilient and automatically adjusting system. The future ecosystem will be characterized by a more distributed power system, blurring currently clear lines between producers and users of power. Utilizing distributed generation, responsive loads and automation at the distribution system, the future ecosystem will see an abundance of software and application-based sensors that work autonomously to optimize energy generation and energy use starting at the smallest application all the way towards the largest entity. This is made possible by the addition of smart, intelligent meters and sensors to all stages of the energy system, able to interconnect, exchange information, and act upon it.

The framework enables transactions of products, rights and other services that support various micro and macro energy objectives. On the micro scale, these objectives include more efficient buildings. On the macro level, more efficient buildings will lead to reduced greenhouse gas emissions, increased grid reliability, an increased share of clean energy sources, and the creation of clean energy jobs. This new

model needs to seamlessly integrate new, distributed generation as well as smart assets while adding value to the building owner/customer and other third parties. It needs to be able to control and connect assets and loads, within buildings, between buildings and, at a possible future state, between buildings, the grid and third-party providers, and enable participants to transact in ways that lead to economic and environmental benefits. The idea is to derive benefits for the customer (e.g., better managing their bills) for participating in new markets and interacting with the grid and third-party providers. Figure 1.4 illustrates the future energy ecosystem, in which self-aware, automatically optimizing buildings are interconnected with a transactional network of distributed energy assets, variable loads, other buildings and the grid.
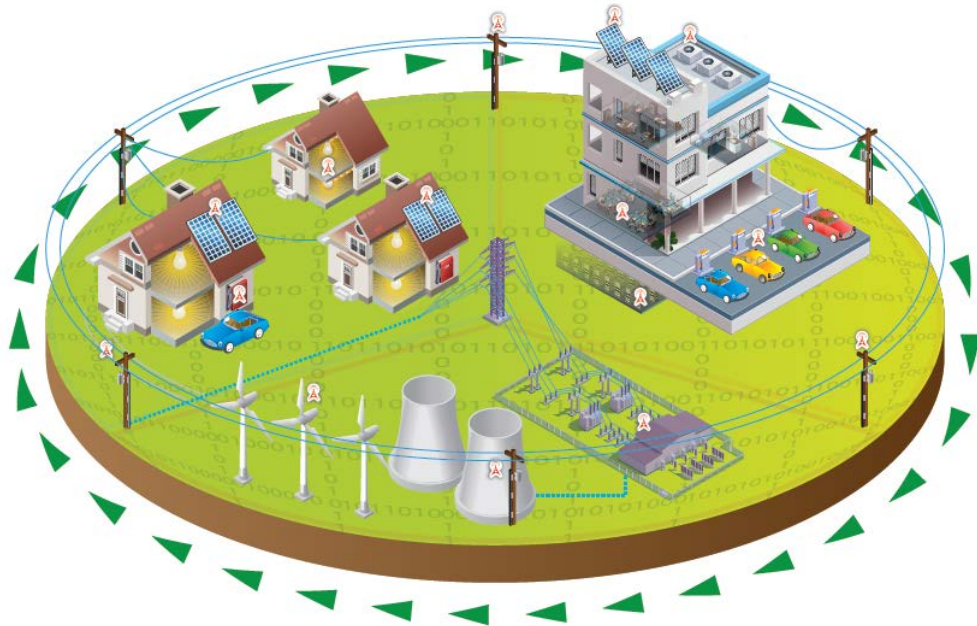
Figure 1.4. Conceptual Overview of Future Energy Ecosystem

More specifically, this future state entails an array of changes in the area of buildings. Existing buildings would be retrofit with transaction-based diagnostics and controls technology, providing insights into current and projected energy use, comfort preferences of tenants or owners, and generation capacity from distributed resources. The added technology would fulfill two main purposes. Owners and tenants could benefit from the diagnostics, commissioning and retuning capabilities in several ways. The sensing and metering technology could, for example, provide building specific advice to owners, outlining return on investments and timescales for efficiency upgrades, such as new equipment or motors, or calculate and point to the amount of energy wasted per year. Transaction-based controls could also provide specific advice for occupants willing to trade their comfort levels against a monetary gain by, for example, adjusting their smart thermostat settings to let the temperature fluctuate within a pre-determined band and getting compensated for the potential change to their comfort level. Unlocking the vast resource of trading comfort levels is one of the key value propositions the transaction-based energy system engenders.

Focusing on the building loads within the ecosystem, packaged air-conditioners and heat pumps or rooftop units (RTUs) installed in 69% of the commercial building floor space, contribute to roughly 571 trillion Btu of site electricity consumption and 1.8 quads of source energy annually. Use of advance

controls and automated fault detection and diagnostics on existing RTUs will result in significant energy and cost savings and also enhanced maintenance by introducing condition-based maintenance practices and targeting maintenance when needed. The technical potential savings based on average savings per RTU of 30% are roughly 171 trillion Btu of site electricity and 531 trillion Btu of source energy annually. In addition to improving efficiency and maintenance of the RTUs, this effort will also make the RTUs more grid-responsive, so they can interact with the grid and provide demand response and ancillary services benefiting both the building owner/customer and the utility. Although it is difficult to predict market uptake of the resulting RTU equipment, engaging utilities, deployment partners and manufacturing partners early in the effort will help post-effort deployment activities. Also, if the results from the field tests and demonstrations show significant savings and grid responsive features, a number of utilities may be interested in providing incentives to promote the product(s) and offset some of the installation cost.

1.5 Examples of Implementation

Past and ongoing demonstration projects have tested how a transactional energy framework can be employed to fulfill a range of objectives, from peak load management in the GridWise Olympic Peninsula Test Bed Demonstration to the intra-building coordination and control of multiple RTUs in the Transactional Network Project. In each case, the transaction-based approach promises to be a more economically efficient method of managing the complex power system as well as achieving within-the-building automation of RTU control to optimize occupant comfort. Controlling end uses with connectivity is less expensive and faster to deploy than investments in new transmission capacity and traditional direct load solutions through distributed assets (or other ancillary service solutions). Additionally, these demonstration projects have successfully engaged a wide range of assets in residential and commercial buildings and/or facilities, further highlighting the potential of a transactional energy framework. A series of use cases illustrating potential applications of transaction-based energy framework and its envisioned benefits to the energy ecosystem are described in Chapters 4, 5, 6 and 7.

1.5.1 Olympic Peninsula Demonstration Project

The purpose of the Olympic Peninsula (OlyPen) Project (2006-2007) was to create and observe a futuristic energy-pricing system using transaction-based controls. Specifically, this project tested whether automated two-way communication between the grid and distributed resources could enable resources to be dispatched based on the energy and demand price signals that they received. In this manner, conventionally passive loads and idle distributed generators can be transformed into elements of a diverse system of grid resources that provide near real-time active grid control and a broad range of economic benefits.

The project was designed to test transactive control with responsive assets, such as residential thermostats, water heaters, clothes dryers, and commercial HVAC systems in 112 residential households, two industrial facilities and one commercial building. The project engaged customers via in-home energy portals that allowed participants to see and manage their energy use. Figure 1.5 shows the simplified tool customers used to adjust their energy use.
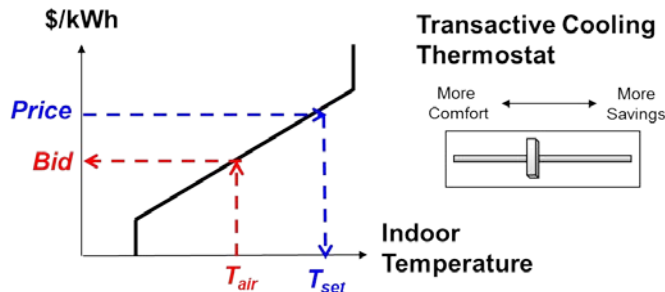
Figure 1.5 Olympic Peninsula Grid Wise Demonstration Project

More comfort on the transactive cooling thermostat slider meant that thermostats would not react to price incentives; whereas, more savings translated in thermostats participating in the market-based transactions, thus delivering savings to customers. The value propositions for the utility were to lower wholesale prices and reduce distribution capacity requirements through load shifting, while for the customer, it was to get a lower electricity bill. The result of this demonstration project was the ability to engage customers in energy use choice via transactive control that led to a reduction of 15% in peak demand (with reductions up to 50%, at times) and an average customer energy cost savings of 10%.

1.5.2 The Transactional Network Project

The Transactional Network (TN) Project is intended to support energy, operational and financial transactions between networked entities (equipment, organizations, buildings, grid, etc.) [Katipamula et al. 2013] The underlying platform of the TN consists of the PNNL developed VOLTTRON Lite™ (VL) application execution software and a number of applications that perform specific functions (fault detection, demand response, weather service, logging service, etc.) VL serves as a single point of contact for interfacing with devices (building equipment, power meters, etc.), external resources, and platform services such as data retrieval and archive. In the initial phase, the focus is on RTUs for small commercial buildings. More details on the platform can be found in the PNNL report on VL [Haack et al. 2013].

The TN platform is designed to facilitate "transactive energy" systems and markets. Transactive energy as used here refers to 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 TN project, being conducted by three national laboratories [Pacific Northwest National Laboratory (PNNL), Lawrence Berkeley National Laboratory (LBNL) and Oak Ridge National Laboratory (ORNL)], examines the role transactive networks could play in optimizing commercial building RTUs. RTUs are used in about 58% of all cooled commercial buildings and serve about 69% of the cooled commercial building floor space within the U.S.[2] The purpose of this project is to demonstrate and propagate an open source, open architecture platform that enables a variety of site/equipment specific applications to be applied in a cost effective and scalable way. This will lower the cost of entry for both existing and new service providers as the data transport or information exchange typically required for operational and energy related products and services will be ubiquitous and interoperable.

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[2] EIA 2003

The objective of the project is to use advanced controls and energy services to enable energy saving retrofit solutions and mitigate reliability issues from distributed renewable energy sources. Three transaction-based control applications (applications) were developed by PNNL to demonstrate the transactional network concept with RTUs: 1) automated fault detection and diagnostic (AFDD) application; 2) a DR application, and 3) smart monitoring and diagnostic system (SMDS) application. The current concept uses an open-source, application-based platform that runs local and remote applications, enabling the RTU network and transactions.

The applications should have the following characteristics:

- Advanced controls for variable-speed drive RTUs

- AFDD of equipment and schedule

- Wireless sensor interoperability

- Demand response (event driven, baseline load shape, measurement and verification - M&V, cost savings)

- Local energy network balancing (e.g., match consumption to peak PV output)

- Optimize consumption across multiple RTUs

- Reduce energy use and peak demand (e.g., supermarket refrigeration).

Even though the current effort involves RTU control automation, it is not transactive beyond a simple demand response concept. However, the future concepts involve two other use cases under consideration:

1. Trading capacity rights within a facility/building: the building (or facility) commits to limiting peak load (capacity), where a share of capacity limit assigned to each RTU is based on its diversified share of peak load. The RTUs, in turn, exchange capacity rights with other RTUs in the building in real time to optimize comfort while meeting the constraints.

2. Diagnostic services: the building (or facility) transacts with a third-party provider for monitoring and diagnostic analyses, conducted remotely over the network, where the fees may be based on either continual services over a subscription period, or a "fee-for-fault" based on number and/or magnitude of faults detected or fixed. This is an example of a contract for building energy services (unrelated to the grid) that is promoted by network capability, and can be considered transactional in the sense that there are real-time fees for service (the fee-for-fault case).

The above concept of managing capacity limits by granting tradable capacity rights can be extended to include transactions between two or more buildings, or even clusters of buildings. The extent of the diagnostic services is purely defined by the geographic range of the energy service providers' target market, which could be local or national in scope.

LBNL developed new software to operate with the VL platform that demonstrated the capability of both the LBNL and PNNL transactive applications at a building at LBNL [Piette et al. 2013]. LBNL designed, prototyped and tested components of this platform related to measuring system response to

various planned modifications to the building operations. These modifications include energy efficient control strategies and automated demand response events. LBNL's VL applications in the TN focus on characterizing the energy savings associated with short- or long-term operational changes in a building. A DR event would be an example of a short-term change whereas an EE measure would be a long-term change. Demand response is a change from normal patterns of electric energy consumption by end-use customers in response to changes in electricity price or incentive payments designed to induce lower electricity use when wholesale market prices are high or when the supply system reliability is jeopardized. The energy and power savings associated with these actions can be quantified and measured against the electric load that might reasonably be anticipated in the absence of those changes. These changes can be translated into economic terms based on an electricity tariff associated with a particular site. Specifically, LBNL developed four different applications to: 1) conduct a baseline electric load shape; 2) conduct measurement and verification of energy and demand savings; 3) estimate the cost savings from participating in DR events or long-term EE interventions; and 4) convey DR events using a DR event scheduler.

ORNL has been working on two applications of the TN technology that enable low-cost retrofits of small and medium commercial buildings for the purposes of improving their energy usage profile. The first application is based on a network of air conditioning thermostats and a centralized computer that coordinates their operation to achieve substantive reductions in peak energy use. A prototype of this new control system was built and deployed in a large gymnasium to coordinate the four rooftop air conditioning units. Based on data collected while operating this prototype, the cost savings achieved by reducing peak power consumption are sufficient to pay back the cost of the prototype within 1 year [Kuruganti et al. 2013]. Moreover, it is possible to reduce the cost of this system by a factor of at least six, creating a system that can pay for itself within 2 months of operation. This remarkably short payoff period suggests a significant commercial potential for the proposed control technology.

The second application is a system for forecasting the average output of a photovoltaic (PV) array for the following hour of operation. A significant feature of this system is its use of publicly available data, which is obtained through a transactional network, to generate forecasts that are accurate enough to guide control applications with a time constant on the order of 1 hour. If the forecasting interval can be made more precise, then there would be significant potential to use this type of technology to coordinate the availability of building PV arrays with energy intensive building functions; in particular, the air conditioning control in the first application could take advantage of such forecasts to improve peak reductions and reduce overall energy usage. The TN Project scope is currently being expanded by ORNL to include supermarket refrigeration, but it is expected that as the platform matures, its applicability will be for the residential building and light industrial building markets as well.

1.6 Description of the Building Controls Framework

The next two chapters lay out the considerable work that needs to be done to realize this future state of the transactional energy framework. They explain four categories of exchangeable services that the framework needs to support. These include: end-user services, energy market services, grid services, and societal services. These services range from building O&M services, grid capacity trade-offs and ancillary services to energy efficiency certificates. These services provide the main functionality of the framework and list the benefits for all participants in the transaction. Chapter 2 of this report describes these services in greater detail.

The framework that enables these services will provide the market structure to facilitate the different transactions to occur. It will also require the development and deployment of new networks, devices and controls to support real-time, two-way communications between the participating players/actors. It will further require new and intelligent applications at numerous nodes throughout the network to facilitate and automate the wide variety of transactions, and to manage and activate control and monitoring systems that are involved in the delivery of transactional energy services.

The purpose of this document is to enable researchers and private vendors to develop the technological solutions that can be deployed at a large scale across the various participating domains (customer to the grid and back), and to ensure that such solutions are compatible and interoperable. Chapter 3 of this report describes such a framework in terms of the network topology of participating nodes, the communication interfaces between them, and a platform architecture that can be implemented at these nodes.

Chapters 4-7 contain an extensive list of "use cases" describing possible applications of transaction-based services, technical requirements to fulfill these, as well as benefits to participating stakeholders. These use cases are envisioned to define essential components that would enable transactions in the energy and energy-related domain and give practical examples to the broader community of electric power and buildings technology organizations, researchers, manufacturers, standards- and codes-developing organizations and vendors.

2.0   Exchangeable Services

2.1 Introduction

A transactional framework must support transactions that exchange products, rights and other services that are valued by the parties to the transactions. The range of these "exchangeable services" is virtually unlimited in theory, but some are expected to be more common than others. Products can include quantities such as energy and electric capacity; services include building-oriented maintenance and control operations as well as grid-oriented ancillary services; rights can include such things as a position in an electric vehicle charging queue or a license to consume electricity at a stated level and price for a defined period of time.

A transaction is defined by the sequence of events that result in an exchange of products, rights, or services, and the associated financial settlement, between two (or more) entities, and is considered valid only if completed in its entirety based on the included terms and conditions. A transaction involves the exchange of products, services and rights, agreed upon by the transacting parties. A transaction may involve delivery of:

- *a physical product*, such as energy or electric power

- *a physical service*, such as a building retrofit or operations and maintenance

- *information*, such as diagnostics, advice, a control strategy or a software application

- *a right* such as a limit on the use of a share of capacity or throughput by another party

- a *financial product*, such as a futures contract (advance purchase of energy).

Underlying most financial products is also a physical commodity, and a financial product is used as a hedge to manage price/quantity volatility associated with the physical commodity, for instance, futures contracts for energy, etc. The participants in a transaction envisioned for the kind of framework discussed here have a broad range of needs, interests, and constraints. Depending on the participants and the exchangeable services involved, there are different bits of information ("parameters") that must be exchanged and various time frames during which the products, services, or rights must be delivered. This chapter discusses a non-exhaustive, but representative set of four major categories of exchangeable services. While each party to any given transaction has their own motivation for the exchange, the four categories are distinguished by the *primary motivation from which the value is derived*:

1. **End-User Services** – energy and energy-related products, services, and rights that the end user purchases to balance and co-optimize their overall energy costs, comfort and convenience.

2. **Energy Market Services** – energy and energy-related products, services, and rights that the electric power grid offers to reflect the costs of production and delivery of power and energy to customers in everyday operations.

3. **Grid Services** – energy and energy-related products, services, and rights that the electric power grid purchases or incentivizes because they are required for its reliable operation.

4. ***Societal Services*** –energy and energy-related products, services, and rights that have a value agreed upon and acknowledged by society, monetized by a governing entity, with benefits provided to all involved or affected parties.

The first two of these, end-user services and energy market services, are likely the least common and least understood categories because they represent the types of transactions that are just getting underway, primarily in the commercial buildings sector. They can offer trade-offs between the different electric end-uses within a building or cost-effective building operation and maintenance services from third-party service providers, can save building owners money by lowering utility bills, and possibly benefit both the building owners and the electric grid and third-party energy service providers through sharing of capital costs to equip buildings with the necessary equipment to support such transactions. Development and widespread implementation of a transactional framework for buildings is unlikely without the need to deliver end-user and energy market services. However, the existence of such a framework will support additional interactions between buildings (as when two data centers coordinate their data processing runs to limit overall building peak loads), between buildings and third parties (e.g., contract maintenance firms), both of which have the potential to increase the economic viability of installing a transactional framework. It will also enable societal services that serve broader social goals to engage directly with buildings, to the benefit of both.

Along these dimensions—type of exchangeable services and type of interaction—there exist a near-continuum of options, and there are many similarities between exchangeable services and interactions. For example, some intra-building interactions where the building manager acts as his/her own aggregator (e.g., coordinating tenants and departments of the same company to meet overall energy and capacity constraints), or many building-to-grid interactions that involve a building owner as one party and an aggregator or utility of some sort as the other party.

2.2 End-User Services

End-user services refer to energy and energy-related products, services, and rights that the end user purchases to balance and co-optimize their overall energy costs, comfort and convenience. The rendering of these services is the result of origination of need and value at the customer premises, and hence, may be labeled as *behind the meter* services. The net result of providing such a service is that buildings and the equipment within the buildings are more efficient, predictable, controllable, and provide required services at lower cost. This may involve a wide range of transactions such as buying energy from a third-party on-site generator or storage system, purchase of diagnostics and valuation services from a third party that supports the operations and maintenance of end-use assets, purchase of energy services by tenants from the building owner, and hierarchical "purchases" of energy by one building subsystem from another (e.g., by an air-handling unit in the form of chilled water from a bank of chillers) that may facilitate advanced control paradigms.

An example of the end-user services is operation and maintenance (O&M) service that is of interest to buildings and third-party service providers, where such a service is used to maintain, repair, replace and/or operate buildings and equipment within buildings, leading to enhancements in overall customer comfort and convenience. Below are more examples illustrating the End-User Services category. Chapter 4 of this report lists some examples of use cases that describe possible transaction-based mechanisms that could be used to provide such end-user services.

2.2.1 M&V for Energy Performance Verification: Energy Charting and Metrics Tool

The Energy Charting and Metrics (ECAM) is a tool developed by PNNL for charting energy performance from the building automation system (BAS). ECAM is used for M&V for building re-tuning. In this scenario, the building O&M service provider installs ECAM on the building's BAS, and uses the ECAM interface to set up trending, monitoring, and visualization of energy use in the building. Figure 2.1 and Figure 2.2 show examples of M&V visualization from ECAM[1] that can help building managers understand how energy is being used and how the energy use is changing over time. Figure 2.1 shows energy intensity as a function of the time of day and the day of the year, while Figure 2.2 shows aggregate load profiles before and after an energy efficiency intervention.
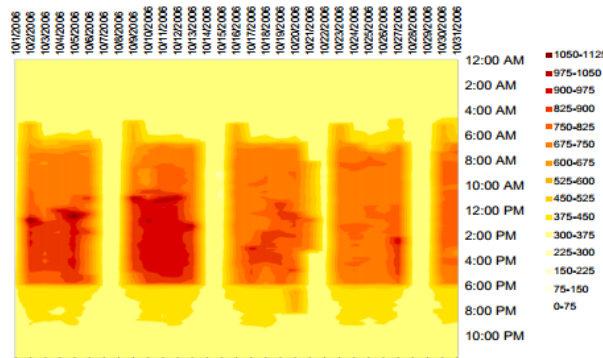
Figure 2.1. Example M&V Visualization: Energy Intensity
as a Function of Time of Day and Day of the Year
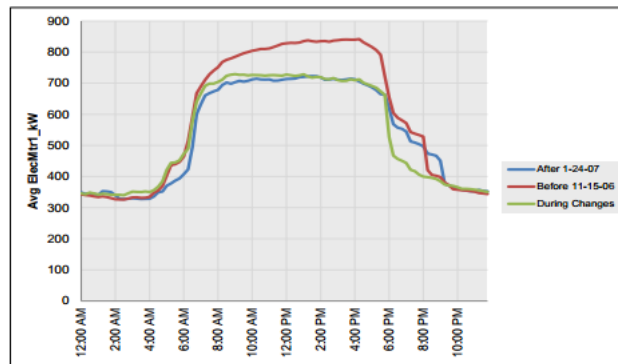
Figure 2.2. Example M&V Visualization: Aggregate Load Profiles
for before and after Efficiency Interventions

2.2.2 Data Centers Trade Computation Priority

In this use case, a data center (server farm or high-performance computing center) shifts computing jobs to another such service provider to save electricity. The data center located where electricity costs are currently high (e.g., during periods of peak demand) shifts jobs to a contemporary where costs are currently lower, and vice versa. Both centers keep a tally (weekly or monthly) on computer jobs shifted and electricity costs saved and regularly post their idle capacity and their electricity costs associated with

computing (including CPU, data storage, and associated air conditioning). Presumably net jobs shifted over an agreed upon period of a week, month, or year are kept near zero to maintain overall asset utilization balance. Each data center benefits from reduced utility bills while grid operators benefit from reduced peak demand and a lower need for capital investment for generation, transmission, and distribution capacity. See Section 4.6 of this report for a more detailed explanation of this example and Figure 2.3 illustrates the transactions
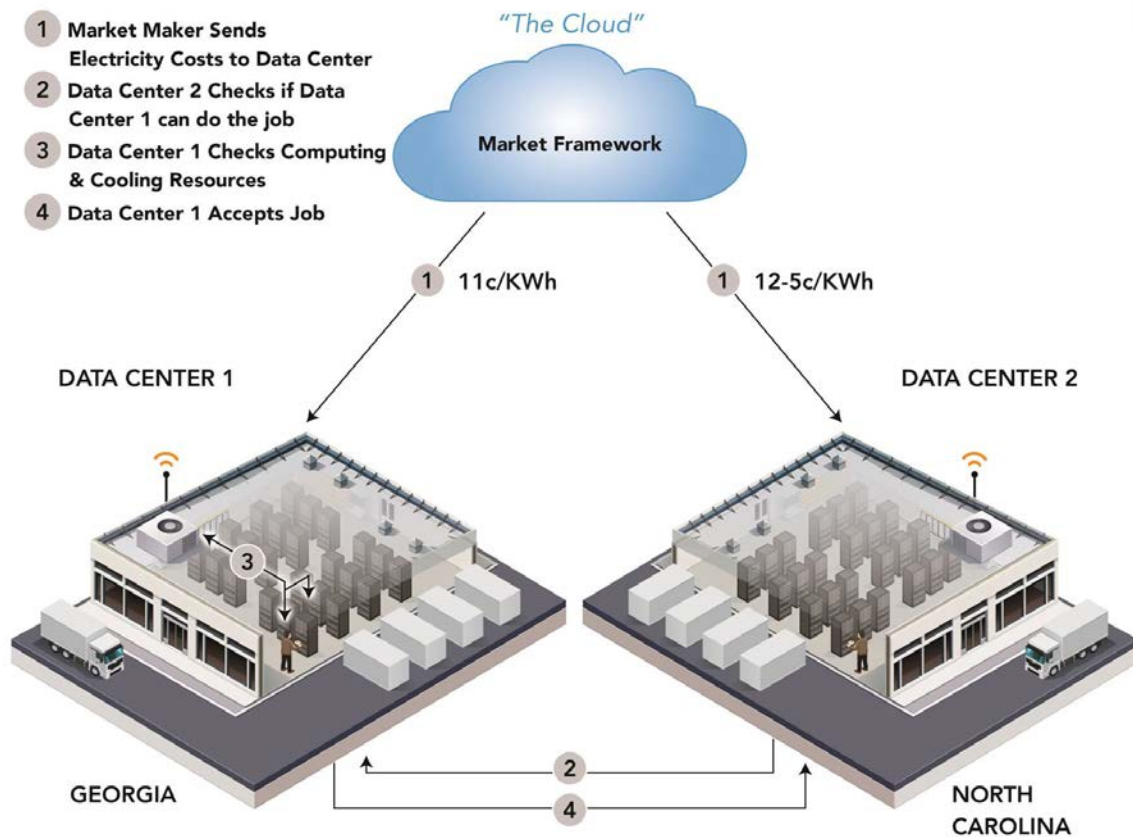
Figure 2.3. Illustration of Data Centers Trading Computation Tasks

Example of Conditioned-Based Maintenance (CBM): Smart Monitoring and Diagnostic System

   The Smart Monitoring and Diagnostic System (SMDS) is a CBM diagnostic tool for small- and medium-sized commercial buildings that used packaged HVAC equipment. It can be installed on new or existing units. A controller is mounted in a small box on the side of the packaged air conditioner or heat pump and provides continuous remote monitoring and diagnostics for the unit. The SMDS works by constantly collecting data from sensors installed on the equipment to measure its performance and detect and diagnose problems with its operation. The unit then sends the results wirelessly, directly from each packaged unit to a network operations center run by a third-party CBM contractor. In the case of SMDS demonstrations on Washington State commercial buildings, NorthWrite has served as the CBM contractor. NorthWrite securely stored data and information on the condition of packaged units and made them available on the web. Participating buildings could view their results at any time using an internet browser. Only users enrolled in the service with the correct authorization can see the results for their packaged units. See Section 4.5 for a more detailed explanation of this example.

While SMDS was developed as a standalone tool, a similar package could be developed with a BAS (rather than a web) interface, and sold as a component of a broader package of tools for building-grid transactions, site energy monitoring and energy performance optimization. In an analogy, the new BAS would be much like a smart phone, while each of the additional services, including CBM were 'apps' that could be downloaded or would come pre-packaged with the BAS. An interoperability framework is one essential element to making transactional energy networks viable. This derives from the need to support a vibrant and growing ecosystem of vendor products and services that interoperate as a network on a common basis and that readily enable secure machine-to-machine connections to be established with minimal effort when installing them. There are two parts to the framework proposed here. First, a general framework and common basis is required for how nodes in such networks will interact. Section 3.0 illustrates the network these diagnostic tools would use.
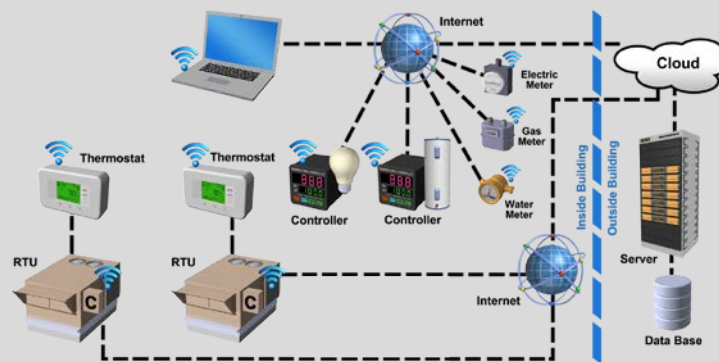
Figure 2.4. Schematic of a Building's Transactive Network
Used to Provide Third-Party O&M Services

Third Party Receives Payment for Energy Services

This use case illustrates how customers, such as commercial building owners, contract with vendors that install, operate, and maintain equipment, such as a building-cooling-heating-power (BCHP) system, thermal or battery storage system, or a conventional generator. The customer desires to obtain a lower energy bill without the capital expenditure for the equipment and systems or the need to operate and maintain them while the service provider desires to earn a return on its investment in the equipment and systems. The service provider installs, operates, and maintains the equipment and systems at its expense and also pays for the electricity and fuel it consumes. On a regular basis, the customer is billed for the electrical and/or thermal energy delivered to the building based on the contract terms, and/or its share of the customer's savings for demand response, ancillary services, etc. In addition to the benefits to customer and service provider, the provided demand management and efficiency from end uses contribute to peak load reduction and thus help grid operators with less need for capital investment for generation, transmission, and distribution capacity. See Section 4.1 for a more detailed explanation.

Descriptions and time scales of different types of O&M services that can be transacted within the buildings-centered transactional framework are presented in Table 2.1. Table 2.2 shows the information that must be exchanged to O&M services for buildings related transactions, while Table 2.3 shows the types of participants that may be involved in an O&M services for buildings-related transaction, by type of interaction.

Table 2.1. General Characteristics of End-User Services

Service	Description	Time Scales
Condition Monitoring	Service provided to allow monitoring of equipment for degradation in performance or faulty behavior. Could be telemetry-based trend analysis or event response/asset utilization optimization.	Information is updated in real time for event response/asset utilization optimization and every few minutes to hours for telemetry-based trend analysis
Condition-Based Maintenance (CBM)	Service provided to repair or replace building equipment based on a process of monitoring the equipment for degradation in performance or faulty behavior.	Responding and fixing faulty equipment would involve a process of physical (manual) response that would take hours to days.
Energy Efficiency Performance Enhancement	Service provided to enhance operations (i.e., energy efficiency) of buildings through coordination and control of building equipment. Service providers can set up and configure energy conservation measures and/or implement advanced control strategies by leveraging BASs.	Efficiency measures could be set up and configured monthly to yearly and the control strategies for BAS can be implemented by building owners/ operators in real time (minutes; or even seconds).
Measurement and Verification Service (M&V) for Energy Savings	A system to track energy consumption by building systems or for the building as a whole, as already used by some commercial users. This can include simple trending of systems; typically used to verify schedules and device functionality. It can also include more rigorous tracking of energy consumption patterns within a building that can be used to verify energy savings from efficiency measure implementation.	M&V can be configured to provide feedback on energy consumption in real time (minutes); however, this time scale does not refer to a transaction between multiple entities.

Table 2.2. Typical Exchange Parameters for Operation and Maintenance Services Transactions

Information	Description
Operational condition	Information on recent operational efficiency compared to long-term efficiency, or other agreed upon metrics of operational efficiency
Contractual agreement	Monthly subscription fees to participate in O&M service programs and any maintenance service rates should be undertaken by building owners. For example, subscription fees could include continuous remote monitoring of the building, and an hourly rate for service visits may be charged to repair or replace faulty equipment
Verification	For services involving building operations enhancement, the total building energy savings should be monitored and verified. Savings should be compared to a previous year's baseline in energy terms (kWh, etc.), dollar terms, or percentage terms.

Table 2.3. Typical Participants in O&M Service Transactions

Transaction Type	Actor/Stakeholder and Role	Exchange Benefits	Time Scale
Building to Other	Actor 1 – O&M service provider installs, sets up and may provide necessary equipment, as well as, provide O&M services based on contractual agreement Actor 2 – customer (i.e., building owner) may subscribe to receive O&M services and may need to purchase additional hardware and software necessary equipment	Creates a revenue stream to provide O&M services • Building owners are able to reduce energy consumption, save money, extend the lifetime of equipment, and avoid catastrophic equipment failure. • Reduced cost for O&M	Sign up, installation and setup can occur once or yearly, subscription to service program occurs monthly, response time for irregular maintenance service occurs within hours to days, BASs should operate in real time (minutes)
Building to Other	Actor 3 – buyer (i.e., building owner) Actor 4 – seller (i.e., building owner) Actor 5 – establishes market or rules for exchange (i.e., aggregator, RTO/ISO, load serving entity)	Ability to lower monthly bills by buying additional energy needed in a competitive market or by transacting with other customers with excess energy available Creates revenue streams for selling excess capacity rights not needed Ability to manage energy in real time to reduce need for investment in additional infrastructure for increasing overall generation capacity	Auctions or agreements for energy exchanges are can be made minutes to day ahead in advance
Intra-Building	Actor 1 – building subsystem components	Ability to operate more efficiently	Priorities for energy exchanges can be made minutes in advance

2.3 Energy Market Services

Energy is typically a product and denotes the quantity of electricity generated and consumed over a period of time. It may be delivered by the grid to a building, or generated by the building (e.g., using solar panels or small turbines) and either fed back to the grid or used to offset purchases from the grid or stored in a battery or thermal storage system. Energy market services refer to energy and energy-related services that help support the efficient utilization of the energy generation and delivery assets. The primary need, and hence, value for energy market services originates *outside the meter*, i.e., within the power grid or the natural gas delivery infrastructure. In a region with a wholesale power market, these services may reflect those costs. In other regions they may reflect power production and delivery costs for a vertically-integrated utility, for example.

Although the value may be derived from the grid benefits, the overall economic benefits for such transactions accrue to both parties involved in the transaction. Energy market services may include mechanisms, such as, *time-of-use* and *real-time* pricing, etc., to help manage constrained resources, such as electricity or water delivery pinch points.[3] Energy market services primarily help customers derive economic gain by offering cost savings opportunities, such as incentives or lower prices for modifying their consumption patterns, proving capacity deferral and other benefits to utilities. Chapter 5 of this report lists some example use cases describing transactive mechanisms that help in the provisioning of energy market services. It is important to note that some of these use cases may fall into multiple service domains because the need and value for these services may originate in those domains concurrently. Today's energy markets are evolving to provide new services beyond electricity to customers. Traditionally, the wholesale energy market consists of a day-ahead and a real-time balancing market to balance generation with demand in a short-term timeframe. Participants in the wholesale market consist of load serving entities, aggregators, and generators. Deregulated retail energy markets[4] allow the customers, for example, to choose an electricity supplier from competing retailers who purchase wholesale energy on their behalf. Following are two use cases that illustrate energy market services within a building and between a building and a service provider.

> **Building Services Respond Intelligently to Economic Signals**
>
> In this use case, individual units of equipment in a building (e.g., a rooftop HVAC unit, a chiller) respond to building-level requests for services (heat, cool, etc.) based on current price signals, current environmental conditions, contracted capacity constraints, etc. See Sections 3.2.1 and 5.4 for more details.

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[3] While not covered in this document, there are several different applications envisioned for energy market services, such as managing urban or agricultural water supply.

[4] Retail restructuring in Texas allows customers to switch between competing load serving entities on a short time scale. However, no retail markets, except for in a few pilot/demonstration projects, exist today that allow retail customers to buy/sell electricity in- or near real time, as was enabled at the wholesale level as a result of wholesale markets restructuring.

Table 2.4 shows the information that must be exchanged to support energy market services transactions.

Table 2.4. Typical Exchange Parameters for Energy Market Services

Information	Description
Price	Payments and penalties as a result of exchange
Quantity	Energy is generally measured and expressed in kWh.
Contractual agreement	The terms and conditions of how penalties and payments are attained should be outlined in the contractual agreement. Additional information may be exchanged in a transaction to support verification of response or delivery.
Verification	Energy usage should be verified.

Dynamic Rate

In this use case, a customer (building owner or tenant) changes their constant, flat rate contract with the utility or retail service provider to a plan with varying electricity rates. The new plan could be governed by a time of use (TOU) system, in which the unit price for electricity is higher during peak hours and lower during off-peak hours, e.g., by a factor of ~2×, or a critical peak pricing (CPP) plan, in which the utility can declare a very high unit price (~10-20×) in cases of grid emergencies, with 24-hour notice to customers, or a combination of TOU and CPP, in which a TOU rate applies on most days, and CPP rates come on during critical peak hours on critical peak days. Another option would be a real-time price (RTP) rate that varies continuously, depending on grid conditions.

This use case illustrates electricity pricing models that help customers lower their bill, if they respond, by shifting some of their load from high-price periods to low-price periods. Depending on the plan, the utility correspondingly obtains daily load shifting by customers that corresponds to electricity production costs (TOU), demand response for peak-load or peak-price management on a limited number of days per year (CPP), or continuously available demand response resource (RTP). A more detailed explanation of this use case can be found in Section 5.1 of this report.

Optimize Electric Vehicle Charging for Dynamic Rate

This use case lays out transactions furthering the integration of electric vehicles (EV) benefiting consumers with lower charging rates and utilities or retail service providers with predictable load curves. Participating EV owners sign up with retail utility or a retail service provider to receive a dynamic (time-varying) rate contract specifically targeting EV charging. To optimize charging of EVs, the customers can use computer aided tools, such as energy management systems (EMS) or building automation systems relaying forecasts in dynamic rates, time limits specified for fully charging EVs, and specified charging levels for emergency use of EVs, etc.

By participating in the dedicated EV charging rate, EV owners can benefit from lower charging rates, thus lowering their electricity bills. The utility or retail service provider obtains daily load shifting by customers that reflects the needs of the grid, such as load reduction during peaks or load increases when there is high wind generation. A more detailed explanation of this use case can be found in Section 5.2 of this report.

Table 2.5 shows the types of participants that may be involved in an energy transaction, by type of interaction.

Table 2.5. Typical Participants and Roles in Energy Market Services Transactions

Transaction Type	Actor/Stakeholder and Role	Exchange Benefits	Timescale
Building to Grid	Actor 1 – establishes market or rules for exchange (i.e., aggregator, RTO/ISO, load serving entity); sets up time-of-use electricity rates, or mechanisms to establish rea- time prices (such as double-action based retail markets)	• Enables short-term balancing of energy supply and demand • Manages intermittency of renewables and load demand variations • Manages high cost of marginal generation	Auctions or agreements for energy exchanges are typically made minutes to day ahead in advance. Long-term power purchase agreements can also be signed based on bilateral negotiations.
	Actor 2 – buyer/customer (i.e., building owner, load serving entity) subscribes to utility rate programs	• Ability to manage energy use in real time and, in turn, reduces cost of electricity • Reduced rates as a result of reducing the need for additional capacity investments and fuel costs	
	Actor 3 – seller (i.e., generator resource owners and/or investors, load serving entity, building owner)	• Creates revenue streams for generating and/or delivering energy • Potential to reduce need for capacity investments.	

2.4 Grid Services

Grid services are defined as energy, and energy-related products, services, and rights that help support enhanced grid planning, operations and metering within both centralized and decentralized structures of asset location and ownership. The need, and hence, value for grid services originate *outside the meter*, i.e., outside the customer premises. Grid services, such as peak-load shifting and ancillary services help maintain grid reliability and resiliency, as well as aid in renewables integration by providing flexibility to the system. Solutions that help in delivery of grid services may borrow from similar concepts developed for integration of energy storage and other demand-side resources into the power system. These concepts must also be cognizant of – and preferably providing solutions for – known problems, such as, measurement and verification, net-metering, voltage instability caused by two-way power flow*s,* etc. Chapter 6 of this report contains some examples of transactive mechanisms that may be used to provision different grid services, while providing commensurate incentives to the providers of these services.

It is expected that two broad categories of grid services will dominate the design and operation of a buildings centered transactional framework. These two categories are summarized in Table 2.6. Each of these exchangeable services is discussed in more detail in the following subsections.

Table 2.6. Major Categories of Exchangeable Products, Services, and Rights

Exchangeable	Classification	Description
Capacity	Right, product	From the perspective of a building owner, this is a right to consume power up to a specified limit, possibly to the level of installed capacity of equipment in the building. From the grid perspective, capacity is a level of power delivered by a provider, which may be the availability of generation or the promise of load reduction.
Ancillary Services	Service	This includes a range of measures used to maintain reliable operation of the power grid, such as regulation, spinning reserve, and flexibility/ramping. Ancillary services are primarily of interest to the grid, but buildings can theoretically supply such services by manipulating either loads or local generation.

2.4.1 Capacity

Capacity refers to the requirement for adequate resource availability to ensure demand can be met at all times. Capacity can be supplied and/or limited by generation resources, transmission and distribution for power infrastructure, dispatchable demand response, and energy efficiency measures (i.e., installing and implementing more efficient devices and/or processes relative to building standards and codes). Capacity resources can be acquired through owning and operating generation capacity, purchasing capacity rights from others through bilateral markets, and/or by obtaining capacity through capacity market auctions or purchases of DR. Investors in capacity need sufficiently long-term incentives (i.e.,

price) to encourage development and maintenance of generation, transmission and/or demand side resources. Typically, utilities, retail service providers, and/or aggregators are responsible for acquiring the resources and/or capacity rights necessary to meet their customers' demand. However, capacity rights can also be acquired and sold directly by customers, which allows service providers to better manage capacity investments.

When capacity rights are being exchanged, the following information, highlighted in Table 2.7, is typically exchanged between transaction participants. Table 2.8 shows the types of participants that may be involved in a capacity transaction, by type of interaction.

Trade of Allocated Capacity Rights

In this use case, customers purchase a "capacity rights" plan (similar to a customer purchasing a rate plan from a mobile service provider) from a utility, retail service provider, third-party distributed asset owner or third-party aggregator or are allocated a share of system capacity from a load serving entity. The "capacity rights" plan establishes a limit on the power that can be used by each consumer. A forward market is setup to allow the consumers and third-party distributed asset owners to buy and sell the capacity rights.
The transactions involve an exchange of a portion of a customer's capacity rights. The initial capacity rights owned by customers are assumed to have been purchased from, or allocated by, a utility, a retail service provider, an aggregator or third-party distributed asset owner. There are currently no examples of this use case today. See Section 6.3 for more details.

Transactive Retail Energy Market

In this use case, customers sign up for a transactive control and coordination program with a retail utility or a retail service provider. This involves a real-time price (RTP) determined by customer bids for electricity demand and a short-term (~5-minute) retail price-discovery process, such as a market. Participating customers change their constant, flat rate contract with their utility or retail service provider to a RTP that varies over time at short intervals (e.g., 5 minutes). Customers need to have interval metering such as with an Advanced Metering Infrastructure (AMI), as well as responsive assets, to engage.

Customers can take advantage of the RTP by shifting some of their load from high-price periods to low-price periods, thereby lowering their bills. The utility or retail service provider correspondingly obtains daily load shifting by customers that corresponds to wholesale electricity costs, as well as continuously available demand response/net load reduction resource for use in an emergency, and precise control of demand and net load to automatically manage capacity constraints, of generation and at various levels of the transmission and distribution systems, on a continuous basis. The first test of the transactive retail energy market was the 2006-2007 Olympic Peninsula Smart Grid Demonstration. Currently, the model is also tested in the American Recovery and Reinvestment (ARRA) co-funded AEP's gridSMART™ Demonstration, and the Pacific Northwest Smart Grid Demonstration. See Section 6.2 for more details.

Cooperative Tenants in a Building or Campus

In this use case, customers within a large building or group of buildings sign up collectively for a transactive control and coordination program with a retail utility or a retail service provider. Individual tenants within a building or buildings within a campus trade share of the overall capacity/energy rights by time shifting operations, etc. This is similar to the use case described in Section 6.3.

Table 2.7. Typical Exchange Parameters for Capacity Transactions

Information	Description
Price	Payments and penalties resulting from exchange.
Quantity of capacity	The capacity resource provider commits to providing a specified quantity in kW, as a market participant. In a building-oriented transaction, a building manager commits to limiting load to a specified level and/or to reducing load by a specified amount, by time shifting building functions or operation of local generation assets.
Contractual agreement	The terms and conditions of how penalties and payments are attained should be outlined in a contractual agreement. There may be a need to exchange information supporting verification of response in a transaction, for example.
Verification	There must be a means to confirm that agreed upon actions were taken, which could be a measurement of total load, evidence that generating assets were dispatched, etc.

Table 2.8. Typical Participants and Roles in Capacity Transactions

Transaction Type	Actor/Stakeholder and Role	Benefit of Exchange	Timescale
Building to Grid	Actor 1 – establishes market or rules for exchange (i.e., aggregator, RTO/ISO, load serving entity)	• Ability to ensure reliable delivery of electricity to customers • Ability to sell into wholesale markets	
	Actor 2 – buyer (i.e., building owner, load serving entity)	• To a load serving entity, the ability to manage capacity in real time to reduce need for investments in additional infrastructure for generation capacity • To a building owner, reductions in utility bills and/or new revenue streams, and predictable access to short-term capacity rights for unexpected business needs.	• Auctions or agreements for capacity rights are typically made months to years in advance for capacity rights
	Actor 3 – seller (i.e., generator resource owners and/or investors, load serving entity, building owner)	• Create revenue streams for maintaining and operating current and future investments • Less need for investment in additional generation, spinning reserves, etc.	
Building to Other	Actor 1 – buyer (i.e., building owner)	Ability to lower monthly bills by buying additional capacity needed in a competitive market or by transacting with other consumers with excess energy needs	Capacity rights can be exchanged hours to years in advance
	Actor 2 – seller (i.e., building owner)	Creates revenue streams for selling short-term excess capacity rights	
	Actor 3 – establishes market or rules for exchange (i.e., aggregator, RTO/ISO, load serving entity)	Ability to manage capacity in real time to reduce need for investment in additional infrastructure for increasing overall generation capacity	

2.4.2 Ancillary Services

Ancillary services procurement is about 6% of peak load, and the need for ancillary services is expected to increase with increased penetration of renewables [MacDonald et al. 2012]. Although there are variations in the implementation in terms of technical, procurement, market structure and settlement points of view, some general characteristics of ancillary services are given in Table 2.9. Currently no explicit market for flexibility/ramping generally exists, but it is getting increased attention as an ancillary service in its own right.

Table 2.10 shows the information that must be exchanged to ancillary service related transactions. Table 2.11 shows the types of participants that may be involved in an ancillary service related transaction, by type of interaction. Figure 2.5 and Figure 2.6 illustrate a conceptual overview of ancillary services. Detailed examples of transactions related to ancillary services are given in Chapter 6 of this report. Other examples include the PJM ancillary service markets.[5]
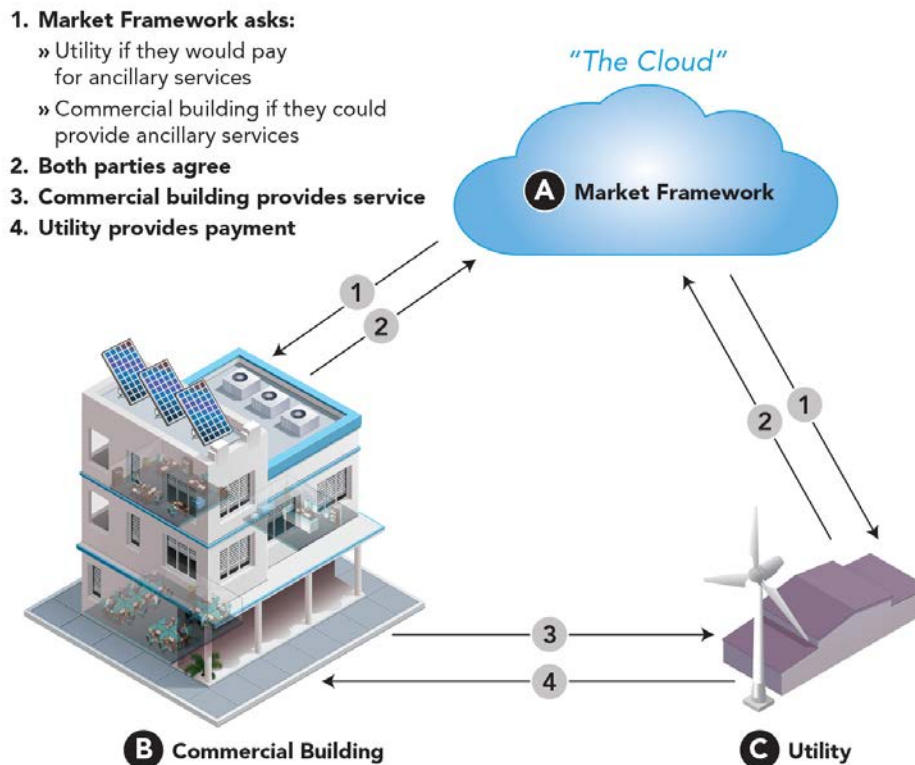
Figure 2.5. Conceptual Overview of Ancillary Services Transaction

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[5] See: http://www.pjm.com/markets-and-operations/ancillary-services.aspx.
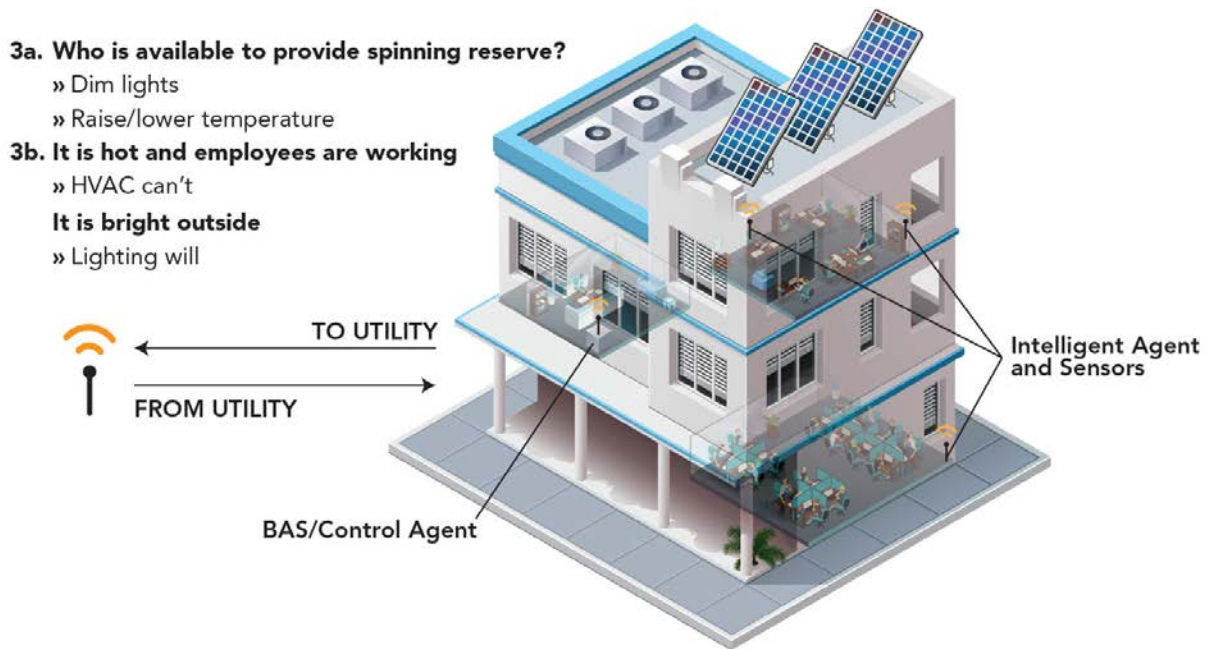
Figure 2.6. Conceptual Overview of Intra-Building Reaction to Request for Ancillary Services

Table 2.9. General Characteristics of Ancillary Services

Service	Description	Timescales
Regulation	Generation is matched with very short-term changes in load by moving the output of selected resources up and down via an automatic control signal. Also another component is maintaining import/export targets for balancing areas.	Regulation signal sent every few seconds. Capacity for regulation is reserved every few minutes to 1 hour
Flexibility/ Ramping	Increasing the output of generators to meet demand that is rising or reducing the output of generators as demand drops. Because of differences between forecast and the actual load, power plants must be available to rapidly adjust for these differences, and are paid a premium for their flexibility, driven by the deployment of renewable energy	Dispatch signal every 5 minutes to 1 hour
Spinning Reserve	The ability of a generator, that is online and synchronized to system frequency, with some spare capacity to increase its output within a certain, short amount of time. Demand-side resources can also be used.	Immediate response reaching full power within about 10 minutes. Capacity for spinning reserve is reserved every 15 minutes to 1 hour
Non-spinning Reserve	Same as spinning reserve, but need not respond immediately; therefore, units can be offline but still must be capable of reaching full output within the required amount of time.	Can be brought online to reach full power within about 10 minutes
Replacement Reserve	Same as non-spinning reserve, but with a 30-minute response time	Can be brought online to reach full power within about 30 minutes

Table 2.10. Typical Exchange Parameters for Ancillary Services Transactions

Parameter	Description
Quantity	Capacity in MW for regulation, ramping/flexibility and operating reserves. In some markets, also MWh for regulation
Price	Payments for regulation, ramping and operating reserves. Payments if reserves are dispatched. Penalties for not being able to respond to dispatch signals.
Contractual agreement	The terms and conditions of how penalties and payments are attained should be outlined in the contractual agreement.
Verification	Length of response and response times should be within requirements as defined in the contract.

Table 2.11. Typical Participants in Ancillary Services Transactions

Transaction Type	Party 1 Actor/Stakeholder and Role	Exchange Benefits	Timescale
Building to Grid	Actor 1 – establishes market or rules for exchange (i.e., aggregator, RTO/ISO, load serving entity)	• Ability to ensure reliable delivery of electricity to customers • Reduced need for overall generation capacity as a result of less capacity held out of markets to meet ancillary service requirements, which also leads to reduced rates for all end use customers.	Capacity for ancillary services are reserved every few minutes/hour to day ahead and control/dispatch signals are sent every few seconds to minutes depending on the type of service being provided
	Actor 2 – buyer (load serving entity)	• Lower utility revenue requirements and market prices for ancillary services	
	Actor 3 – seller (i.e., generator resource owners and/or investors, load serving entities, building owners)	• Revenue streams for providing ancillary services needed to maintain grid reliability	

2.5 Societal Services

Societal services refer to energy and energy-related services that have a value agreed upon and acknowledged by society, and provided to all involved or affected parties, and whereby settlements may be made by the larger governing entity. The responsibility of monetizing the societal value, in most cases, would be performed by the said governing entity, as well. Examples of societal services may include participation by utilities, and third party provided into emissions cap-trade markets etc., using energy efficiency certificates (white tags), acquired from customers (buildings) using transactive mechanisms. The value (monetary or other) gained from providing societal services would be shared between the involved parties. Chapter 7 of this report provides examples of use cases with details on the transactive mechanisms that could be employed for the provisioning of societal services.

Figure 2.7 and Figure 2.8 show an illustrated example of customers signing up with a retail service provider to receive power rationing services under global emergency conditions (i.e. blackouts).[6]
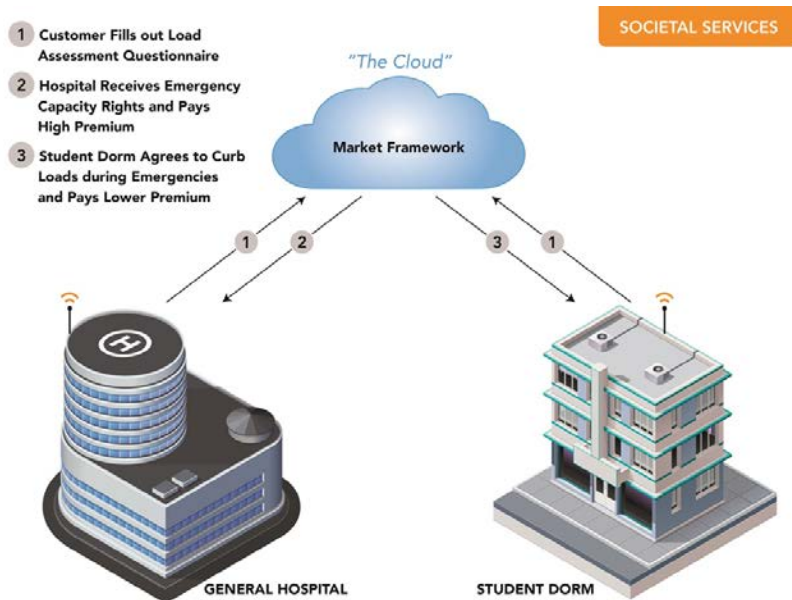
Figure 2.7. Emergency Power Rationing Agreement - Part 1

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[6] See Section 7.1 for a more detailed explanation of this example.
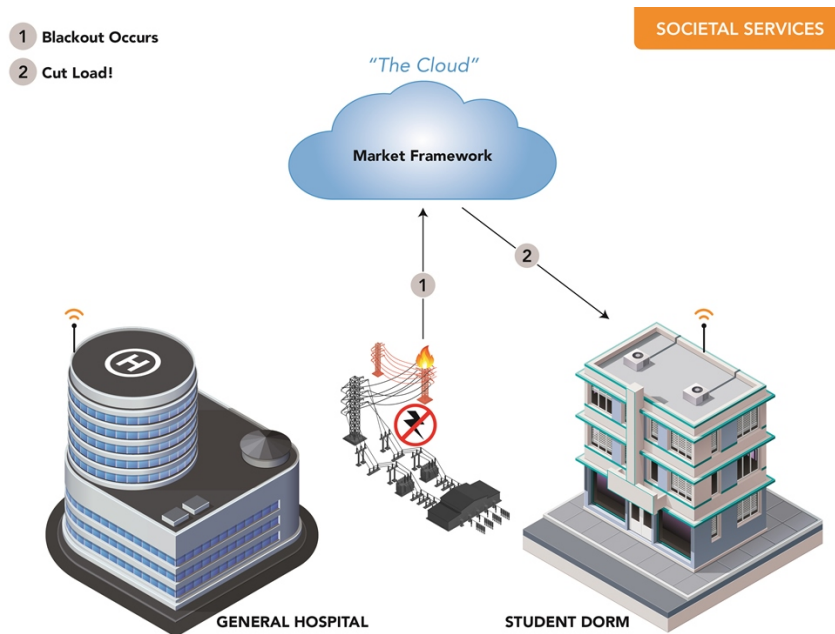
Figure 2.8. Emergency Power Rationing Agreement - Part 2

Three more examples of societal services the transactional energy framework could support are shown below.

Air Shed Management

In this use case, an air quality management surcharge incentivizes building owners to reduce power consumption. During "smog alerts," an air shed management authority raises electricity and/or natural gas rates above regular rates to encourage load curtailments, particularly for customer segments and end uses that have high contributions of local pollutants, as well to shift electricity generation to cleaner and extra-regional sources, including curtailment of distributed generation and combined cooling-heating-power systems in the air shed district. The surcharges are sent out with hourly granularity, a 48-hour look-ahead, and are updated on a regular (e.g., daily or hourly basis) and are applied to existing utility rates, whether flat or time-varying dynamic rates, via the utility billing infrastructure.

The air shed management authority's goal would be to reflect the costs of shifting electricity generation to cleaner and extra-regional sources, and thereby encourage curtailment of end-use loads (gas, electric, and other fuels), and of fuel-powered distributed generation and combined cooling-heating-power systems in the district, in proportion to the benefit that doing so provides to air quality. Customers would receive a lower energy bill if they respond to the surcharges by curtailing consumption during surcharge periods or shifting their consumption to lower surcharge periods. See Section 7.3 for more details of how this use case may be transacted.

Example of societal service provided by India's Perform, Achieve and Trade (PAT) scheme

One of the other examples of a societal service is India's development of an energy efficiency scheme to govern large energy consumers. They recognized the tremendous potential to improve efficiency in energy-intensive industries and the electricity sector, which together were responsible for about 60% of India's greenhouse gas emissions in 2007. The Perform, Achieve and Trade (PAT) scheme aims to tap into this potential.

The PAT scheme originated in the 2001 Energy Conservation Act, which empowers the Indian Government to identify energy-intensive industries as designated consumers and set mandatory energy conservation standards for them. Under the Act, the Ministry of Power's Bureau of Energy Efficiency (BEE) identified designated consumers from 15 sectors, including the 8 industrial sectors targeted in the PAT scheme: aluminum, chlor-alkali, textile, pulp and paper, iron and steel, fertilizer, cement and thermal power plants. The scheme covers 478 facilities. Each facility under the PAT scheme has been assigned a specific energy consumption (SEC) reduction target compared to its baseline SEC, to be achieved by March 2015. SEC is energy consumed per unit of production, expressed in ton of oil equivalent. The designated consumers receive tradable, certified energy savings credits if they achieve efficiency gains beyond their target. If they fall short of the target, they can buy energy savings credits to make up the difference. Energy savings credits will be issued to eligible facilities annually after the first year of the compliance period (2012). BEE has not set a minimum price for trading of energy savings credits; the market will determine the price.

Example of societal service provided by Japan's Efficiency Benchmarking scheme

A similar mandatory program to the one described above was introduced in Japan that established benchmarks for all businesses in the industrial sector. The benchmarks require 1 percent improvements in annual energy efficiency. Designated sub-sectors of the economy had energy efficiency targets set according to the best-performing companies in each sub-sector. Targets are set for both mid-term (2015) and long-term (2020). Industries that take early action and achieve their targets can become exempt from the 1 percent annual improvement target by helping small and medium-sized enterprises increase energy efficiency. Individual sector benchmarks are based on internal studies and are negotiated between the government and that particular sub-sector. The legislation also includes a number of financial incentives and has been expanded over the years to increase energy management requirements. Fourteen thousand factories – representing 90 percent of Japanese industry – are required to appoint certified energy managers. Class 1, the high-energy users, must develop shorter-term and long-term energy efficiency plans.

3.0   Transaction-Based Energy Networks

Enabling the various exchangeable energy and energy-related services discussed in Chapter 2 will require the development and deployment of new networks, devices and controls to support real-time two-way communications between participating parties. It will also require new and intelligent applications at numerous nodes throughout the network to facilitate and automate the wide variety of transactions, and to manage and activate control and monitoring systems that are involved in the delivery of transactional energy services.

It is not the intent of this report to prescribe any specific technological solution for implementing transactional energy services. However, to enable researchers and private vendors to develop solutions that can be deployed at a large scale across the various participating domains, and to ensure that such solutions are compatible and interoperable, a general framework and set of communication protocols that support interoperability are required.

This chapter describes such a framework in terms of the network topology of participating nodes and the communication interfaces between them. First, we describe the basic concept of a node in such a network. Then we illustrate how the logical nodes in a transactional network are related to the nodes of corresponding physical network, in three general domains:

1. Networks consisting of end-use systems, devices, and tenants within buildings or facilities.

2. Networks connecting customer devices, buildings, and facilities to other external third-party energy and service providers.

3. Buildings-to-grid networks consisting of customer buildings, distribution systems, transmission, and electric power generation.

We then describe two real-world examples, developed as part of two transactional grid control demonstrations that, taken together, implement a building-to-grid network much as illustrated in the following section. Finally, we propose a general framework for interoperability applicable for all these types of transactional networks and which is built upon the foundation of a transaction as the primary machine-readable unit of communication and a common basis for interaction between the nodes at all scales in all three types of networks.

3.1 Concept of a Transactional Node

A logical node is used in a transactional energy network to represent the interests of the party at that physical location in exchanging a product or service with another party in the network. Applications hosted by a node implement transactions automatically as applications on behalf of the owner or steward of the node, subject to approval by the party owning or represented by the node, according to their expressed needs for energy, services, profit, or cost management. Examples of where logical nodes are used include where energy is:

- produced or transformed (e.g., a generator, a transformer, or an air conditioner)

- sold (e.g., an independent system operator's energy market for electricity)

- purchased (e.g., by a customer, a retail utility, or a load serving entity)

- transformed in value (e.g., wholesale to retail)

- managed (e.g., a building, a tenant, a transmission line, a substation, or a distribution feeder)

- consumed (e.g., by a building energy system or device, a battery, a thermal energy storage system, or an electric vehicle).

Other examples include where exchangeable services or rights are bought or sold, rather than energy itself, including

- a cap-and-trade market for capacity rights, carbon and air shed emissions, etc.

- diagnostic and O&M services

- energy information, advice, and retrofit services.

In this fashion, non-traditional parties such as service providers or governmental organizations become engaged in transactional energy networks.

A node's application may also reflect such exchanges by exerting control over local physical assets, again acting as applications implementing the owner's needs and wishes in that regard. Often such local control reflects physical constraints in the throughput of energy through the physical systems or equipment at the node's location. To achieve the desired responses, local control may be combined with an increase in the price of energy supplied by the node to other nodes. In other cases, local comfort or service constraints may be reflected, such as indoor air temperature or lighting levels in a building space. For example, these may tradeoff a degree of comfort or service with respect to the cost of the energy required to supply it.

Thus, even within the boundaries of a system with a single owner, such as a building or a utility, it may be convenient to define additional transactional nodes to reflect the dynamic value of transactions occurring with the rest of the network. This adopts the transactional approach as a convenient means for tapping into the self-organizing property of a well-formed transactional network to serve as a plug-and-play, distributed control system that continually attempts to optimize the multitude of tradeoffs between cost and performance in increasingly complex energy systems and dynamic pricing environment.

Figure 3.1 provides a conceptual illustration of a generic transactional node that is generally applicable to all the nodes in such energy networks. Inputs to the node are shown in light colored arrows, outputs in dark arrows; the shading of the two-headed arrows indicates two-way data flows are possible.
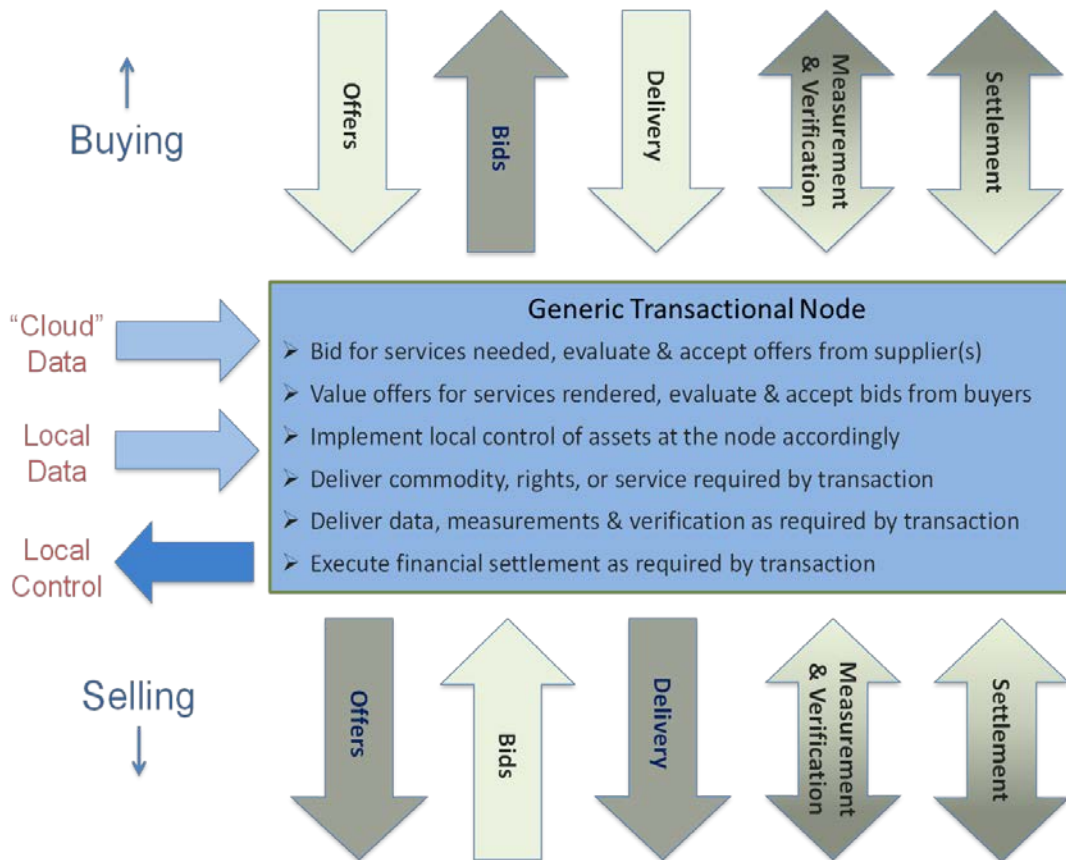
Figure 3.1. Conceptual Diagram of a Transactional Node

The logical node buys services it needs from adjacent nodes and sells services required by adjacent nodes. It does this based on the offers it receives from sellers and the bids it receives from buyers, informed by local data from sensors on the systems and assets for which it is responsible and remote data such as weather information from the internet "Cloud." It then balances supply and demand for services with its own local needs and objectives (defined by the node's owner), and exerts control over local assets, to assure those objectives are met, including any energy products it is contracted to deliver via the physical assets it manages. In other cases, delivery may involve a manual physical element such as an installation of equipment or involve an electronic transfer of information, such as diagnostic reports for equipment or systems. It must supply all data required by the terms of the contract to complete the transaction and/or verify delivery. Finally, it may be required to execute its part of a financial settlement process as defined by the transaction's contract. These interchanges between nodes can occur at any intervals, regular, or irregular, and in any sequence, as defined in the contract.

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3.2 Physical and Logical Transactional Networks

3.2.1 Intra-Building Networks

Figure 3.2 shows a physical representation of a built-up HVAC system in a large, multi-tenant commercial building. It is heated and cooled with a system of cooling towers, chillers, boilers, a hot and chilled water distribution system, and AHUs with variable-air volume (VAV) boxes with reheat coils for delivering conditioned air to individual zones on each floor. For purposes of illustration, we have assumed each floor is occupied by a different tenant. Not shown is the natural gas or electrical systems in the building; the former powering the boilers and the latter powering the rest of the HVAC equipment, as well as the lights and plug circuits on each floor.

Figure 3.3 shows a representation of a logical network within the same building. The boxes with dashed blue lines indicate three domains within the building: the HVAC system (thermal), and the gas and electric distribution systems, which are now shown explicitly. In the context of a transaction-based system, the building node purchases electricity and natural gas from the utilities, and is responsible for overall minimization of energy costs for the building.

Extending the transaction-based approach inside the building allows the possibility of tenants actually purchasing their electrical and thermal HVAC energy from the building owner/operator. This can be used to engage tenants in both energy efficiency and demand response, whereby they are encouraged to trade off a degree of comfort or quality of service in exchange for lower energy bills. Such tradeoffs might encourage adjustments to thermostat settings as a function of cost, within occupant specified limits, for example. The same approach can, in principle, be applied to business divisions even if the building is occupied by a single enterprise.

Boilers

Cooling Towers

Chillers

Zone / VAV Boxes

Air Handling Units
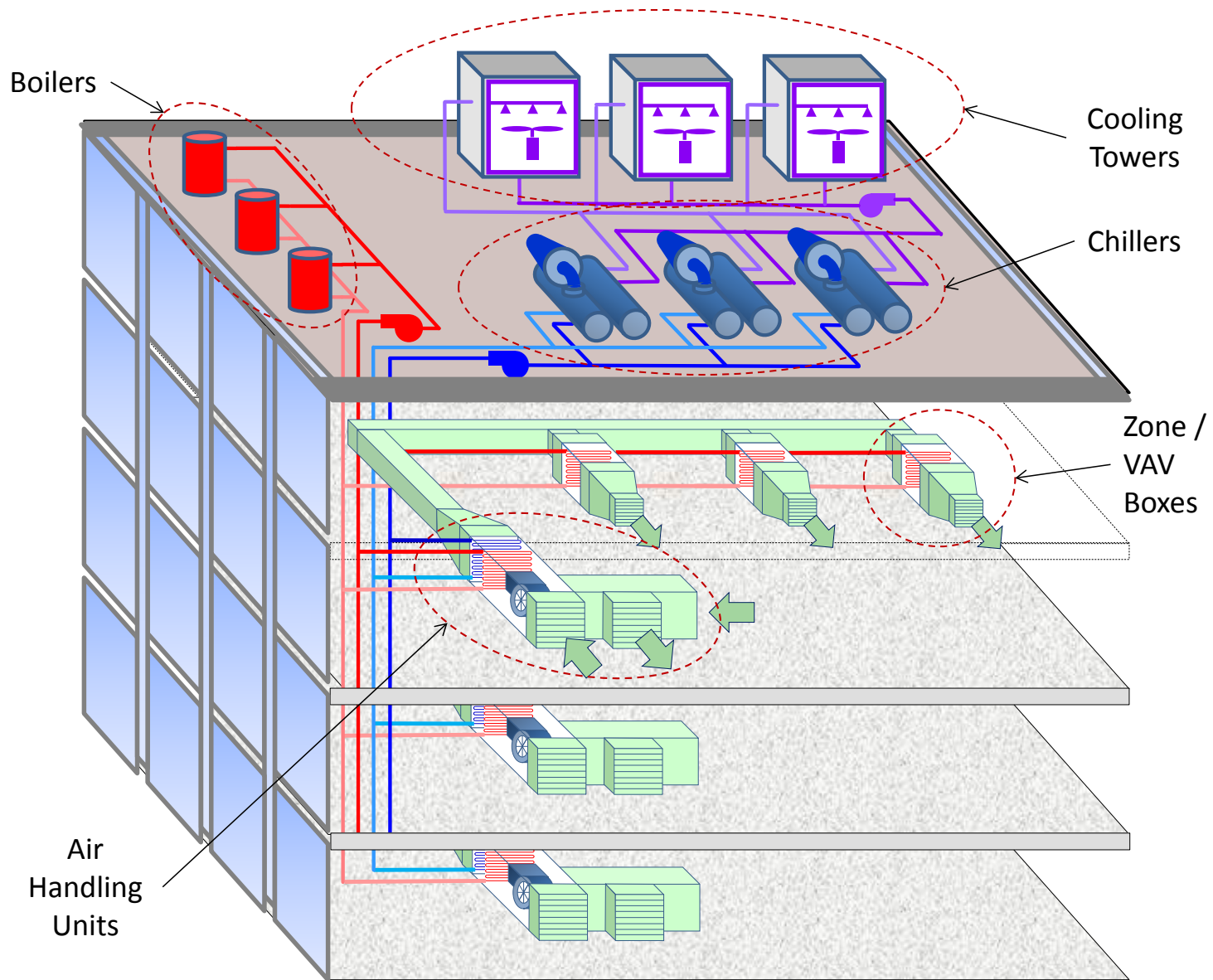
Figure 3.2. Physical Representation of an Intra-Building Network

Engaging occupants in considering these tradeoffs and making them systematically and automatically by embedding them in the control system to achieve higher levels of efficiency and flexibility in the use of energy is a fundamental goal of applying a transaction-based approach within buildings. In the case of demand response, dynamic prices or incentives for electricity inherently penetrate the enterprise boundary at the meter and cascade down within the building systems to the occupants.

Although actual financial transactions may not be taking place between nodes inside the building, another reason the transaction-based approach might be extended inside the building is to leverage the inherently modular nature of such an application-based approach, simplifying the addition of new types of equipment and sources of energy. Foremost may be to leverage the economically-driven transactional approach to automatically reflect tradeoffs among flow rates and supply temperature set points and in the

Figure 3.3. Logical Representation of an Intra-Building Network

dispatch of banks of boilers and chillers in complex, built-up HVAC systems.

We now describe the intra-building network as an extension of the transaction-based network outside the building boundary. During cooling periods, the chillers "purchase" electricity from the building to create chilled water. They also obtain cooling water from the cooling towers, which similarly must obtain the electricity consumed for their pumps and fans from the building. If these purchases of electricity are expressed with the common denominator of the effect on the chillers' efficiencies of

- less pumping and fan power required for slower liquid flow rates,

- higher supply temperatures (cooling water or chilled water supply),

then the tradeoff between these and with the chiller efficiencies can be made explicit and inherent by the transaction-based approach. A simpler, but similar, tradeoff exists between the hot water supply temperature, and flow rate.

Similarly, the AHUs obtain chilled water from the chillers and hot water from the boilers to produce conditioned air from a mixture of fresh outside air and air returning from the zones. In turn, the conditioned air is purchased by each VAV box, adding reheat energy as necessary, to provide the thermal comfort to each zone on each floor. A similar tradeoff between air flow rate and air supply temperature is another opportunity to try to optimize the overall cost, terminating in the final tradeoff between thermal comfort in the zone and its need for conditioned air. By using a transactional approach to this optimization problem, and using nodes to express the hierarchical nature of the system and assigning them responsibility for expressing the current effect of tradeoffs available to them to the nodes above that supply them with energy, better decisions about the global effect of these tradeoffs can potentially be made. (See Use Case *Transactive Control for Large Commercial Building HVAC Systems* in Section 4.4 of this report for more details).

A likely requirement for such a system to function is the need to measure the thermal energy flows involved. Critical to this is measurement of flow rates, or estimating them from fan or pump curves and pressure drops, so that the energy flows can be computed with reasonable accuracy. More accurate results may also result from measurement of temperature differences in flows, rather than individual supply and return temperatures.

To make the transaction-based system comprehensive across the entire consumption model in the building, end-use metering of electricity for lighting and plug loads would also be needed.

3.2.2 Customer to Third-Party Energy and Service Networks

Figure 3.4 illustrates a set of customer's devices, buildings, and facilities managing their electricity and natural gas energy costs by interacting with third-party energy providers, service providers, and each other. Shown on the left are a small/medium sized commercial building heated and cooled with RTUs and a large commercial building heated and cooled with a built-up system of chillers, boilers and a water distribution system. One building also provides charging power to electric vehicles (EVs) in its parking lot. Shown at right is a facility consisting of two buildings with RTUs, under single management. The facility also serves EVs. In addition to interacting with the electric power system as described in the previous section, and the natural gas supply system, these customer elements (circled by red dotted lines) are depicted as interacting for various purposes via the internet with third-party service providers located "in the Cloud."

Also shown in Figure 3.4 are two forms of third-party energy providers designed to illustrate the range of many possible such interactions. At the lower left, such a provider has constructed a building-cooling-heating-and-power (BCHP) system consisting of a natural gas genset, a heat recovery system, and heat-driven absorption chiller and associated cooling tower. This system generates electricity and produces hot and/or chilled water via the heat recovery system, and provides them to the building. Its owner finances, installs, and maintains such systems. We have chosen to also equip this facility with a thermal energy storage tank, to illustrate a second such third-party opportunity that could be offered in combination, or as a standalone proposition. It should be noted that such systems can be owned by and embedded in a building or facility itself. Although the business arrangements are different, the advantages and complexities of adding such systems to building operations are the same.

At the upper right is another type of third-party energy system consisting of a distributed generator (in this case, a PV solar system), complete with inverters, switchgear, and other necessary equipment. It is owned and operated to provide electricity to the distribution network for use by other customers. It could just as easily supply electricity directly to a building or facility, rather than indirectly via the distribution network. It also could be owned and operated by the building or facility itself. To illustrate a second, related opportunity, we have equipped it with a battery storage system as well. The battery could be offered in combination with the distributed generator or as a separate proposition.

The corresponding logical network is shown in Figure 3.5. It shows four examples of customers interacting with third parties via transaction-based networks. Clockwise from the upper left, first is a network of third-party energy service providers operating BCHP, thermal energy storage (TES), distributed generation (DG), and distributed storage (DS) systems and selling energy (electric or thermal) as a product to buildings and facilities directly or via electricity distribution or district heating/cooling utility systems. Depending on the nature of their contract with the provider, the customers can purchase energy from the provider when it is cheaper than from the electric and gas utilities. Alternatively, the provider might sell back to the utilities for resale to customers, or rent or lease use of their physical distribution systems to wheel the energy to its customers.
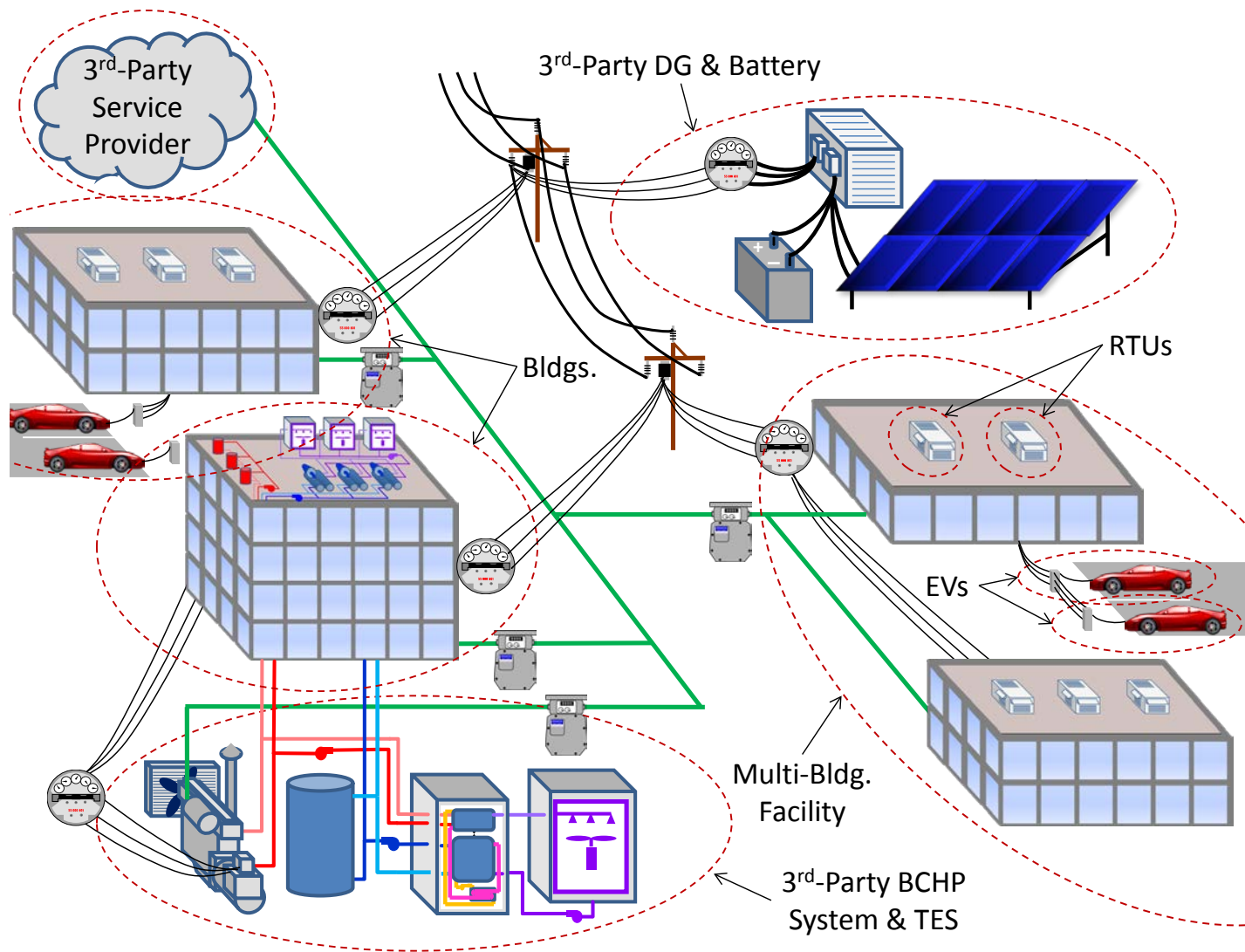
Figure 3.4. Physical Representation of Customer and Third-Party Networks
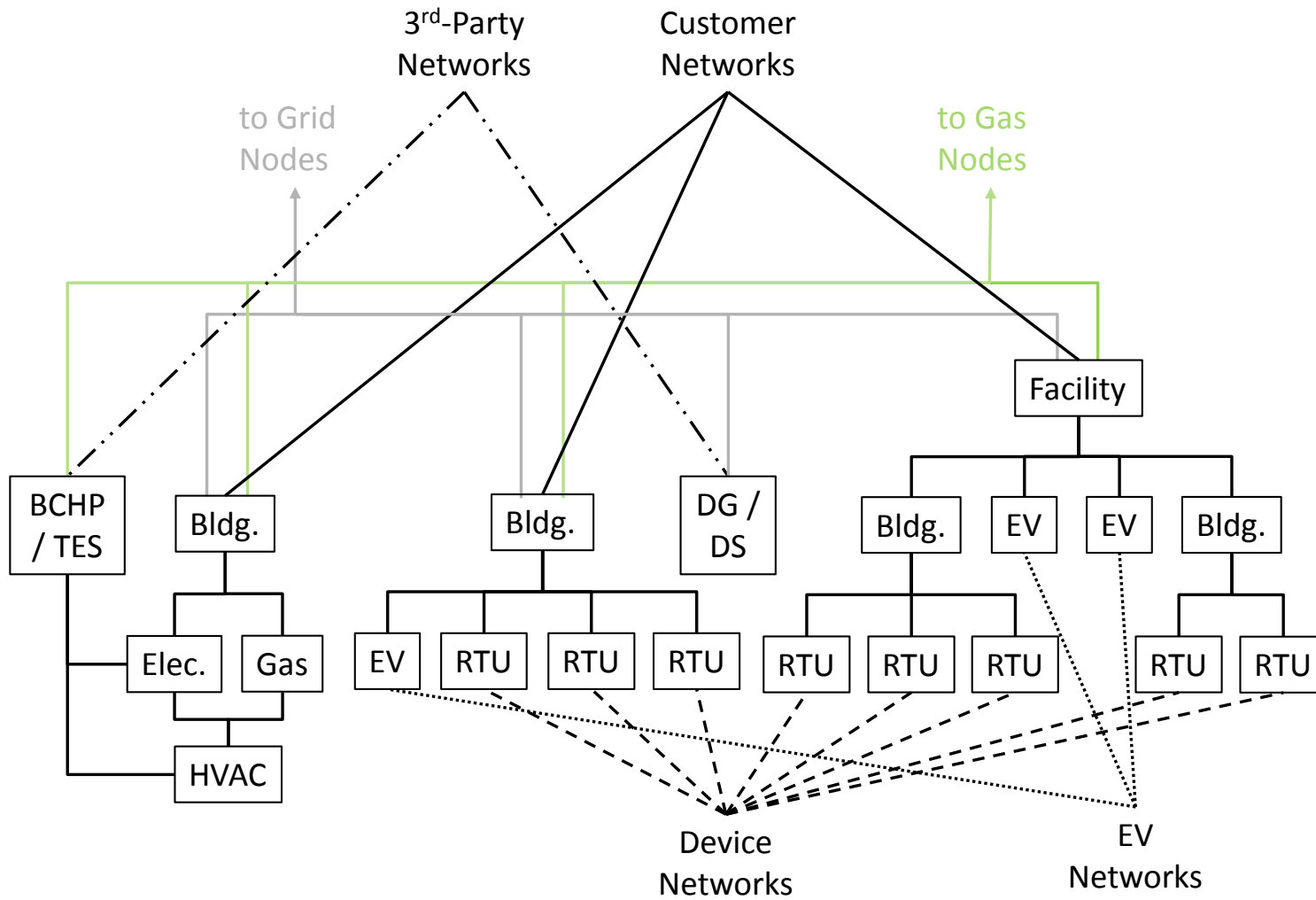
Figure 3.5. Logical Representation of Customer and Third-Party Networks

The second example shows a customer network consisting of buildings and facilities that may interact with each other, or third-party service providers, to limit energy costs. Such a network could, for example, be used to:

- Trade peak demand capacity rights issued by a utility (see Use Case *Trading Allocated Capacity Rights* in Section 6.3 of this report).

- Trade excess electricity or thermal energy generated by a building or facility with another who needs it.

- Arrange for third-party financing of energy retrofits (see Use Case *Efficiency Shared Savings* in Section 4.2 of this report).

- Arrange for and send data to a service provider who provides diagnostic services on end-use systems, devices, equipment, and appliances for a fee, perhaps on a per-problem detected or corrected basis (see Use Case *Diagnostics and Automated Commissioning Services* in Section 4.5 of this report).

- Allow a customer or a diagnostics service provider to arrange for O&M services to correct problems found, perhaps from an "eBay style" marketplace of offers to provide and bids to buy such services.

- Allow an O&M service provider to optimize dispatch of repair trucks so that smaller problems in the vicinity can be fixed cost-effectively, perhaps from bids for repair services posted in a marketplace.

- Connect customers with third-party aggregators of demand response, who in turn trade the resulting savings into grid energy, capacity, and ancillary services markets (see Use Cases *Dynamic Rate* in Section 5.1, and *Interruptible Service or Direct Load Control*, and *Ancillary Services via Aggregator* in Sections 6.1 and 6.4, respectively, of this report).

- Trade measured and verified energy efficiency with renewable portfolio standards, carbon or air shed markets (see Use Case *Efficiency Incentive Payment* in Section 7.2 of this report).

At the bottom of Figure 3.5, the third and fourth networks both consist of customer devices directly interacting with each other or third parties. Two such networks are illustrated: one consisting of RTUs and one of EVs. EVs are a particularly interesting case because they are mobile with respect to the physical supply system. Such networks could, for example, be used to:

- Purchase power for EV charging from a third-party provider at prices independent of which utility serves the charging station.

- Allow RTUs and EVs, separately or together, to interact to limit peak load as part of a capacity trading network.

- Support devices such as RTUs and EVs interacting with facilities or buildings to manage energy or peak demand charges.

- Allow buildings or facilities to charge customers and/or employees for EV charging energy.

- Support trading of positions in an EV charging queue (see Use Case *Trading Positions in an Electric Vehicle Charging Queue* in Section 4.8 of this report).

3.2.3   Building-to-Grid Networks

Figure 3.6 illustrates the primary nodes in a traditional electrical power grid. A fleet of large, central generators are connected at various points of a high-voltage transmission network. Power is delivered by the network to a set of substations and transformed to distribution voltages for delivery to customers. Generally the transmission system is a true mesh network, with power potentially flowing in either direction on any given line and through multiple paths between any two given points (i.e., nodes), depending on the levels of power being injected or withdrawn at the various nodes.
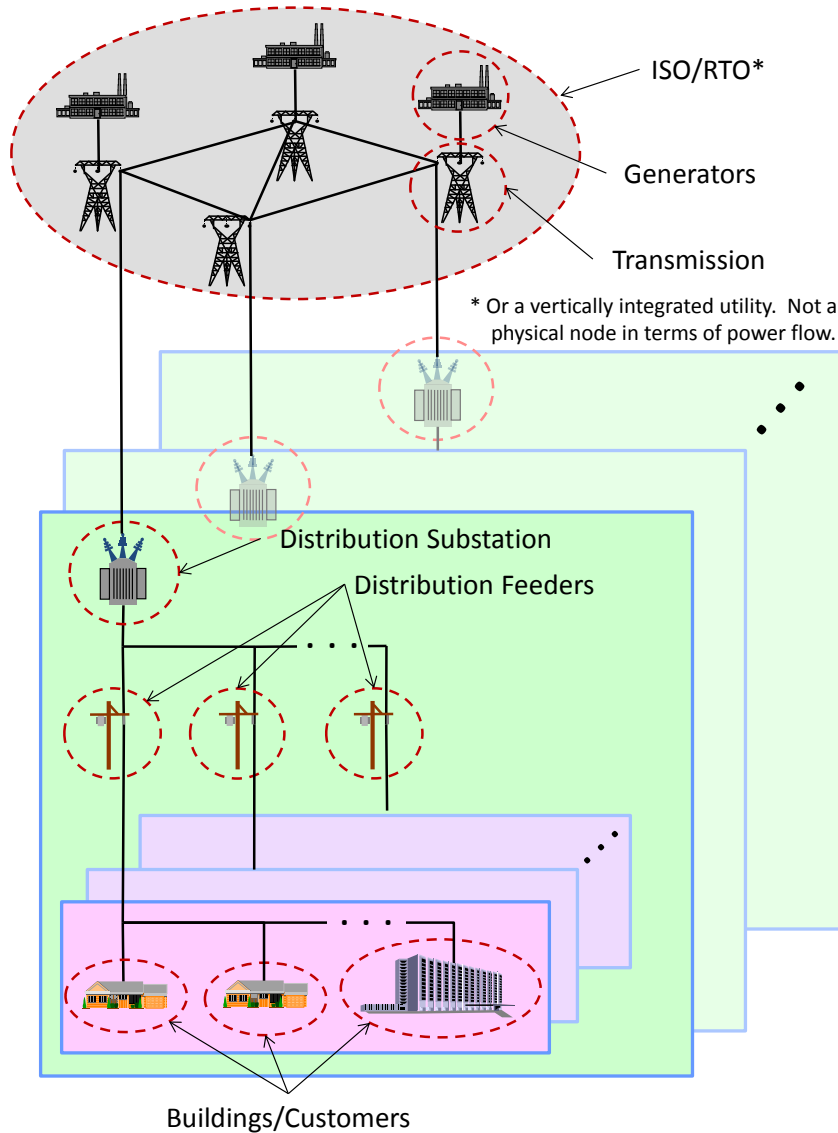
Figure 3.6. Physical Representation of a Buildings-to-Grid Transactional Network

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These and other exemplary nodes in the power system are circled by the dotted red lines. Not shown are details such as transmission substations that convert power to and from parts of the network with lower transmission voltages.

Also shown as a node, albeit not a physical one, is an entity such as a balancing authority, a vertically-integrated utility, an independent system operator (ISO), or a Regional Transmission Operator (RTO) that dispatches the available generation to meet the load as it varies, while avoiding overloading the transmission lines and supplying the necessary ancillary services needed to keep the grid stable and reliable. Each substation typically provides power to multiple feeders in the distribution network it serves. These networks are typically operated as radial (one path from substation to customer) rather than as mesh networks (sometimes used in high-density urban areas, for example). Each feeder, typically, then branches out to deliver power to customers, unless it is dedicated to a single customer, for example. We have indicated each feeder and each customer as nodes. Not shown are customer transformers that step down the distribution voltage to service-level voltages. These typically serve 1 to 10 customers, and can also be considered system nodes in the distribution network.   Also not shown are other controllable elements of the distribution network, such as capacitor banks and voltage regulators, for example.

Note that the topology of radial distribution networks can change if they are connected to lines from adjacent feeders with normally-open switches (not shown). In the event of a short circuit that can be located and isolated, these switches can be closed to power intact parts of the damaged feeder via other paths temporarily. Thus customers in effect can be "moved" by the distribution utility between feeders and substations, in a topological sense. Similarly, transmission lines are put in and out of service by operators, so any specific representation of a power grid network may be best thought of as a snapshot in time.

Figure 3.7 presents a logical buildings-to-grid network from the viewpoint of communications and control. The nodes in the logical network correspond to those in the physical network shown in Figure 3.6. As noted previously, additional nodes may be defined to represent other physical elements of the system. When considered as a transaction-based network operated by an ISO or RTO, the generators (G) offer to sell power to the ISO/RTO's energy market, which determines the least-cost feasible solution to generate the power required by each distribution substation, and the price of energy at that point (the locational marginal price, or LMP). When the transmission network is entirely unconstrained, the LMP is the market clearing price for the system as a whole. When it is constrained by transmission line capacity or stability considerations, a somewhat more expensive set of power plants must be dispatched, and the clearing price at transmission nodes (T) associated with the constraint will rise to reflect the higher cost of power delivered at that location.

From a transactional point of view, this network can be viewed as the ISO/RTO buying power from generators, and determining the price at which to offer it at each transmission node. The load serving entity represented by the distribution substation (D), in effect, buys it from the transmission node serving it and converts its price from wholesale to retail and delivers it to customers. In effect, the ISO/RTO is using the nodal price of power as an indirect means of controlling the dispatch of the generators. This is the essence of a transactional energy network.

The distribution substation can be considered to "sell" to each feeder (F), which in turn "sells" to each building or customer (B). Today, this is typically done as a single, blended price, with a fixed energy cost for a given customer class (residential, commercial or industrial) and, in some cases, a fixed peak demand charge during peak demand periods (e.g., for large commercial buildings and/or industrial

Figure 3.7. Logical Representation of a Buildings-to-Grid Transactional Network

customers). There is no locational or time-differentiated price as there is in the transmission network. The transaction-based control paradigm used for the transmission system can be extended to the distribution system. Then a substation or feeder, when its throughput is limited by its physical capacity, can increase its selling price to reduce the load it serves to match its capacity, for example. This assumes that there are customers (or other third parties, as discussed in Section 3.2.2) who are able to reduce the load it must serve either by reducing demand or dispatching distributed generation or storage devices. Such rates may remain fully regulated by public utility commissions via utility rate cases. It also assumes that customers have agreed to such dynamic rates, and that they have been crafted to be equitable and provide proper incentives for customers to respond appropriately.

The extension of the wholesale transactional approach to the distribution network described above represents just one of the use cases, which describes several other approaches. A number of others can be envisioned. We provide a description of actual projects demonstrating this approach in Section 3.3.

3.3 Demonstration of Buildings-to-Grid Transaction Networks

Two demonstrations of transactional building-to-grid networks are currently on-going as part of the Department of Energy's Office of Electricity Smart Grid Investment Grant and Demonstration Program.[1] Taken together, these two demonstrations illustrate an actual transactional network illustrated in Figure 3.6 in physical form and in its logical representation in Figure 3.7. The largest of these, the Pacific Northwest Smart Grid Demonstration (PNWSGD) project, is a $178M, 5-year project, led by Battelle Memorial Institute, spanning 5 states, engaging 11 municipal, cooperative, and investor-owned utilities across in collaboration with the Bonneville Power Administration, 2 universities, and 5 vendor partners.

Among the project's primary goals is to develop a regional communications and control infrastructure that uses transactive incentive signals to engage a wide variety of responsive assets, quantify smart grid costs and benefits, contribute to development of interoperability standards for transaction-based control of power grids, and, in particular, facilitate the integration of wind and other renewable resources that are rapidly penetrating the region's power system. It is by far the largest project of its kind in the world, and unique in its goal of facilitating wind integration at the regional scale.

The PNWSGD has established a transactional representation of a grid control node as shown in Figure 3.8, which can be viewed as a more specific version of that proposed earlier in Figure 3.1 of Section 3.1 that is more narrowly suited to the purposes of implementing control. The incentive signals and load estimates used by the demonstration essentially are examples of the general concept of bids and offers in Figure 3.1. The local control and data signals are literally the same as proposed in Figure 3.1.
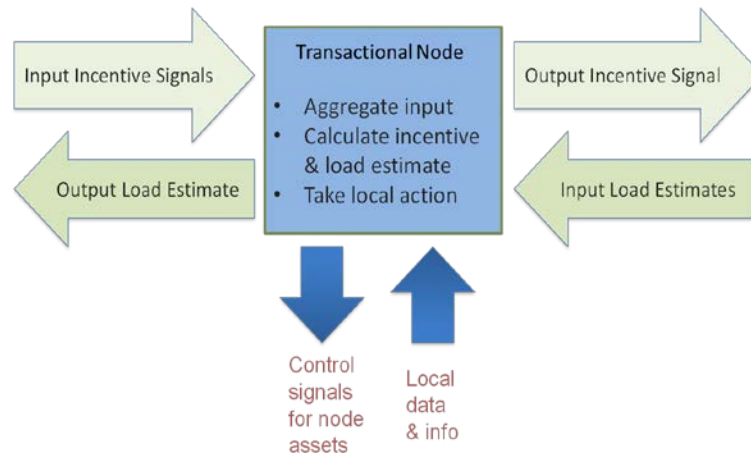
Figure 3.8. Representation of Transactional Grid Control Node in the
PNWSGD Project

The PNWSGD has implemented a regional network of such transactional nodes at the transmission level and at the points of delivery to the 11 distribution utilities. Figure 3.9 shows the set of transmission zones in the Pacific Northwest, defined by the major cut planes (shown as red lines) where the

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[1] Funded as part of the economic stimulus by the American Recovery and Reconstruction Act of 2009.
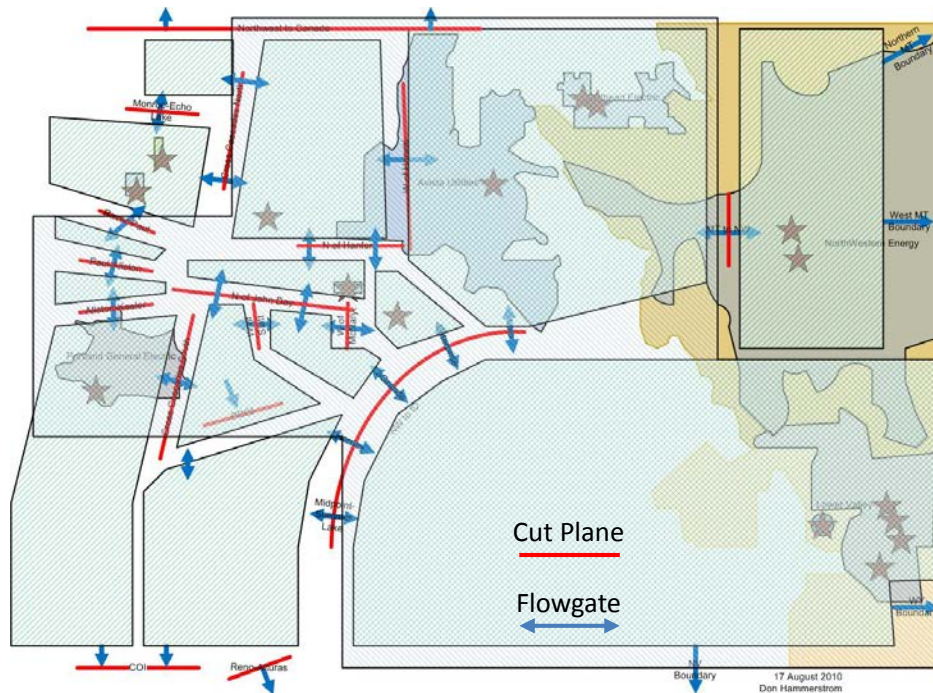
Figure 3.9. Physical Network of Transmission Zones in the PNWSGD

significant transmission constraints lie, superimposed on a disjointed map of the region (Washington, Oregon, western Idaho, and parts of Montana and Wyoming). Because transmission within each zone is relatively unconstrained, the cost of electricity within each zone is considered uniform. Each zone is represented as a transmission node. The goal of adjacent transmission nodes in the network is to manage power flow across the constrained pathways (blue arrows) at or below their limits. They do this by essentially negotiating the cost of energy in their zone as the sum of the cost of that produced by generators in the zone, including renewables, and the cost of energy imported from adjacent transmission nodes. Together these must equal the cost of energy delivered to the distribution utilities within the zone. This simultaneous negotiation between all adjacent nodes, both transmission peers and distribution delivery points, occurs in iterative fashion until convergence is reached. This is done every 5 minutes. Look-ahead prices and loads for a 48-hour period are also negotiated as an informative process, although strict convergence for them is not required.

The distribution utility nodes in this process are negotiating their demand from the transmission system as a function of their willingness to dispatch a wide variety of local, distributed assets under their control. These range from dispatch of a wide variety of distributed assets totaling over 50 MW, ranging from battery storage, to volt-VAR control systems[1] that affect consumption, to demand response from various types of commercial and residential buildings.

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[1] Volt-VAR control (VVC) is a fundamental operating requirement of all electric distribution systems. The prime purpose of VVC is to maintain acceptable voltage at all points along the distribution feeder under all loading conditions. See: http://cialab.ee.washington.edu/nwess/2012/talks/uluski.pdf

Although the transactional approach is not (yet) carried down to these distributed assets, that is exactly what is being done in the ARRA co-funded AEP gridSmart™ Demonstration program, another such large project. In this project AEP (the utility) receives power from PJM (the ISO) at the price of the wholesale market clearing prices at its delivery point near Columbus, Ohio (i.e., the locational marginal price). The PJM 5-minute real-time wholesale price is transformed into a real-time 5-minute <u>retail</u> price via a ratemaking process approved by the Ohio Public Utility Commission (PUC). The retail rate is designed to be revenue neutral. That is, it neither rewards nor penalizes the average customer for simply signing up – if they do not shift load whatsoever, the sum of their annual utility bills would remain the same. This is true even to the extent of adjusting it for fluctuations in wholesale prices from year to year caused by weather or economic conditions (i.e., the wholesale market price risk is managed by AEP and the PUC as part of the ratemaking process, as usual, rather than being thrust upon retail consumers).

About 240 customers signed up for this real-time rate, and were given a home energy management system and a smart thermostat that automatically would respond to price fluctuations to save them money on their energy bills by shifting some of their air conditioning load to lower-price periods. This only occurred to whatever extent each customer allowed their thermostat to vary around their normal setting. They could also respond to displayed prices by manually delaying use of other appliances.

A double auction clearing mechanism was used for the customers on each distribution feeder to clear at a higher retail price when loads would otherwise exceed maximum capacity of the system, providing further opportunity for customers to save energy costs. Excess revenue collected by the utility plus a reward for actual response during such times was provided to the customer as a lump-sum payment at the end of each monthly billing period based on time-series load data from their AMI meter and their bidding history in the marketplace.

In this fashion, the transactive real-time price signal was delivered directly to the customers' home energy management nodes, which, in turn, managed their smart thermostats accordingly. Between the PNWSGD and AEP's gridSMART project, a broad range of buildings-to-grid transactions and associated value streams have been demonstrated in the field from generation to transmission, distribution, and customer nodes.

3.4 Transaction as the Framework for Node Interoperability

An interoperability framework is one essential element to making transactional energy networks viable. This derives from the need to support a vibrant and growing ecosystem of vendor products and services that interoperate as a network on a common basis and that readily enable secure machine-to-machine connections to be established with minimal effort when installing them. There are two parts to the framework proposed here. First, a general framework and common basis is required for how nodes in such networks will interact. In Section 3.1 we describe how a transactional node can be defined to accomplish this. The second is a basic interoperability framework for the *information* exchanged electronically between such nodes.

Here, we propose that the basic construct for the information exchange is the *contract defining the transaction*, because it explicitly addresses the business context, the business procedure, the business

tactics, the business strategy, and to some extent the economic and regulatory policy authorizing the transaction.

The basic properties that define a transaction include the following:

a. *Exchangeable products, services and rights*: The basic transaction must be clearly and formally defined in terms of:

    i. *Quantity and quality*: For example, an energy product might define the kWh, Btu, or quantity of fuel involved; an electric energy product sold by a utility might further define voltage, power factor, and harmonic content limits involved. A thermal energy product might further define the type of fluid (e.g., air, water, and steam), temperature, pressure, flow rate and maximum pressure drop.

    ii. *Time, place, and means of delivery*: The stipulated time and duration of the delivery, optionally including future time intervals, the location of delivery, and the means of delivery (physical energy flow, physical service, electronic information, certification of a right or financial product) all must be articulated. In the case of financial products time of delivery refers to maturation of a contract, which is settled at the contracted date and time.

    iii. *Price or value*: the price or value of an exchangeable. This must specifically include its *status* – informative only (non-binding), binding (tender), offer, bid, accepted, cleared, ex post facto, etc.

b. *Transacting parties*: A transaction unambiguously identifies two or more *willing* participants that settle on the terms and conditions of a contract.

c. *Monitoring/regulating entity:* A transaction may define a monitoring/regulating entity that authorizes the rights of a market maker to operate an exchange, ensures that terms and conditions have been satisfactorily met, and/or provides arbitration in case disputes arise.

d. *Process for agreeing on a transaction*: The participants may either directly negotiate to reach a consensus, or may use the services of an arbitrator to do so. A commodities exchange (e.g., a corn futures market) is an example of the latter, where participants do not directly engage in negotiations, but rather are matched by an explicit auctioneer.

    i. *Negotiation:* A transaction may be completed either through bilateral or multi-lateral negotiations between willing participants. In such instances, the transacting parties may write up contracts terms and conditions specific to a transaction, which may not necessarily be the same for a similar contract between a different set of transacting parties.

    ii. *Auction*: An auction is a market mechanism to match a willing buyer with a willing seller without any direct negotiations between the parties. The participants submit their bids and offers, to buy and sell products/services, and an "auctioneer" clears the market to determine the settlement price and quantity.

e. *Contract of terms and conditions*: A transaction involves a legally binding set of contract, terms and conditions, which may include the following (not an exhaustive list):

 i. *Measurement and verification/validation*: Contracts may also contain terms and conditions related to measurement and verification of delivered product/service contingent on fulfillment of which, a transaction may be deemed as completed successfully.

 ii. *Financial settlements and means of payment*: A transaction will most likely include terms of financial settlement, as well as a payment mechanism, in return for products or services provided by the involved parties.

 iii. *Financial penalties*: A contract may also include terms and conditions that list the financial penalty that may be levied on either party for not fulfilling their respective obligations to complete a transaction.

 iv. *Default terms and condit*ions: A contract may also include default terms and conditions that may be applied in case of emergencies, technical outage, etc. For instance, a contract may include provisions to revert to default prices, in case of a communication system failure leading to devices not receiving real-time price signals.

 v. *Repudiation*: Contracts may also include formal methods of repudiation in case of unsatisfactory provision of products and services. The terms and conditions may also specify methods for settling such disputes.

 vi. *Acknowledgement*: For a transaction to have been completed successfully, a formal method of acknowledgement of delivery of products/services in exchange for a financial settlement may also be stipulated in the contract terms and conditions.

As with any other interoperability approach, the formulation proposed here of 1) a transactional node, and 2) the use of the transaction as the basis for information exchanged by such nodes in a transactional network, must be adopted by a community of users to reach maturity and become viable. We are not suggesting that such an effort be undertaken from scratch; many useful standards for smart grid information exchanges have been proposed, adopted, or are under construction. These should be utilized in such an effort wherever relevant and useful. What is being proposed here is the development and adoption of an enhanced, higher level standard for general energy-related transactions in the context of the general principles under which commercial business is conducted.

4.0   End-User Services

This chapter describes a non-exhaustive, but representative, set of use cases illustrating the end-user services, defined in Chapter 2 of this report.[1]

Chapter 2 describes end-user services as energy and energy-related products, services, and rights that the end user purchases to balance and co-optimize their overall energy costs, comfort and convenience. The rendering of these services is originates with a need and value at the customer premises, and hence, may be labeled as *behind the meter* services. The net result of providing such a service is that buildings and the equipment within the buildings are more efficient, predictable, controllable, and provide required services at lower cost. This may involve a wide range of transactions such as buying energy from a third -party on-site generator or storage system, purchase of diagnostics and valuation services from a third party that supports the operations and maintenance of end-use assets, purchase of energy services by tenants from the building owner, and hierarchical "purchases" of energy by one building subsystem from another (e.g., by an air-handling unit in the form of chilled water from a bank of chillers) that may facilitate advanced control paradigms.

Example use cases of end-user services described here are:

- Third-party energy provider
- Efficiency shared savings
- Tenant contracts with building owner for energy
- Transactive control for large commercial building HVAC systems
- Diagnostic and automated commissioning services
- Data centers trade computation jobs
- Microgrid coordinating demand response, distributed generation and storage
- Trading positions in an electric vehicle charging queue

Each of these use cases is described further, below.

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[1] The use cases are described in a format inspired, in part, by the National Institute of Standards (NIST) Smart Grid Interoperability Panel's template (see IKBUseCaseTemplateV1_0.doc, 7/9/2013). The references to NIST 1.x in parentheses after a section heading refer to a use case element in that document. Headers reflecting the number and title of each use case are supplied to ease navigation of the use cases by the reader. A table of contents appears at the beginning of each category for that purpose, as well.
The authors include these use cases for illustration purposes only. They are far from an exhaustive set; we expect many more will be forthcoming in the future as transactive approaches are embraced. Engendering such creative invention is part of the purpose of this reference document. The use cases are not completely described or conceptualized here. Further, a number of them, particularly those for energy market services and grid services, may be mutually exclusive or compete with each other. Regardless, these use cases have not yet been assembled into a coherent, integrated schema for grid operations. A few of the uses cases (e.g., 5.1 Dynamic Rate and 6.1 Interruptible Service or Direct Load Control) are more representative of current practices that we expect will eventually be overtaken by more advanced, transactive approaches. The presence of any of the use cases here should not be interpreted as an endorsement for it.

4.1 Third-Party Energy Provider

Type of Transaction: Building to Other (Service Provider)

Brief Description (NIST 1.3)

Customer (typically a commercial building owner) contracts with a vendor that installs, operates, and maintains equipment at its expense, such as a building-cooling-heating-power (BCHP) system, thermal or battery storage system, or a conventional generator. It then bills the customer for the energy services provided to the building and/or shares in the proceeds from value provided to the electric power grid (e.g., net reduction in demand, ancillary services, etc.).

Narrative (NIST 1.4)

What is being transacted?

- Two forms for this transaction are envisioned:
  1. Customer agrees to purchase energy from the service provider's system when it is advantageous to do so. This may be in the form of thermal and/or electrical energy.
  2. Customer agrees to share savings it receives from its electric utility for demand response, ancillary services, etc.

Why is it being transacted?

- Customer desires to obtain a lower energy bill without the capital expenditure for the equipment and systems or the need to operate and maintain them.
- Service provider desires to earn a return on its investment in the equipment and systems.

How is it being transacted?

- Customer signs contract with service provider.
- Service provider installs, operates, and maintains equipment and systems at their expense.
- Service provider pays for the electricity and fuel it consumes.
- Service provider measures and bills for (1) the electrical and/or thermal energy delivered to the building based on the contract terms, and/or (2) its share of the customer's savings for demand response, ancillary services, etc.
- Customer pays bill with credit card transaction or automatic bill-pay arrangement.

What is the time scale of the transaction?

- One-time contract between customer and service provider.
- Periodic (monthly) bills from service provider to consumer for its share of the monthly energy savings based on an agreed upon formula for the energy savings and the current rates for gas and electricity.

Actor/Stakeholder Roles (NIST 1.5)

Who is transacting?

A. *Consumer (building owner).*

B. *Service provider, who* most commonly may be a *third-party vendor* but who could also be a *utility,* a *retail electricity service provider*.

Who is the market maker?

- (B).

Who else needs to be notified or acknowledge a transaction has been made?

- The electric utility or load serving entity may need to be notified.

Are there other transactions associated with this?

- See other related building-to-grid use cases: 5.1 Dynamic Rate, 6.4 Ancillary Services via Aggregator, 6.2 Transactive Retail Energy Market, and 6.5 Transactive Acquisition of Ancillary Services.

- An electric utility or aggregator may choose to be a financial participant in the contract (see use cases: 7.2 Efficiency Incentive Payment and 5.5 Trading Efficiency to Relieve Congestion).

- Business model could expand to full ownership and operation of the HVAC and lighting equipment in a building.

Information Exchanged (NIST 1.6)

How is the transaction verified?

- Contractual notice exchanged (paperwork or electronic) between (A) and (B).

How is the transacted commodity measured and verified?

- Electrical and/or gas sub-metering measures consumption by service provider's system(s).

- Electric energy (kWh) and thermal energy (Btu in air or water flows) delivered to the building are metered.

- Savings or incentives for demand management and ancillary services are determined as in the related use cases (above).

Activities/Services (NIST 1.7)

What equipment and technology is required?

- Interval electric power, gas, and thermal energy metering systems.

- Algorithms that determine when energy from the service provider is less expensive than from the utility and associated controls that implement it.

- Algorithms that determine the savings to the consumer when responding to utility prices and incentives so that they can be equitably shared with the service provider.

What is the benefit for the building?

- Reduced utility bills (gas and electric).

- Incentive payments from utility or aggregator for load reductions or ancillary services.

What is the benefit for the grid?

- Increase demand management and efficiency from end uses that contribute to peak loads reduce the need for capital investment for generation, transmission, and distribution capacity.

- When utilities are subject to a Renewable Portfolio Standard (RPS) requirement, they can earn credit for efficiency where allowed, or when subject to a carbon market or tax, they can save money by reducing their need to purchase credits or pay taxes.

What is the benefit for renewables?

- Renewable generation could be included.

What is the benefit for energy efficiency?

- Significant source-to-sink energy efficiency and carbon reduction (gas plus electricity) can be achieved by BCHP systems.

- Marginal energy savings may be achieved by careful optimization of the combined operation of the service provider's and the customer's systems.

Contracts/Regulations (NIST 1.8)

- Normal commercial business rules would seem to apply.

- Where a regulated utility is involved, PUC approval must be sought to offer such services.

Current Examples of this Transaction

- There is some third-party ownership and operation of combined-heating-power (CHP) systems.

4.2 Efficiency Shared Savings

Type of Transaction: Building to Other (Service Provider)

Brief Description (NIST 1.3)

Customer (typically a commercial building owner) signs up with an energy service company (ESCO) who provides energy efficiency retrofits and services in exchange for a shared savings contract.

Narrative (NIST 1.4)

What is being transacted?

- Customer agrees to split the estimated savings in energy bills (gas and electric) with an ESCO for a stipulated number of years, with the savings resulting from the latter's investment in efficiency retrofits and other services at the customer premise.

- In a more transactional approach, the ESCO could create a market for such services and customers would sign up on line.

Why is it being transacted?

- Customer obtains a lower energy bill without need for a capital expenditure for an efficiency retrofit.

- ESCO has lower cost of capital than (non-Federal) consumers. Profit is made when share of savings exceeds capital and labor investment at customer premises.

What is the time scale of the transaction?

- One time contract for customer sign-up.

- ESCO bills consumer for its share of the monthly energy savings based on an agreed upon formula for the energy savings and the current rates for gas and electricity.

Actor/Stakeholder Roles (NIST 1.5)

Who is transacting?

A. *Consumer (building owner)*, perhaps representing lease/rental tenants (occupants) collectively. ESCOs tend to work primarily with large commercial buildings and institutional customers (with large facilities).

B. *Energy services company,* which can be a *utility,* a *retail service provider*, or a *third-party aggregator* that may also interact with the customer as an energy supplier and perhaps also engage them in demand response.

Who is the market maker?

- (B).

Who else needs to be notified or acknowledge a transaction has been made?

- N/A.

Are there other transactions associated with this?

- Where there are wholesale energy markets for electricity that allow demand response participation, (B) may also schedule and aggregate demand response from a collection of customers and bid it as a block of demand reduction into the day-ahead or real-time market.

Information Exchanged (NIST 1.6)

How is the transaction verified?

- Contractual notice exchanged (paperwork or electronic) between (A) and (B).

How is the transacted commodity measured and verified?

- Load data from utility meter is compared to statistical/engineering model of pre-retrofit consumption as a function of weather.

- Adjustment clauses may also apply for changed occupancy or usage patterns.

- Lack of transparency in such approaches has been noted to be a source of friction in the relationship with the building/facility customer. Alternatives based on a more measurement-intensive approach, and/or in which the ESCO pays the energy bill and the customer pays the ESCO a bill for end-use services, are worthy of exploration.

Activities/Services (NIST 1.7)

What equipment and technology is required?

- None for current practice.

- (Desirable) Continuous or spot end-use metering can improve targeting of efficiency measures and support improved baseline models and adjustment factors.

- (Desirable) Data from commercial building control systems or smart residential thermostats and appliances can likewise support improved targeting and measurement.

What is the benefit for the building?

- Reduced utility bills, energy use and reduced environmental emissions.

- Improved comfort if ESCOs commission building systems

- Outsourcing of energy expertise, freeing up management to focus on core business, e.g., healthcare or education.

What is the benefit for the grid?

- Increased efficiency from end uses that contribute to peak loads reduces the need for capital investment for generation, transmission, and distribution capacity.

- When utilities are subject to a renewable portfolio standards (RPS) requirement, they can earn credit for efficiency where allowed.

- When utilities are subject to a carbon market or tax, they can save money by reducing their need to purchase credits or pay taxes.

What is the benefit for renewables?

- N/A.

What is the benefit for energy efficiency?

- Lack of need for efficiency investment on the part of consumers spurs penetration of efficiency measures.

Contracts/Regulations (NIST 1.8)

- Today, nearly all ESCO contracts are bilateral with consumers and subject only to the laws of commerce.

- Where a regulated utility is involved, PUC approval must be sought to offer such services.

Current Examples of this Transaction

- Numerous examples of ESCO services are offered by companies such as Honeywell, Johnson Controls, and Rockwell among others.

- Federal facilities such as military bases are a common customer (see [Federal Energy Management Program).]

4.3 Tenant Contracts with Building Owner for Energy

Type of Transaction: Intra-Building

Brief Description (NIST 1.3)

Building or facility owner or operator (1) passes through energy costs (including dynamic rates), peak demand charges, etc. to tenants of or business divisions occupying the building, or (2) gives them a monthly allowance for energy consumption that is covered in the tenant's monthly rent. In the case of (2), if the monthly allowance is exceeded by the tenant/division, the tenant incurs a penalty, or they may receive a rebate to the extent the monthly allowance is not exceeded. Tenants or business divisions are also allowed to trade surplus allowances with other tenants/divisions who have a need for an additional allowance.

This engages tenants and business divisions in conserving energy, managing peaks loads, and responding to dynamic rates by co-optimizing comfort or quality of service for the costs of their provision.

Narrative (NIST 1.4)

What is being transacted?

There are two forms to these transactions, with the same basic intent of engaging building occupants in conserving energy, managing peaks loads, and responding to dynamic rates:

- (1) Energy costs are passed through to the building occupants in the form of a monthly energy bill from the tenant. If dynamic rates or a peak load ratchet are involved, building owner expresses those to tenant in near real time.

- (2) The tenant/division agrees to a monthly allowance for energy use, given by the building owner, as a part of a lease agreement. Rebates and penalties are given monthly based on whether the tenant/division is below or exceeds the monthly allowance, respectively. Tenants can exchange excess allowance with others tenants/divisions that are in deficit at an agreed upon price.

Why is it being transacted?

- (1 and 2) Building owner passes through energy costs.

- (1) Building owner allocates energy costs, peak demand charges, and dynamic prices to individual tenants or business divisions as an engagement mechanism.

- (2) Building owners can manage the monthly operating costs for electricity within a small tolerance of a desired threshold (equivalent to the aggregate allowance of tenants/divisions). Also, the tenants/divisions have the opportunity to receive payments if their electricity allowance is not exceeded.

How is it being transacted?

- In transaction (1):

- Building owner bills tenants or business divisions for energy costs (including those based on dynamic rates) and any peak demand charges, monthly based on metered energy use.

- In transaction (2):

  - A tenant or business division signs an agreement with the owner/operator that includes a monthly allowance for electricity. The building owner sends each tenant the same dynamic rate that it receives to enable the tenants to make informed decisions on how to utilize their loads via a building automation system (BAS) or energy management system (EMS).

  - An "eBay-like" market is used for customers to offer and bid on surplus allowance.

  - The building owner is notified of the exchanges.

  - The tenant/divisions receive rebates or penalties relative to the amount the electricity bill for the tenant is below or above the monthly allowance.

  - Both transactions are classified as an over-the-counter (OTC) or bilateral transactions.

What is the time scale of the transaction?

- Irregular, long-term, perhaps annual for lease agreement.

- In (1), monthly bills, unless dynamic rates or peak demand charges are involved. Then rates and consumption information must be exchanged

  - If TOU price is used, perhaps daily

  - If CPP is used, demand response service is provided by customers upon irregular requests from utility and typically lasts 1 hour or more (up to contractual limits). 24-hour advance notice may be required for CPP events.

  - If RTP is used, demand response occurs as price changes at hourly intervals or less.

  - For peak demand charges, notification of a potential peak load is required on a short-term, irregular basis.

- In (2), rebates and penalties are distributed monthly.

Actor/Stakeholder Roles (NIST 1.5)

Who is transacting?

A. *Tenant/business division*, often but not always building owner, perhaps representing lease/rental tenants (occupants) collectively

B. *Building/facility owner*

Who is the market maker?

- (B)

Who else needs to be notified or acknowledge a transaction has been made?

- N/A

Are there other transactions associated with this?

- (1) Building owner participating in a contractual dynamic rate program or a transactive retail energy market is involved in those transactions between the building and the grid (see Use Cases 5.1 Dynamic Rate, 5.4 Transactive Energy Market Exchange, and 6.2 Transactive Retail Energy Market).

Information Exchanged (NIST 1.6)

How is the transaction verified?

- Contractual notice exchanged (paperwork or electronic) between (A) and (B).

How is the transacted commodity measured and verified?

- (1 and 2) Sub-metering or non-intrusive load monitoring (NILM) of tenant energy use, and thermal energy delivery in large commercial buildings with built up HVAC systems, are required.

- (2) The dynamic rates are used to calculate whether the allowance has been exceeded or not.

Activities/Services (NIST 1.7)

What equipment and technology is required?

- Electric sub-metering equipment required to provide load data time-series for billing.

What equipment and technology is desirable?

- NILM technology (hardware and software used to disaggregate building loads) may be desirable.

- Control systems capable of automating the customer's desired response.

- Demand response resource forecasting as a function of time of day, day-of-week and weather if CPP or RTP rates are involved.

What is the benefit for the building?

- Lower electric bills result, to the extent load is shifted or energy consumption is reduced by tenants.

- Ability to better manage monthly electricity bills because the monthly allowances given to the RTP signal are sent to tenants.

What is the benefit for the grid?

- Reduced investment for generation capacity to meet peak loads (CPP, RTP, and to a lesser extent TOU).

- Reduced fuel costs or wholesale purchase costs for electricity (TOU, RTP).

- Reduced expenditure for emergency reserves (CPP, RTP). Ability to balance the intermittency of renewables at the sub-hourly level.

What is the benefit for renewables?

- (1) Emergency response can sustain grid reliability in the face of increased strain on transmission system for long-distance delivery of renewable power to load centers.

What is the benefit for energy efficiency?

- Home/building networks can be leveraged for energy efficiency applications, better control, diagnostics, and advice.

Contracts/Regulations (NIST 1.8)

- (1 and 2) Sub-metering and billing is subject to approval by PU Cs in some states.

- (1) Dynamic rates are subject to public utility commission approval (investor-owned utilities) or board of directors' approval (public utilities).

- (2) The contract should contain the monthly allowance for electricity bills and the formula for determining rebates and penalties as a result of staying below or exceeding monthly allowance.

Current Examples of this Transaction

- None as described. Sub-metering and tenant billing is a well-known but seldom practiced strategy. This use case extends such approaches considerably.

4.4 Transactive Control for Large Commercial Building HVAC Systems

Type of Transaction: Within Building (End-User Services)

Brief Description (NIST 1.3)

Customer/building operator uses transactive concepts in a hierarchical control system for a multi-zone commercial building with a complex, built-up HVAC system comprising chillers, cooling towers, air-handling units, etc.

Narrative (NIST 1.4)

What is being transacted?

A set of transactive markets for energy is created at each of a hierarchical set of control layers, corresponding to the layers of the HVAC system, which converts or delivers heating and cooling energy to building zones. The markets are used to control the equipment or systems at each layer to maximize comfort in the occupied zones while minimizing energy cost.

- The control layer purchases energy from the layer above, and sells to the components in the layer below.

- The purchase of offered energy is in one of several forms, depending on the layer of the HVAC system involved:

  – electricity and natural gas at the building level

  – cooling water from the cooling tower(s) for the chiller(s)

  – chilled water from the chillers and hot water from the boilers for the air handlers

  – conditioned air for the air handlers, VAV boxes, and zones

  – reheat energy (electricity or hot water) for the air handlers or zones for temperature and/or humidity control.

- These are likely to be pseudo-transactions, i.e., not literal financial exchanges, with the possible exception of the bottom-most layer supplying thermal comfort to the zones.

- At the discretion of the building owner/operator, the purchases of energy by individual zones may be mapped to the tenants or business divisions occupying the corresponding space and actually billed to them.

Why is it being transacted?

Customer/building operator desires to create a hierarchical transaction-based framework for their HVAC control system to:

- Reflect the value of occupant comfort in terms of its energy cost so these can be appropriately balanced.

- Decrease monthly utility bills by increasing the energy efficiency of the HVAC system via the self-optimizing properties of a transactive approach.

- Incorporate a continuous demand response capability that maximizes incentives or bill savings while minimizing effects on the occupants.

- Seamlessly incorporate additional system components, and new energy and cost-savings technologies like thermal or battery storage, into the building's operation in a plug-and-play fashion to minimize costs of integrating them with the existing controls.

- (Optionally) pass through costs associated with HVAC energy usage to departments or tenants to provide incentive for their collaboration in achieving cost savings.

How is it being transacted?

For example:

- At the highest layer, the building/owner operator purchases electricity and natural gas to heat and cool the building (the building layer), and sells them to the system components in other layers below. This may be a simple pass through of the cost. Aggregating the total energy cost of the building is the primary function of the building layer.

- A bank of cooling towers (or the individual stages of one or more cooling towers), each purchase electricity needed to operate their fans and pumps (the heat rejection layer). In turn, it creates cooling water at a range of possible temperatures and flow rates (and corresponding costs) and "offers" this as a commodity for purchase by the building's chillers.

- A bank of chillers (the chilled water production layer) each bid to purchase electricity from the building layer and cooling water from the chilled water production layer and the layer offers to sell their collective output to the buildings air-handling units.

- A bank of boilers (the hot water production layer) each bid to purchase electricity and/or natural gas from the building layer and offers to sell their collective output to the buildings' air-handling units and any reheat coils in the VAV boxes or zones.

- The buildings' air-handling units (the air-handler layer) each bid to purchase chilled and hot water from their respective layers to produce conditioned air, and each air handler offers to sell its output to any VAV boxes and/or zones it supplies.

- The VAV boxes and zones may be a single layer if they have a one-to-one correspondence or two layers if a VAV box serves more than one zone. Each node bids to purchase conditioned air from the air handler serving it, and sells conditioned air to the zone(s) it serves.

- The zone layer balances comfort against cost and bids to purchase conditioned air from the air-handler layer (or VAV layer if present). It also bids to purchase energy for reheat from the hot water layer or electricity from the building layer to power any reheat coils that are present.

- (Optional). The zones may also purchase electricity for lighting and plug loads, and may similarly balance the quality of service for the occupants against cost of energy to supply those services.

What is the time scale of the transaction?

- Transactions regarding energy dispatch of equipment would take place relatively frequently, perhaps initiated when any component requests a change in state. This might correspond roughly to a 1-minute time scale.

- Any actual billing transactions with tenants or business divisions would presumably occur on a monthly basis or other convenient interval.

Actor/Stakeholder Roles (NIST 1.5)

Who is transacting?

A. Each *node of the intermediate layers* of the building's hierarchical control system transacts with the node of the layer(s) above it that supplies it with energy, and with the nodes of the layer(s) below it that it supplies. The layer nodes are fundamentally optimization and control applications for the building operator.

B. The *building layer node* at the top of the hierarchy may transact with the supplying utilities in real time to purchase energy (e.g., electricity, natural gas, etc.) needed by the building, or may simply reflect the current rate schedule to the layers below. The building layer is an application acting to reflect actual utility costs to the layers of the HVAC system, on behalf of the building owner or operator who pays the utility bills.

C. Each *node of zone layer* at the bottom of the hierarchy transacts comfort conditions or quality of service for lighting and plug loads with the zone occupants' willingness to pay.

D. *Zone occupants* transact with the zone layer node that serves them to reflect their willingness to tradeoff comfort or quality of service to reduce their energy bill or meet their energy budget allocated by the building owner/operator. These may be literal transactions in which funds are transferred or budgets affected, or pseudo transactions useful for control but for which the occupants are not actually billed.

E. *Building owner/operator* may engage in the transactions in one of several ways. Owners/operators may choose to assign the comfort/quality-of-service tradeoff parameters for the occupant zone nodes to reflect their own values and desire to save energy costs, particularly in an owner-occupied building. They may choose to let the occupants make those decisions, particularly in tenant-occupied buildings and bill them individually for their use. They may also assign them an energy budget and debit their consumption against it.

F. *Utility or retail load-serving entity* may be transacting with the building owner via the building layer node to reflect opportunities for demand response.

Who is the market maker?

- The building owner/operator (E).

Who else needs to be notified or acknowledge a transaction has been made?

- N/A.

Are there other transactions associated with this?

- Utility or retail load-serving entity may, in turn, be transacting with a wholesale energy market, reflecting the price flexibility of the building in its purchases of energy or sales of load reduction into that market.

Information Exchanged (NIST 1.6)

How is the transaction verified?

- Offers, bids, and clearing prices for energy exchange markets at each intermediate layer node are continually archived within the building systems.

- Transactions with the utility or third parties for energy supply could take many forms, discussed in other use cases in this document.

How is the transacted commodity measured and verified?

- Interval metering of energy supplied at the building's utility service entrance for commercial/industrial customers is required.

- Btus flowing to each node, through nodes, or from each node of each layer node likely must be measured or estimated (see Equipment and Technology, below).

- Zone level metering of lighting and plug loads may be required if this optional feature is included.

Activities/Services (NIST 1.7)

What equipment and technology is required?

- The fundamental proposition of this use case is that transaction-based controls have the self-optimizing and plug-and-play properties indicated. This needs to be established, and then transferred into commercial control systems offered by vendors.

- Convenient and intuitive user interfaces are required to set the system up, particularly for the occupants' expression of the energy cost tradeoff with comfort/quality of services.

- Measurements of energy in fluid flows require integrating the flow rate and temperature differential of the supply and return flows. These temperatures are generally available in large building control systems today, but may not be suitably accurate for this purpose. In lieu of the expensive flow meters, proxy measurements for flow may be based on pump/fan characteristics, speeds, and pressure differentials (for example).

What is the benefit for the building?

- Lower energy cost from:
  - more efficient, system-level optimization and performance diagnostics of the building's heating/cooling system.
  - induced conservation by building occupants.
  - the inherent ability of the system to provide continuous demand response to dynamic prices or incentives, to supply grid services valued by a utility or aggregator. (Or incentives)
  - incorporating additional system components and new energy and cost-savings technologies like thermal or battery storage into the building's control system.

What is the benefit for the grid?

- Seamlessly obtain needed grid services (e.g., dispatchable), potentially at lower cost than from power plants.

- Reduced investment for generation capacity to meet peak loads.

- Reduced fuel costs or purchase costs for electricity produced on peak.

What is the benefit for renewables?

- Lower cost grid services mitigate operational costs induced by the need to manage variable output from renewable generation, thereby promoting increased penetration.

What is the benefit for energy efficiency?

- Increased energy efficiency and conservation in large commercial buildings with complex HVAC systems, at lower cost than many physical measures.

Contracts/Regulations (NIST 1.8)

- Sub-metering and billing by building owners of electricity or gas consumed by tenants is prohibited in some states. State public utility commissions do not generally regulate billing for thermal energy flows within buildings, however.

Current Examples of this Transaction

- Contract networks for control of commercial buildings have been the subject of research at HP Corporation. See: Huberman, B., and S. Clearwater "Thermal Markets for Controlling Building Environments" Energy Engineering, 91, 26--56 (1994).

4.5 Diagnostic and Automated Commissioning Services

Type of Transaction: Building to Other (Service Provider)

Brief Description (NIST 1.3)

Customer (typically a commercial building operator or owner) signs up with a service provider for remote diagnostic services and/or automated commissioning services.

Narrative (NIST 1.4)

What is being transacted?

Customer is paying a fee for remote diagnostic services and/or automated commissioning services from the service provider, using data provided by a building automation system. This could take two forms:

1. Fee may be for a one-time service or continual services over a period of time, such as a month.

2. Fee may be on the basis of number or magnitude of faults detected.

Why is it being transacted?

- Customer desires a lower energy bill and better comfort from improved building operation.
- Service provider desires a profit for services rendered.

How is it being transacted?

- Service provider creates a web application posting terms and conditions for services offered, including confidentiality.
- Customer enables exchange of building metadata with the service provider.
- Web application detects relevant building, systems, and equipment information and data streams available from the building, using the building's metadata.
- Service provider lists services that can be supported by the data available from the consumers building.
- Customer signs up for selected services on line.
- Data streams from the building are delivered to service provider per agreed upon schedule (may include continuous streaming if supported).
- Diagnostic and commissioning information including savings estimates are delivered by service provider to customer electronically (e.g., via a web application).
- Service provider bills customer for service provided electronically.
- Customer pays bill with credit card transaction or automatic bill-pay arrangement.

What is the time scale of the transaction?

- One-time contract for customer sign-up.

- One-time delivery of building metadata.

- Periodic or continuous delivery of time-series data from building management system.

Actor/Stakeholder Roles (NIST 1.5)

Who is transacting?

A. Consumer (building owner or operator).

B. Service provider.

Who is the market maker?

- (B).

Who else needs to be notified or acknowledge a transaction has been made?

- N/A.

Are there other transactions associated with this?

- Service provider may also offer corrective action services remotely and/or via dispatched personnel.

- Savings may be transacted with a utility or aggregator to help meet regulatory requirements for efficiency or in RPS or carbon markets, for example.

Information Exchanged (NIST 1.6)

How is the transaction verified?

- Contractual notice exchanged (paperwork or electronic) between (A) and (B).

How is the transacted commodity measured and verified?

- Service provider periodically or continually delivers results of data analysis with conclusions and recommendations.

- Where the fee is based on the number or magnitude of savings from corrective actions identified, they may be based on savings estimates from the provider or actual savings achieved if corrective actions are also involved.

Activities/Services (NIST 1.7)

What equipment and technology is required?

- Description of building, systems, equipment, and control schemes, and how they are described, must be defined and standardized for use in such services.

- Means of describing data streams available from building management systems, and means of mapping them to diagnostic procedures and arranging for automatically uploading them to the service provider, must be developed and standardized.

- Effective analytic procedures for detecting and diagnosing faults and identifying corrective actions and savings potential must be developed for use by the service provider.

- Web applications that effectively communicate and support the business operations involved must be available.

What is the benefit for the building?

- Reduced utility bills from improved building operations.

- Improved comfort and environmental services to building tenants and occupants.

- Reduced expenditures for operations and maintenance.

What is the benefit for the grid?

- Increase efficiency from end uses that contribute to peak loads and reduce the need for capital investment for generation, transmission, and distribution capacity.

- When utilities are subject to a RPS requirement, or a carbon market or tax, they can earn credit for efficiency where allowed.

What is the benefit for renewables?

- Diagnostics could also be provided for renewable distributed generation systems.

- The installed base of renewable generation serves a higher fraction of the total load as the total load decreases, resulting in a cleaner overall electric power system.

What is the benefit for energy efficiency?

- May be a more cost effective delivery mechanism than traditional labor-intensive approaches to achieve vast potential energy savings from improved building operations at scale.

Contracts/Regulations (NIST 1.8)

- Normal commercial business rules would seem to apply.

Current Examples of this Transaction

- Northwrite Corporation (Portland, OR) is an example of a company offering such automated services electronically over the internet.

- Cimmetrics (Boston, MA) is an example of a company offering human-in-the-loop services remotely.

None of these currently approach the level of automation described in this use case because the fundamental data standardization, detection, and automated delivery technologies do not currently exist.

4.6 Data Centers Trade Computation Jobs

Type of Transaction: Service Provider to Service Provider

Brief Description (NIST 1.3)

A data center (server farm or high-performance computing center) shifts computing jobs to another such service provider where electricity costs are cheaper.

Narrative (NIST 1.4)

What is being transacted?

- Data center located where electricity costs are currently high (e.g., during periods of peak demand) shifts jobs to a contemporary data center where costs are currently lower, and vice versa.

- Data centers split the resulting electricity savings achieved by both.

Why is it being transacted?

- Each data center desires to lower its electricity bill while maintaining market share.

How is it being transacted?

- Their idle capacity and their electricity costs associated with computing (including CPU, data storage, and associated air conditioning) are posted at regular intervals.

- Data center (A) with currently high costs checks availability of data center (B) with lower costs.

- Data center (A) requests to shift job(s) to data center (B).

- Data center (B) accepts offer.

- Data center (A) delivers job to data center (B).

- Data center (B) runs job.

- A tally is kept on computer jobs shifted and electricity costs saved. Presumably net jobs shifted over an agreed upon period of 1 week, month, or year are kept near zero to maintain overall asset utilization balance.

- Data centers split the resulting electricity savings achieved by both.

What is the time scale of the transaction?

- One-time contract for partnering agreement sign-up.

- Transfer of job within 1 second or less.

- Periodic or continuous tally and settlement of energy savings.

- Agreed upon adjustment for any imbalance in overall jobs run.

Actor/Stakeholder Roles (NIST 1.5)

Who is transacting?

   A. Data center with currently high electricity costs.

   B. Data center with currently low electricity costs.

Who is the market maker?

- An independent third party could establish a market for bilateral transactions, or a more sophisticated version supporting multi-lateral transactions.

Who else needs to be notified or acknowledge a transaction has been made?

- The local distribution utility may need to be notified so it can account for load swapping in its load estimation and forecasting.

Are there other transactions associated with this?

- N/A.

Information Exchanged (NIST 1.6)

How is the transaction verified?

- Contractual notice exchanged (paperwork or electronic) establishing contract between (A) and (B).

- Tally records jobs shifted.

How is the transacted commodity measured and verified?

- Inherent in above for computer resources.

- Each data center must compute electricity costs per unit of computing so that electricity savings can be accurately accounted.

Activities/Services (NIST 1.7)

What equipment and technology is required?

- Applications supporting real-time transfer of computing jobs.

- Means of estimating electricity costs per unit of computing.

- Applications that record jobs transferred and electricity saved.

What is the benefit for the building?

- Each data center benefits from reduced utility bills.

What is the benefit for the grid?

- Reduced peak demand reduces the need for capital investment for generation, transmission, and distribution capacity.

- Ability to shift load on short notice can help balance intermittency from renewable resources.

What is the benefit for renewables?

- See above regarding balancing.

What is the benefit for energy efficiency?

- Some energy efficiency benefits may occur as a result of lower air conditioning costs during cooler hours of the day at the off-peak data center.

Contracts/Regulations (NIST 1.8)

- Normal commercial business rules would seem to apply.

Current Examples of this Transaction

- No examples of this transaction currently exist of which we are aware.

4.7 Microgrid Coordinating Demand Response, Distributed Generation and Storage

Type of Transaction: Building to Building

Brief Description (NIST 1.3)

Consumers sign up to participate in a transactive energy market within a microgrid to balance its resources and loads when operating in islanded mode to ensure reliable electricity services. In example presented here, all resources are independently owned by building owners, including distributed generation and storage (DG and DS). The microgrid use case is built upon use case 6.2 Transactive Retail Energy Market, and only primary differences or additions to it will be highlighted here.

Narrative (NIST 1.4)

What is being transacted?

- Each building, DS, and DG owner connected in an islanded microgrid ("members") agrees to pay an annual fee to an independent microgrid operator (IMO) to manage the microgrid economically, reliably, and equitably between these stakeholders, including energy trading.

- Consumers and DG/DS resource owners also agree to pay (when consuming) or receive (when injecting energy) based on a real-time price (RTP) that varies over time at short intervals (e.g., 5-min) based on a market clearing mechanism operated by the IMO.

Why is it being transacted?

- A microgrid can be connected with or islanded from a large-scale power system. In the islanded mode, the energy and capacity is limited to the resources on hand and should be managed to maintain security and reliability, while also considering economics. Assuming all the resources are owned by members, a transactive energy market is used to help ensure economic, reliable and secure operation of the microgrid.

- The market-based RTP is used by the IMO to balance the microgrid's building loads and charging of DSs with output from DGs and DSs in the microgrid.

- When in grid-connected mode, all members agree that the IMO will use the same transactive RTP market mechanism to

  – reflect the rate from the load serving entity and allocate energy costs to members

  – aggregate services from the members and offer them to the grid to earn incentives from the grid.

How is it being transacted?

- Consumers sign up with an independent microgrid operator (IMO) to manage energy trading between buildings, DSs, and DGs within a microgrid.

- At each interval, the consumer's energy management system assembles a bid curve for electricity supply or demand as a function of RTP, based on information from resources and/or loads they manage.

- The IMO uses a price-discovery mechanism (e.g., the clearing price of a double-auction market for electricity) that considers economics, while simultaneously managing system security and reliability constraints.

- Consumers are notified by the IMO of the RTP cleared by the market at each interval.

- The transactions are made using a double auction approach.

What is the time scale of the transaction?

- Irregular, long-term ~(annual or until-further-notice) for membership sign up.

- Member bid curves, price-discovery, and response of loads and distributed assets to RTP occurs at hourly or sub-hourly intervals (e.g., 5 minutes may be required for relatively precise control).

- Members are billed or credited in a monthly settlement of the energy sold and purchased by the members. Settlement could also occur in near real time with a credit-card-like transaction.

Actor/Stakeholder Roles (NIST 1.5)

Who is transacting?

A. Microgrid *members*, e.g., *building* or *facility owners/operators*, with or without distributed assets (i.e., DG, DS, or demand response capabilities).

B. *IMO* (independent microgrid operator) may bid for or offer energy into the market from assets it operates that are owned collectively by the members.

Who is the market maker?

- The IMO

Who else needs to be notified or acknowledge a transaction has been made?

- N/A.

Are there other transactions associated with this?

- Member assets could also participate in a unit commitment and/or ancillary service market for the microgrid for purposes of enhancing its reliability and economic efficiency.

- Building, DG, and DS owners may also be responsible for additional annual fees associated with the IMO operations and equipment or upgrades needed to ensure reliable service is provided by the microgrid.

- The IMO may act as a distributed asset aggregator on behalf of the members when not operating in islanded mode.

Information Exchanged (NIST 1.6)

How is the transaction verified?

- Contractual notice exchanged (paperwork or electronic) between (A) and (B).

- Real-time posting of cleared prices, net energy consumed or produced, and cost to date for the billing period, for each member.

How is the transacted commodity measured and verified?

- Time-series load data from advanced metering infrastructure (AMI) meters is integrated with time-series RTP data by (B) to compute member bills.

- Credit for any additional incentives earned for response when grid connected can be constructed from the member's bid history.

Activities/Services (NIST 1.7)

What equipment and technology is required?

- Interval metering is required (AMI) to provide net-load data time-series.

- A wide-area communication network with bandwidth sufficient for broadcasting demand bids and the RTP on a 5-minute interval is required.

- Price-discovery mechanisms that consider bids and reconfiguration schemes to coordinate distributed energy resources economically and reliably.

- Automated price responsive controls for thermostats, water heaters, HVAC equipment, lighting, etc. that implement the customer's desired response are required.

- Home/building energy management systems and local area communications network capable of assembling the demand bid curve, implementing control, and/or broadcasting the RTP to the appliances and equipment within a building are required.

- A user interface for the member to set the price responsiveness of their appliances and equipment is required (e.g., personal computer, mobile phone app, home energy display).

- (Desirable) A means of forecasting RTPs 24-hours ahead allows the members to optimize their response over time.

- (Desirable) Applications for optimizing a building's response given a 24-hour forecast of RTPs hosted by a home/building energy manager.

What is the benefit for the building?

- Improved reliability provided by the microgrid.

- Ability to control costs by utilizing the microgrids energy resources that are independent of the power grid.

- Potential for revenue from sales of energy from DERs to the microgrid.

What is the benefit for the grid?

- If the microgrid is permanently islanded, or if it responds to energy market costs or incentives for grid services when grid connected, the grid's need to invest in capacity can be reduced, its wholesale energy production or market costs reduced.

What is the benefit for renewables?

- Balancing the intermittent output from renewables at the sub-hourly level by the microgrid reduces integration costs.

- Microgrids may incorporate significant amounts of distributed renewable generation (e.g., solar photovoltaic systems)

What is the benefit for energy efficiency?

- Home/building networks can be leveraged for energy efficiency applications, better control, diagnostics, and advice.

Contracts/Regulations (NIST 1.8)

- Isolated microgrids with high penetration of renewables could experience reliability issues if proper regulations are not in place to ensure that the right equipment or resources are available to absorb surpluses and deficits in generation and demand. This implies that:

  – the IMO should ensure that the appropriate mix of DG, DS, DR, and non-responsive loads are transacting at all times

  – the IMO should ensure that curtailment or dump load equipment and procedures are available along with who is responsible for investments

  – bidding rules should also be in place so that poor bidding does not cause system collapse.

Current Examples of this Transaction

- N/A.

4.8 Trading Positions in an Electric Vehicle Charging Queue

Type of Transaction: Customer to Customer

Brief Description (NIST 1.3)

A limited number of electric vehicle (EV) charging stations are available at a parking lot. Re-charging is available on a first-come-first-served basis. A vehicle changes positions in the charging queue with another owner for a negotiated price.

Narrative (NIST 1.4)

What is being transacted?

- An EV owner (A) trades positions in the charging queue with another EV owner (B) that has a preferred position for a negotiated price.

Why is it being transacted?

- (A) needs his vehicle charged earlier than his position in the queue.

- (B) can accept a later charging time and is willing to exchange positions in the queue for a payment from (A).

How is it being transacted?

- A limited number of EV charging stations are available at the parking lot. An attendant moves EVs to the charging slot on a first-come-first-served basis based on a queue.

- The charging queue is posted by a market maker in an on-line web application accessible by smart phone with estimated charge completion times.

- (B) arrives at the parking lot, is assigned the next charging position in the queue (by default).

- (B)'s vehicle communicates state-of-charge information to web application so charging time can be estimated and posted.

- (B) logs into web application, indicates willingness to trade by posting a latest acceptable charging time and an offer price to swap positions via the web application.

- (A) arrives at the parking lot, is assigned the next charging position in the queue (by default).

- (A)'s vehicle communicates state-of-charge information to web application so charging time can be estimated and posted.

- (A) logs into web application, checks his position in the queue, determines that the charge completion time is too late, views posted offers and prices that have acceptable charging times, and accepts the offer from (B).

- Market maker updates charging queue for parking lot attendant, and bills (A) and credits (B), retaining a transaction fee for the service (optional).

- Bill and credit show up on (A)'s and (B)'s parking fee, or via a credit card transaction.

What is the time scale of the transaction?

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- Asynchronous bilateral transaction occurs on time scale of less than 1 minute, as a matter of convenience.

Actor/Stakeholder Roles (NIST 1.5)

Who is transacting?

A. EV owner with urgent need for vehicle charging.

B. EV owner without urgency to charge.

C. Market maker facilitating transaction.

Who is the market maker?

- The parking lot management or a third-party web-based business.

Who else needs to be notified or acknowledge a transaction has been made?

- The parking lot attendant must be aware of the queue and must update the queue as vehicles are charged (removing them from the trading list).

Are there other transactions associated with this?

- N/A

Information Exchanged (NIST 1.6)

How is the transaction verified?

- Market maker sends confirmation of positions traded and price accepted to both parties via an e-mail or text message.

How is the transacted commodity measured and verified?

- Vehicle owner is notified when vehicle charging is complete.

- Some guarantee of charging vehicles in the prescribed order is required on the part of the parking lot management, with a refund and perhaps a penalty payment if a mistake is made.

Activities/Services (NIST 1.7)

What equipment and technology is required?

- Wireless/cell phone access at parking lot.

- (Desirable) A kiosk for trades for those without cell phone availability.

- (Desirable) Communications to vehicle charge management system to obtain state-of-charge when entering queue.

- (Desirable) State-of-charge estimating application on-board vehicle.

- Web-application for charging queue, offers, and bids.

- Modified parking fee billing software and/or credit card network access.

- (Desirable) Web application for parking lot attendant to verify charging order (e.g., it could scan the license plate).

What is the benefit for the building?

Parking lot management may:

- Receive a share of the proceeds from the market maker.

- Obtain higher level of customer satisfaction.

- Save capital expense because it needs fewer charging stations to meet customer needs.

What is the benefit for the grid?

- System could be leveraged to include peak load management via a dynamic charging fee or surcharge.

What is the benefit for renewables?

- System could potentially be linked to a green power signal or premium.

What is the benefit for energy efficiency?

- N/A

Contracts/Regulations (NIST 1.8)

- Some regulatory oversight of market makers may be required.

Current Examples of this Transaction

- This has reportedly been envisioned in association with charging stations for the Bay Area Rapid Transit system in San Francisco.

5.0   Energy Market Services

Chapter 2 describes energy market services as energy and energy-related services that help support the efficient utilization of the energy generation and delivery assets. The primary need, and hence, value for energy market services originates *outside the meter*, i.e., within the power grid or the natural gas delivery infrastructure. In a region with a wholesale power market, these services may reflect those costs. In other regions they may reflect power production and delivery costs for a vertically-integrated utility, for example.

Although the value may be derived from the grid benefits, the overall economic benefits for such transactions accrue to both parties involved in the transaction. Energy market services may include mechanisms, such as, *time-of-use* and *real-time* pricing, etc., those help manage constrained resources, such as electricity or water delivery pinch points. Energy market services primarily help customers derive economic gain by offering cost savings opportunities, such as incentives or lower prices for modifying their consumption patterns, proving capacity deferral and other benefits to utilities.

Example use cases describing transactive mechanisms that help with the efficient utilization of energy generation and delivery system resources and assets described here are:

- Dynamic rate
- Optimize electric vehicle charging for dynamic rate
- End-use differentiated dynamic rates
- Transactive energy market exchange
- Trading efficiency to relieve congestion
- Differentiated reliability service.

These are examples of services that originate both *outside and behind the meter*, i.e., within customer premises. Each of these example use cases is described further below.

5.1 Dynamic Rate

Type of Transaction: Building to Grid

Brief Description (NIST 1.3)

Customer signs up with retail utility or a retail service provider for a dynamic (time-varying) rate program such as (1) a time-of-use (TOU), (2) a critical-peak-price (CPP), or (3) a real-time price (RTP).

Narrative (NIST 1.4)

What is being transacted?

Customer changes their contract with utility or retail service provider for electricity purchased at a constant, flat rate for a contract with a rate that varies over time. This is typically in one of several forms:

1) TOU rate in which the unit price is higher during peak hours and lower during off-peak hours, e.g., by a factor of ~2×

– a third, intermediate level during shoulder hours may also be incorporated.

2) CPP rate in which a very high unit price (~10-20×) can be declared by the utility or retail service provider, with 24-hour notice to customers

   – limited to a maximum number of days per year (typically 10 or 15) and hours per day (typically 4 to 6).

3) TOU/CPP rate, which is a combination of a TOU rate on most, normal days with a CPP rate during critical peak hours on critical peak days.

4) RTP rate that varies continuously may require 24-hour ahead prices be delivered to the consumer.

Why is it being transacted?

- Assuming the utility or retail service provider has properly structured the dynamic rate to be revenue neutral (for the average customer load shape), an incentive is created for customers to sign up and voluntarily engage in demand response.

- The utility or retail service provider correspondingly obtains:

  – daily load shifting by customers that corresponds to electricity production costs (TOU)

  – demand response for peak-load or peak-price management on a limited number of days per year (CPP)

  – continuously available demand response resource (RTP).

How is it being transacted?

- Customer signs up for a dynamic rate program.

- Dynamic rates are sent to customers for them to decide how to utilize their loads.

  – 24-hr advance notice via phone, e-mail or pager is required for CPP events

- The customer can take advantage of the rate by shifting some of their load from high-price periods to low-price periods, thereby lowering their bill.

  – This can be accomplished by demand response, battery or thermal storage, and/or use of a dispatchable distributed generator (in the subsequent discussion the term demand response will be used, but in principle refers to net load reduction from any of the above).

- The transaction is classified as an over-the-counter (OTC) transaction. Today, such exchanges are only marginally automated or conducted electronically. Doing so in a more "e-commerce" style would make them much more "transactive" in the context of this reference document.

What is the time scale of the transaction?

- Irregular, long-term ~(annual or until-further-notice) for program signup.

- TOU load shifting occurs every day.

- CPP demand response service is provided by customers upon irregular requests from utility and typically lasts 1 hour or more (up to contractual limits).

  – 24-hour advance notice is required for CPP events.

- RTP demand response occurs as price changes at hourly intervals or less.

- Customer savings from shifting load to lower-price periods are reflected in monthly electric bills.

Actor/Stakeholder Roles (NIST 1.5)

Who is transacting?

   A. *Consumer (ratepayer)*, often but not always building owner, perhaps representing lease/rental tenants (occupants) collectively.

   B. *Utility, retail service provider,* or a *third-party aggregator.*

Who is the market maker?

- (B).

Who else needs to be notified or acknowledge a transaction has been made?

- If a CPP event is called by retail service provider that is not the utility/load serving entity, the latter may need to be informed (if required by regulation or policy). For example, the aggregator may either be held responsible for providing a certain level of load reduction by the utility or may be receiving additional benefits from the utility for providing the load reduction services.

Are there other transactions associated with this?

- Where there are wholesale electricity markets that allow demand response participation, (B) aggregates CPP demand response from a collection of customers and either i) bids it as a block of demand reduction into the day-ahead or real-time market, or ii) reduces their bid for electricity to serve their load by that amount.

Information Exchanged (NIST 1.6)

How is the transaction verified?

- Contractual notice exchanged (paperwork or electronic) between (A) and (B).

How is the transacted commodity measured and verified?

- Metered time-series load data is integrated with price time-series data by (B) to compute customer bill.

Activities/Services (NIST 1.7)

What equipment and technology is required?

- Interval metering (AMI/AMR) is required to provide load data time-series.

What equipment and technology is desirable?

- Thermostats, water heater controls, etc. that automate the customer's desired response by TOU time blocks and/or a CPP/RTP signal (from the utility or retail service provider).

  – Use of a CPP/RTP signal requires a higher bandwidth network than typical AMI networks have.

- Demand response resource forecasting as a function of time-of-day, day-of-week and weather for CPP and RTP.

What is the benefit for the building?

- Lower electric bills result, to the extent load is shifted.

- Reduced rates result (for all customers) by lowering utility revenue requirements resulting from benefits provided to the grid.

What is the benefit for the grid?

- Reduced expenditure for emergency reserves (CPP, RTP).

- Reduced investment for generation capacity to meet peak loads (CPP, RTP, and to a lesser extent TOU).

- Reduced fuel costs or wholesale purchase costs for electricity (TOU, RTP).

What is the benefit for renewables?

- Emergency response can sustain grid reliability in the face of increased strain on transmission system for long-distance delivery of renewable power to load centers.

- PV solar output is more valuable to the consumer under dynamic rates because peak output usually corresponds to higher-price periods.

What is the benefit for energy efficiency?

- Provides more cost savings for efficiency from end uses (air conditioning, water heating, commercial lighting) that tend to consume more energy during peak periods (TOU). Note the converse is also true, however.

Contracts/Regulations (NIST 1.8)

- Dynamic rates are subject to public utility commission approval (investor-owned utilities) or board of directors' approval (public utilities).

Current Examples of this Transaction

- A number of utility opt-in dynamic rate programs exist, but are often in pilot form.

5.2 Optimize Electric Vehicle Charging for Dynamic Rate

Type of Transaction: Building to Grid

Brief Description (NIST 1.3)

Customer signs up with retail utility or a retail service provider for a dynamic (time-varying) rate program to charge electric vehicles (EVs).

Narrative (NIST 1.4)

What is being transacted?

- Customer signs up with utility or retail service provider to provide electricity used to charge EVs via dynamic (time-varying) rate program. The customer is responsible for any EV charging based on the dynamic rates received.

- The customers can use EMSs or building automation systems that will consider forecasts in dynamic rates, time limits specified for fully charging EVs, and specified charging levels for emergency use of EVs, etc. to optimize charging of EVs.

Why is it being transacted?

- Assuming the utility or retail service provider has properly structured the dynamic rate to be revenue neutral (for the average customer load shape), an incentive is created for customers to sign up and voluntarily engage in charging in periods that will result in lower electricity bills.

- The utility or retail service provider correspondingly obtains:

  - daily load shifting by customers that reflects the needs of the grid, such as load reduction during peaks or load increases when there is high wind generation.

What is the timescale of the transaction?

- Long-term ~ (annual or until-further-notice) for program sign-up.

- Change in charging schedule occurs at hourly intervals or less as a result of price changes.

- Customer savings from charging EVs to lower-price periods is reflected in monthly electric bills.

How is it being transacted?

- Customer signs up for EV dynamic rate program.

- Dynamic rates are sent to customers for them to decide how to utilize their loads.

- Customer uses EMS or BAS to develop charging schedules for plugged-in EV based on dynamic rate forecasts. This enables the customer to take advantage of the rate by shifting EV charging from high-price periods to low-price periods, thereby lowering electricity bills.

Actor/Stakeholder Roles (NIST 1.5)

Who is transacting?

   A. *Consumer (ratepayer)*, often but not always building owner or tenants, who owns an EV.

   B. *Utility or retail service provider.*

Who is the market maker?

- (B) (most likely, but could also be a third-party aggregator interacting with a utility).

Who else needs to be notified or acknowledge a transaction has been made?

- N/A

Are there other transactions associated with this?

- N/A

Information Exchanged (NIST 1.6)

How is the transaction verified?

- Contractual notice exchanged (paperwork or electronic) between (A) and (B).

- Notification of RTP by (B) to (A).

How is the transacted commodity measured and verified?

- Metered time-series load data is integrated with price time-series data by (B) to compute customer bill.

Activities/Services (NIST 1.7)

What equipment and technology is required?

- Interval metering is required (AMI/AMR) to provide load data time-series.

- (Desirable) EV charging controls, etc. that automate the customer's desired response by dynamic rate signal received from the utility or retail service provider.

    – Use of a RTP signal requires a higher bandwidth network than typical AMI networks have.

- (Desirable) Real-time price forecasting as a function of time-of-day, day-of-week and weather for (RTP) or forecasted prices from service provider.

What is the benefit for the building?

- Lower electric bills result, to the extent EV charging is shifted to low-price periods.

- Reduced rates result (for all customers) by lowering utility revenue requirements based on benefits provided to the grid.

What is the benefit for the grid?

- The utility or retail service provider can use dedicated rates for dedicated loads to encourage specific loads. For example, giving electric vehicles a special TOU rate can encourage EV sales, which in turn benefits the grid with a predictable load curve.

- Reduced expenditure for emergency reserves (RTP).

- Reduced investment for generation capacity to meet peak loads (RTP, and to a lesser extent TOU).

- Reduced fuel costs or wholesale purchase costs for electricity (TOU, RTP).

What is the benefit for renewables?

- A dynamic rate for EVs could benefit the integration of wind power by providing a dedicated load for wind generated at night, for example.

What is the benefit for energy efficiency?

- N/A

Contracts/Regulations (NIST 1.8)

- Dynamic rates are subject to public utility commission approval (investor-owned utilities) or board of directors' approval (public utilities).

Current Examples of this Transaction

- N/A

5.3 End-Use Differentiated Dynamic Rates

Type of Transaction: Building to Grid

Brief Description (NIST 1.3)

Customer signs up with retail utility or a retail service provider for different dynamic (time-varying) rate programs for different end uses: e.g., a time-of-use rate (TOU) for process end uses like dishwashing and clothes washing and drying that are driven by occupant usage patterns, and 2) a real-time price (RTP) for end uses like space conditioning and water heating where automated controls can be employed to respond to short-term changes in price. The essential driver for splitting the loads into two rate classes is that loads driven by behavior are best shifted by the occupants' awareness of consistent pricing patterns, whereas loads that operate more continuously and have thermostatic controls can be programmed to respond automatically to rates that vary more dynamically. Such a "split rate" approach may be both more equitable and more effective for encouraging load shifting at appropriate times.

Narrative (NIST 1.4)

What is being transacted?

- Customer changes their contract with utility or retail service provider for electricity purchased to one with a rate that varies over time, depending on the end use involved. The customer pays for consumption with either:
  - A TOU rate in which the unit price is higher during peak hours and lower during off-peak hours, e.g., by a factor of ~2x (a third, intermediate level during shoulder hours may also be incorporated).
  - A RTP rate, which varies continuously on hourly (or 5- or 15-minute) intervals, perhaps requiring 24-hour ahead prices be delivered to the consumer.
- The applicable rate is dependent on the type of load and the availability of automated controls. Customer bill for RTP loads is based on sub-metering them, or a means of estimating them with reasonable accuracy. The remainder of customer power consumption is billed at an RTP rate.

Why is it being transacted?

- Assuming the utility or retail service provider has properly structured the dynamic rate to be revenue neutral (for the average customer load shape), an incentive is created for customers to sign up and voluntarily engage in demand response by shifting some of their usage to periods with lower prices.
- The utility or retail service provider correspondingly obtains:
  - daily load shifting by customers that corresponds to electricity production costs (TOU)
  - continuously available demand response resource (RTP).
- A TOU rate encourages changes in time-of-use of appliances on a regular, daily basis but cannot signal greater response to short term, or irregular intermittent needs of the grid in the way an RTP can.

- For example, TOU may be used for certain loads that need to be engaged at predictable times, such as electric vehicles or washing machines, where the customer knows in advance when to take advantage of lower charging rates during off-peak hours.
- RTP can be used for space conditioning and water heaters that can be engaged through programmable controls to dynamically respond to prices.

What is the time scale of the transaction?

- Long-term ~ (annual or until-further-notice) for program sign-up.

- Ongoing (demand response occurs as price changes at hourly intervals or less).

- Customer savings accrued from shifting load to lower-price periods are reflected in monthly electric bills.

How is it being transacted?

- Customer signs up with utility for RTP rate for end uses that will be managed with dynamic demand response, e.g., air conditioning and water heating.

- Customer's other end uses are charged a TOU rate because customer manages them by shifting his usage patterns on a regular basis.

- Utility arranges for separate metering.

Actor/Stakeholder Roles (NIST 1.5)

Who is transacting?

A. *Consumer (ratepayer)*, often but not always the building owner, perhaps also representing the collective response of lease/rental tenants to the grid.

B. *Utility or retail service provider*.

Who is the market maker?

- (B) (most likely, but could also be a third-party aggregator interacting with a utility).

Who else needs to be notified or acknowledge a transaction has been made?

- The distribution utility may need to be informed if they are not the retail service provider, so they can take into account the effect of customer response to RTP signals on their distribution system. This would be required if an aggregator was setting RTP rates to provide load reduction services to the distribution system.

Are there other transactions associated with this?

- The utility/retail service provider or aggregator may trade the demand response from the RTP loads in a wholesale energy market.

Information Exchanged (NIST 1.6)

How is the transaction verified?

- Contractual notice exchanged (paperwork or electronic) between (A) and (B).

- Notification of RTP by (B) to (A).

How is the transacted commodity measured and verified?

- Metered time-series load data is integrated with price time-series data by (B) to compute customer bill.

Activities/Services (NIST 1.7)

What equipment and technology is required?

- Interval metering is required (AMI/AMR) to provide load data time-series.

- A means of determining the consumption of the RTP end uses at the rate's time interval is required. This could be in the form of sub-metering of the end use(s), or a means of reasonably estimating them through a disaggregation process.

- (Desirable) thermostats, water heater controls, etc. that automate the customer's desired response by TOU time blocks and/or a RTP signal (from the utility or retail service provider).

  – Use of a RTP signal requires a higher bandwidth network than current AMI networks typically have.

- (Desirable) demand response resource forecasting as a function of time of day, day-of-week and weather for (RTP).

What is the benefit for the building?

- Lower electric bills result, to the extent load is shifted.

- Reduced rates result (for all customers) by lowering utility revenue requirements based on benefits provided to the grid.

What is the benefit for the grid?

- Reduced investment for generation capacity to meet peak loads (RTP, and to a lesser extent TOU).

- Reduced fuel costs or wholesale purchase costs for electricity (TOU, RTP).

- Reduced expenditure for emergency reserves (RTP).

- The utility or retail service provider can use dedicated rates for dedicated loads to encourage specific loads. For example, giving electric vehicles a special TOU rate can encourage electric vehicle (EV) sales, which in turn benefits the grid with more desirable load shape.

What is the benefit for renewables?

- A TOU for EVs could benefit the integration of wind power by providing a dedicated load for wind generated at night, for example.

- TOU and RTP can benefit PV solar in a net metering situation because PV output is often correlated with higher-price periods.

What is the benefit for energy efficiency?

- TOU provides more cost savings for efficiency from end uses (air conditioning, water heating, commercial lighting) that tend to consume more energy during peak periods. Note the converse is also true, however; end uses that tend to consume more energy during off-peak TOU periods will exhibit less reward when their efficiency is improved.

Contracts/Regulations (NIST 1.8)

- Dynamic rates are subject to public utility commission approval (investor-owned utilities) or board of directors' approval (public utilities).

Current Examples of this Transaction

- A number of utility opt-in dynamic rate programs exist, but most are often in pilot form. A combination of RTP and TOU rates for different end uses (as described here) does not exist in the U.S. to our knowledge.

5.4 Transactive Energy Market Exchange

Type of Transaction: Building to Grid

Brief Description (NIST 1.3)

Customer purchases electric energy and delivery services from generation and transmission and distribution (T&D) suppliers in an asynchronous, bi-lateral, stock market-like transaction. Separate forward contracts can be purchased at various time scales. Customer can re-sell contracts for unneeded energy and delivery back into the market.

Narrative (NIST 1.4)

What is being transacted?

- Energy, and energy transport products can be offered and purchased in an electronic marketplace, organized and operated much like a stock market, at various time scales: year ahead (i.e., base load), month ahead (i.e., load shape), and 1-hour (i.e., spot market) and 5-minutes ahead (i.e., real time).

- Separate forward contracts can be purchased by the consumer from tenders offered by suppliers and deliverers, to meet needs for electric energy. Unneeded energy under contract for supply and delivery can be re-sold by offering it back to the market as a tender.

How is it being transacted?

Bi-lateral transactions between a customer and suppliers of energy and delivery services are conducted in an asynchronous fashion much like a stock market:

- An *Indication of Interest* is non-binding and may include
  - a request for a *tender*
  - a forecast of usage by a buyer
  - a forecast of price by a seller.
- A *tender* is a bid or offer for an energy transaction with an expiration date and time.
- A *transaction* is formed by accepting a *tender*.
- *Publication* communicates the transacted prices, quantities, and costs or revenues back to the market.
- *Delivery* is the metered quantity delivered.
- *Settlement* is the payment for the contract. Customer pays bill with credit card transaction or automatic bill-pay arrangement.

Why is it being transacted?

- By optimizing his portfolio of purchases across the long and short term, a consumer can reduce his overall cost for electricity.

- Generation suppliers can offer tenders that optimize their operating efficiency and return on investment.

- T&D suppliers can explicitly manage capacity constraints at each point in the system via the quantity of their tenders for delivery.

What is the time scale of the transaction?

Several time scales, depending on type of power purchased. For example:

- Base load energy is purchased about 1-year ahead.

- Load shape energy is purchased about 1-month ahead.

- Spot market energy is purchased every hour.

- Real-time imbalance energy is purchased every 5 minutes unless otherwise provided under the terms of a contract.

Actor/Stakeholder Roles (NIST 1.5)

Who is transacting?

A. *Customer* (consumer of electric energy; may also be a supplier)
B. *Generators*
C. *Transmission owner/operator or utility*
D. *Distribution utility*
E. *Aggregators*
F. *Microgrid operators*
G. *Third-party equipment owners* (e.g., thermal or electric energy storage systems, distributed generation)

Who is the market maker?

- An independent system operator (ISO) or a third-party market operator may set up and operate a market for generation and transmission services for a region.

- A distribution utility or a third-party market operator may set up and operate a market for distribution services for their service territory.

- A facility or microgrid owner may set up and operate a market for service within their footprint.

Who else needs to acknowledge/verify a transaction has been made?

- Transactions for generation, transmission, and distribution of energy need to be linked or otherwise coordinated across markets at these scales.

Are there other transactions associated with this?

- A number of hedging and derivative products can be envisioned.

Information Exchanged (NIST 1.6)

How is the transaction verified?

- Electronic verification of *tenders* between transacting parties is provided by the market.

How is the transacted commodity measured and verified?

- Metered time-series load data is integrated with prices spelled out in the contract terms to compute the customer payment due to the suppliers.

Activities/Services (NIST 1.7)

What equipment and technology is required?

- Interval metering is required (AMI/AMR) to provide load data time-series.

- A wide-area communication network with bandwidth sufficient for the high volume of transactions is required. This is likely the customers broadband.

- A standardized protocol (proceeding as a subset of the TEMiX protocol) for the electricity transactions.

- A portfolio optimizer that manages the purchase and resale of the customer's energy contracts to minimize overall costs.

- Market operating software that coordinates generation and delivery markets (if separate).

- A standardized protocol for the financial settlement transactions.

- A home/building energy management system and local area communications network capable of acting on the customers behalf implementing control, and/or broadcasting the prices to the appliances and equipment is required (e.g., a smart thermostat, an AMI meter, a personal computer).

- A user interface for the customer to set the price responsiveness of their appliances and equipment is required (e.g., personal computer, mobile phone app, home energy display).

What equipment and technology is desired?

- Automated price responsive controls for thermostats, water heaters, HVAC equipment, lighting, etc. that implement the customer's desired response are required.

- Applications for optimizing a building's response given a 24-hour forecast of RTPs hosted by a home/building energy manager.

What is the benefit for building customers?

- Customers can take advantage of forward markets to better manage their energy consumption, lower their bill, and, in specific cases, sell energy back to the grid, creating new value streams.

- Reduced rates result (for all customers) by lowering utility revenue requirements resulting from benefits provided to the grid.

What is the benefit for the grid?

- The various time-horizons of forward and spot contracts provide clear basis for merchant generators, ISOs, utilities, retail service providers, and aggregators to forecast net consumer load and the need for future capacity, including the type of generation needed (base load, intermediate, and peaking plants).

- The high cost for spot market purchases for peak power will reduce peak demand, thus leading to reduced investment for transmission and generation capacity to meet peak loads.

- Reduced fuel costs generators may result from better scheduling via their *tenders*.

- Reduced congestion costs caused by transmission constraints.

- Ability to balance the intermittency of renewables at the sub-hourly level.

- Increased ability to manage an emergency.

What is the benefit for renewables?

- Generation agnostic, supports lowest cost option, and hence,
    - Increases integration of renewables in times of oversupply/low cost.

What is the benefit for energy efficiency?

- Home/building networks can be leveraged for energy efficiency applications for better control, diagnostics, and advice.

Contracts/Regulations (NIST 1.8)

- Tariffs would be subject to FERC approvals where these are used in interstate commerce, and public utility commission approval (investor-owned utilities) or board of directors' approval (public utilities).

- Hedges and derivatives other than the basic transactions may or may not be allowed and may or may not be regulated by the combined action of these entities.

Current Examples of this Transaction

There are no current deployments. Dr. Ed Cazalet of TeMix, Inc. is actively constructing prototype software and tools around these concepts. We have attempted to represent many of his ideas here as described in various presentations at GridWise™ Architecture Council meetings and workshops.

5.5 Trading Efficiency to Relieve Congestion

Type of Transaction: Building to Grid

Brief Description (NIST 1.3)

The utility or aggregator sets up an "eBay-like" marketplace to obtain efficiency that specifically targets an area served by a congested, capacity-limited element of a distribution or transmission system. This use case is a modification of the previously described use cases 4.2 Efficiency Shared Savings and 7.2 Efficiency Incentive Payment. Only key differences will be noted here.

Narrative (NIST 1.4)

Why is it being transacted?

- In addition to other values, the utility or aggregator may obtain from energy efficiency described in the related use cases, the utility desires to focus such investment on customers served by a congested distribution substation or feeder, or a congested transmission line, to defer a pending investment increasing its capacity.

- Customer may obtain an investment from the utility or aggregator because of the customer's location, or a higher investment level to achieve a higher level of savings. The resulting energy savings result in lower electric bills and/or a higher incentive payment for the efficiency achieved.

How is it being transacted?

- In addition to the process described in the related use cases, an eBay-like system of identifying customers in the right locations could be established if there were postings by customers of energy audit-like results expressing their savings opportunity and their required investment threshold.

- Utility or aggregator could then readily target the lowest cost opportunities in the correct location.

What is the benefit for the grid?

- In addition to other benefits cited in the related use cases, the utility or load-serving entity avoids capital investment to upgrade distribution and transmission system capacity.

- It may also avoid transmission congestion charges associated with higher locational marginal prices (LMPs) where wholesale markets have been implemented.

Current Examples of this Transaction

- Areas where LMPs are high because of transmission congestion have received increased attention from efficiency programs operated by states and utilities. The well-known load pocket in Western Connecticut is one such example.

- We are not aware of a transaction-based approach being implemented as described above.

5.6   Differentiated Reliability Service

Type of Transaction: Building to Grid

Brief Description (NIST 1.3)

Customer signs up for premium reliability service, paying a surcharge for being more likely to have service quickly restored after a distribution-level outage. The distribution utility uses the additional revenue to help it invest in deployment of fault detection, location, isolation, and reconfiguration (FDLIR) technology, making the system more reliable for all customers, without burdening customers without need for improved reliability with higher overall rates. This assumes that the distribution system has the ability to "back feed" power from adjacent feeders, or has some distributed energy resources (DERs) it can use to provide power to premium customers in some circumstances. It further assumes that automated metering infrastructure (AMI) with remote disconnect capability is deployed.

When a distribution outage occurs, the utility uses the FDLIR technology to quickly isolate the faulted section, to determine how many customers can be supported with the available capacity from adjacent feeders and DERs. If all customers cannot be supported given the current time-of-day, day-of-week, and weather, then it uses the remote disconnect feature of the AMI system to reduce the load that must be served. First priority goes to the premium customers.

Narrative (NIST 1.4)

What is being transacted?

- Customer signs up with load service entity (LSE) to receive level of electricity service reliability in the aftermath of a local outage.

- The customer agrees to pay a monthly premium for the service.

Why is it being transacted?

- Power outages cause over $100 billion in economic losses, annually. Over 90% of accumulated time of customer outages occur as a result of distribution-level problems. Investment in FDLIR and other technologies that can improve distribution reliability is lagging. This is caused by, in part, the fact that many customers are unwilling to undergo rate increases to support such investments because they are generally satisfied with the reliability of their service. Other customers, particular businesses, may be willing to pay higher rates to support such investments.   Differentiated reliability services can create a revenue stream to provide more reliable services to consumers who value it, and in turn, minimize these economic losses.

- Premium customer desires the maximum possible reliability.

- Note the investments in FDILR, DERs, and other technology will improve reliability in general for non-premium customers, also.

How is it being transacted?

- Customer signs up for a premium reliability plans.

- The distribution utility gives first priority to premium customers in the aftermath of an outage.

- On-line reports provided by the distribution utility explaining their outage restoration actions and timelines may be essential for customer acceptance.

What is the time scale of the transaction?

- Irregular, long-term ~(annual or until-further-notice) for program sign-up depending on changes in customer values or loads. For example, if critical loads are no longer used, customers may want to consider a plan without a premium.

- Emergency situations are typically unpredictable and occur irregularly.

- Premiums are paid monthly by customers.

- Post-outage reports explaining restoration actions and timelines may be posted on line.

Actor/Stakeholder Roles (NIST 1.5)

Who is transacting?

A. *Consumer (ratepayer)*, often but not always building owner, perhaps representing lease/rental tenants (occupants) collectively.
B. *Distribution utility*.

Who is the market maker?

- (B).

Who else needs to be notified or acknowledge a transaction has been made?

- N/A

Are there other transactions associated with this?

- N/A

Information Exchanged (NIST 1.6)

How is the transaction verified?

- Contractual notice exchanged (paperwork or electronic) between (A) and (B).

How is the transacted commodity measured and verified?

- Not required. Post-outage reports may be provided after each event to assure premium customers that they received priority, and that restoration of non-premium customers was also maximized within that constraint.

- If terms of the agreement are not met by the distribution utility, penalties may be due to customers individually or collectively (e.g., via a public utility commission).

Activities/Services (NIST 1.7)

What equipment and technology is required?

- AMI with remote disconnect switches and a network with sufficient bandwidth to communicate with customer meters quickly in the aftermath of an outage.

- Time-series load data from the AMI meters can be used to improve the forecast for the load upon restoration of service, maximizing the number of premium and non-premium customers whose power can be restored almost immediately.

- Optimization algorithms and reconfiguration schemes need to incorporate the use of DERs and AMI networks in the fashion described.

What is the benefit for the building?

- Reliable service delivered to minimize economic losses after outages.

What is the benefit for the grid?

- Revenue streams for investment in improving overall reliability, such as FDLIR and distributed energy resources.

What is the benefit for renewables?

- N/A

What is the benefit for energy efficiency?

- N/A

Contracts/Regulations (NIST 1.8)

- Regulators may need to establish rules and policies that protect both premium and regular customers, including penalties for inappropriate utility use of such systems.

- Regulatory oversight may be needed to ensure the utility does not allow distribution reliability to regress, in general.

- Regulatory oversight may be necessary to ensure disadvantaged customers (e.g., the elderly or poor) are not disadvantaged by the utility offering differentiated reliability service plans.

Current Examples of this Transaction

- N/A

6.0   Grid Services

Chapter 2 defines grid services as energy, and energy-related products, services, and rights that help support enhanced grid planning, operations and metering within both centralized and decentralized structures of asset location and ownership. The need, and hence, value for grid services originate *outside the meter*, i.e., outside the customer premises. Grid services, such as peak-load shifting and ancillary services help maintain grid reliability and resiliency, as well as aid in renewables integration by providing flexibility to the system. Solutions that help in delivery of grid services may borrow from similar concepts developed for integration of energy storage and other demand-side resources into the power system. These concepts must also be cognizant of – and preferably providing solutions for – known problems, such as, measurement and verification, net-metering, voltage instability resulting from two-way power flow*s,* etc. Examples of transactive mechanisms that may be employed for provisioning different grid services must also provide commensurate incentives to the providers of these services.

We expect that two broad categories of grid services will dominate the design and operation of a buildings-centered transactional framework: management of capacity constraints, and the provision of ancillary services. Example use cases described here are:

- Interruptible Service or Direct Load Control
- Transactive Retail Energy Market
- Trading Allocated Capacity Rights
- Ancillary Services via Aggregator
- Transactive Acquisition of Ancillary Services
- Distribution-Level Ancillary Services
- Rate Dependent Priority for Cold Load Pickup

Each of these use cases is described further in the sections below.

6.1 Interruptible Service or Direct Load Control

Type of Transaction: Building to Grid

Brief Description (NIST 1.3)

Customer signs up with retail utility/load serving entity or a demand response aggregator for (1) interruptible service or (2) direct load control program, in exchange for a reduced rate or a credit on their electric bill.

Narrative (NIST 1.4)

What is being transacted?

In exchange for a discount on their effective monthly utility bill,

1) Customer trades right of retail utility/load serving entity to cut off their electric service in an emergency

2) Customer trades right of utility to a) shut off or cycle their water heater or air conditioner (AC) or b) move their AC thermostat up "X" degrees

In both cases, the utility is limited to exercise the right a maximum number of days per year (typically 5 or 10) and hours per day (typically 5 or 6).

Why is it being transacted?

Customers desire to decrease monthly utility bill, and the utility desires to acquire:

- Emergency load reduction capability (Option 1)

- Demand response resource for peak load/peak price management on a limited number of days per year (Option 2).

How is it being transacted?

- Customer signs up for program (1) or (2).

- Service is provided by customers upon request from utility.

- Advance notice via phone call or pager is required for interruptible events; some advance notice may be required contractually for direct load control events.

- Incentives appear as credits or rate reductions in customer's monthly electric bills.

- This transaction is considered to be an over-the-counter transaction. Today, such exchanges are only marginally automated or conducted electronically. Doing so in a more "e-commerce" style would make them much more "transactive" in the context of this reference document.

What is the time scale of the transaction?

- Irregular, long-term (e.g., annual or until-further-notice) for program sign-up.

- Service provided by customers upon irregular requests and lasts for 1 hour or more, up to contractual limits.

- Advance notice of service required is short-term (e.g., 10-minutes).

- Customer incentives are received monthly.

Actor/Stakeholder Roles (NIST 1.5)

Who is transacting?

A. *Consumer (ratepayer)*, often but not always building owner, perhaps representing lease/rental tenants (occupants) collectively.

B. *Utility or retail load-serving entity*, or a *third-party aggregator* operating in a wholesale electricity energy and/or capacity market.

Who is the market maker?

- (B).

Who else needs to be notified or acknowledge a transaction has been made?

- If an event is called by an aggregator, the distribution utility may need to be informed. For example, the aggregator may either be held responsible for providing a certain level of load reduction by the utility or may be receiving additional benefits from the utility for providing the load reduction services.

Are there other transactions associated with this?

- In option (2), if there are wholesale electricity markets that allow demand response participation, (B) schedules and aggregates demand response from a collection of customers and either i) bids it as a block of demand reduction into the day-ahead or real-time market, or ii) reduces their bid for electricity to serve their load by that amount.

Information Exchanged (NIST 1.6)

How is the transaction verified?

- Contractual notice exchanged (paperwork or electronic) between (A) and (B).

How is the transacted commodity measured and verified?

- Interval metering for commercial/industrial customers is typical for (1).

- Not required for (2).

Activities/Services (NIST 1.7)

What equipment and technology is required?

- None for (1).

- Load control switch and one-way, low-bandwidth communications system for (2).

- (Desirable) Demand response resource forecasting as a function of time-of-day, day-of-week and weather for (2).

What is the benefit for the building?

- Discount on electric bill for providing the service.

- Reduced rates result (for all customers) from lowering utility revenue requirements resulting from deferring capacity investments.

What is the benefit for the grid?

- Reduced expenditure for emergency reserves.

- Reduced investment for generation capacity to meet peak loads.

- Reduced fuel costs or purchase costs for electricity produced on peak.

What is the benefit for renewables?

- Emergency response can sustain grid reliability in the face of increased strain on transmission system for long-distance delivery of renewable power to load centers.

- Emergency response can help accommodate fast decreases in availability of renewable power (cloud passing, sudden decreases in wind velocity)

What is the benefit for energy efficiency?

- N/A.

Contracts/Regulations (NIST 1.8)

- Rates for interruptible service and incentives for direct load control are subject to approval by a public utility commission (investor-owned utilities) or board of directors (public utilities).

Current Examples of this Transaction

- Numerous examples of these utility programs exist.

- Direct load control is especially common among rural cooperatives.

6.2 Transactive Retail Energy Market

Type of Transaction: Building to Grid

Brief Description (NIST 1.3)

Customer signs up with retail utility or a retail service provider for a transactive control and coordination program, involving a real-time price (RTP) determined by customer bids for electricity demand from a short-term (~5-minute) retail price-discovery process (e.g., a market).

Narrative (NIST 1.4)

What is being transacted?

- Customer changes their contract with utility or retail service provider for electricity purchased at a constant, flat rate, for a contract with a real-time price (RTP) that varies over time at short intervals (e.g., 5 minutes).

Why is it being transacted?

- The customer can take advantage of the RTP by shifting some of their load from high-price periods to low-price periods, thereby lowering their bill.

- The utility or retail service provider correspondingly obtains:

  - daily load shifting by customers that corresponds to wholesale electricity costs

  - continuously available demand response/net load reduction resource for use in an emergency

  - precise control of demand and net load to automatically manage capacity constraints, of generation and at various levels of the transmission and distribution systems, on a continuous basis.

How is it being transacted?

- The customer signs up for the transactive control and coordination program

  - This can be accomplished via demand response, battery or thermal storage, and/or use of a fuel-based distributed generator.

- At each interval, the customer's energy management system assembles a bid curve for electricity demand as a function of RTP.

- The RTP is the result of a price-discovery mechanism (e.g., the clearing price of a local retail double-auction market for electricity) that reflects wholesale production or market purchase costs for electricity, and simultaneously manages transmission and distribution capacity constraints. For example,

  - When no constraints are present, the base RTP is a retail markup of the wholesale cost of electricity, per a typical rate case.

  - When constraints are present, the RTP rises to balance demand with available supply.

- Revenues collected when the RTP is above the base RTP (during times of when supply is constrained) can be built into the rate case.

- Alternatively, it can be returned as a credit on the customer's monthly bill along with an additional incentive for response during such periods, constructed from the customer's bids.

- Consumers are notified by the retail service provider or aggregator of RTP at each interval.

- Demand bid curves at each interval can be used to construct incentives and rebates.

- The transactions can be made using a bilateral or double auction transaction approach.

What is the timescale of the transaction?

- Irregular, long-term ~(annual or until-further-notice) for program sign-up.

- Customer bid curves, price-discovery, and response of loads and distributed assets to RTP occurs at hourly or sub-hourly intervals (e.g., 5 minutes is preferable for precision control).

- Customer incentives from shifting load to lower-price periods are reflected in monthly electric bills.

Actor/Stakeholder Roles (NIST 1.5)

Who is transacting?

A. *Consumer (ratepayer)*, often but not always building owner, perhaps representing lease/rental tenants (occupants) collectively.

B. *Utility or retail service provider.*

Who is the market maker?

- (B).

Who else needs to be notified or acknowledge a transaction has been made?

- If a retail service provider other than the distribution utility is involved, distribution benefits can only be taken into account if the transactions are fully consistent with distribution constraints. Therefore coordination with the distribution utility would be required.

- The same is true for the transmission utility or operator.

Are there other transactions associated with this?

- A hierarchical chain of wholesale markets can be utilized to simultaneously manage constraints at any point above the retail price-discovery node.

Information Exchanged (NIST 1.6)

How is the transaction verified?

- Contractual notice exchanged (paperwork or electronic) between (A) and (B).

How is the transacted commodity measured and verified?

- Metered time-series load data is integrated with price time-series data by (B) to compute customer bill.

- Any additional incentives for response can be constructed from the customer's bid history for the month.

Activities/Services (NIST 1.7)

What equipment and technology is required?

- Interval metering is required (AMI/AMR) to provide load data time-series.

- A wide-area communication network with bandwidth sufficient for assembling demand bids and broadcasting the RTP on a 5-minute interval is required.

- Automated price responsive controls for thermostats, water heaters, HVAC equipment, lighting, etc. that implement the customer's desired response are required.

- A home/building energy management system and local area communications network capable of assembling the demand bid curve, implementing control, and/or broadcasting the RTP to the appliances and equipment is required (e.g., a smart thermostat, an AMI meter, a personal computer).

- A user interface for the customer to set the price responsiveness of their appliances and equipment is required (e.g., personal computer, mobile phone app, home energy display).

- (Desirable) A means of forecasting RTPs 24-hours ahead allows the consumer to optimize their response over time.

- (Desirable) Applications for optimizing a building's response given a 24-hour forecast of RTPs hosted by a home/building energy manager.

What is the benefit for the building?

- Lower electric bills result, to the extent load is shifted from high-price periods to low-price periods.

- Reduced rates result (for all customers) by lowering utility revenue requirements resulting from benefits provided to the grid.

What is the benefit for the grid?

- Reduced investment for generation capacity to meet peak loads.

- Reduced investment for transmission capacity to meet peak loads.

- Reduced investment for distribution capacity to meet peak loads.

- Reduced fuel costs or wholesale purchase costs for electricity.

- Reduced congestion costs resulting from transmission constraints.

- Ability to balance the intermittency of renewables at the sub-hourly level.

- Increased ability to manage an emergency.

What is the benefit for renewables?

- Balancing the intermittency of renewables at the sub-hourly level reduces integration costs.

- Emergency response can sustain grid reliability in the face of increased strain on transmission system for long-distance delivery of renewable power to load centers.

- PV solar output is more valuable to the consumer under dynamic rates because peak output corresponds to higher-price periods.

What is the benefit for energy efficiency?

- Home/building networks can be leveraged for energy efficiency applications, better control, diagnostics, and advice.

Contracts/Regulations (NIST 1.8)

- Dynamic rates are subject to public utility commission approval (investor-owned utilities) or board of directors' approval (public utilities).

Current Examples of this Transaction

- Olympic Peninsula Smart Grid Demonstration (2006-7)

- AEP's gridSmart[sm] Demonstration (ongoing)

- Pacific Northwest Smart Grid Demonstration (ongoing)

6.3 Trading Allocated Capacity Rights

Type of Transaction: Building to Building

Brief Description (NIST 1.3)

Existing customer rate plans explicitly include (1) payment for the right to utilize a specified amount of system capacity (kW), or (2) customers are allocated their share of the system capacity by their service provider. An allocation may be based on a utility's standard "rules-of-thumb" regarding diversified peak loads for a customer class, for example. Customers are encouraged to trade their short-term capacity rights with each other in near real time, so the capacity right need only reflect a customer's diversified share of peak load, rather than their absolute peak load.

The customer is required to manage their average load over short time intervals (e.g., a 5-min interval) to not exceed their current capacity limit. In this fashion, peak demand at any constrained point in the grid can be managed. The governing constraint may be in overall generation capacity or at a point of delivery in the transmission or distribution systems. In the case of (2) a forward market is also set up to allow customers to trade for long-term capacity rights.

Narrative (NIST 1.4)

What is being transacted?

- Customers exchange capacity rights with each other to cover their average load over short time intervals (e.g., 5-min).

- Capacity rights may be obtained by one of two mechanisms:

  1. Customers may have purchased them with their rate plan. Customers need sign up only for the amount of diversified capacity they require.

  2. Customers may be allocated their share of the system capacity by their service provider. Any excess capacity may be held by the utility for future customers. A multi-tiered approach may be used to reflect capacity limits of generation, transmission, or distribution system levels.

- Capacity rights are assumed to have been purchased from or allocated by a utility, a retail service provider, an aggregator or third-party distributed asset owner.

Why is it being transacted?

- Managing current grid capacity constraints and limiting future investments in capacity.

- Customers can benefit by being able to better manage their peak loads, or installing more efficient air conditioning equipment (for example), and thereby being able to sign up for a cheaper plan with less capacity or sell some of their long-term allocated capacity rights.

How is it being transacted?

- Customer acquires capacity rights through (1) or (2).

- Under (2), if a forward market is set up, the consumers can submit bids periodically to buy and sell allocated capacity rights.

- The transactions can be made using a double auction or a brokered transaction approach.

- The market operator notifies customers of the clearing price and delivers short- or long-term certificates for capacity rights purchased.

What is the time scale of the transaction?

The transactions should be made frequently as load forecasts are continuously updated to provide more accurate information about customer needs, therefore the time scales for transactions are:

- Long-term rights: months/years.

- Short-term rights: 5-min real time and, optionally, 5-min rights a day ahead.

Actor/Stakeholder Roles (NIST 1.5)

Who is transacting?

A. *Consumer (ratepayer)*, often but not always the building owner, perhaps representing lease/rental tenants (occupants) collectively, buys and sells capacity rights.

B. *Utility or retail load-serving entity*, or a *third-party aggregator*, or an *ISO/RTO* operating a wholesale market, issues allocated capacity rights or "leases" them as a component of customer rates.

C. (Optionally)A *third-party energy provider* or a *microgrid operator* may offer or allocate issue such rights.

Who is the market maker?

- May be the allocating or issuing entity, or an independent market operator.

Who else needs to be notified or acknowledge a transaction has been made?

- If an independent market operator is involved, notification of trades to the allocating or issuing entity may be required.

Are there other transactions associated with this?

- N/A.

Information Exchanged (NIST 1.6)

How is the transaction verified?

- Contractual notice exchanged (paperwork or electronic) between (A) and (B) and/or (C).

How is the transacted commodity measured and verified?

- Metered time-series load data from advanced metering infrastructure (AMI) is required to verify that consumption remained at or less than the capacity rights held by each customer at that time.

Activities/Services (NIST 1.7)

What equipment and technology is required?

- Interval metering is required (AMI) to provide load and generation time-series data to determine if the compliance with the capacity rights are met.

- Internet service to communicate the quantities, price, and time periods for exchange of capacity rights.

What is the benefit for the building?

- Ability to lower monthly bills by buying additional capacity needed and selling excess capacity not needed in a competitive market.

What is the benefit for the grid?

- Ability to manage capacity in real time to reduce need for investment in additional infrastructure for increasing overall generation, transmission and distribution capacity

What is the benefit for renewables?

- N/A

What is the benefit for energy efficiency?

- To extent more efficient equipment also has lower peak draw, encourages installing more efficient air conditioning equipment (from above).

Contracts/Regulations (NIST 1.8)

- Contracts must include the capacity limit in MW, the time period for which the contract is valid and penalties for overages.

Current Examples of this Transaction

- N/A

6.4 Ancillary Services via Aggregator

Type of Transaction: Building to Grid

Brief Description (NIST 1.3)

Customer signs up with a demand response aggregator or utility to provide ancillary services in the form of (1) regulation, or (2) spinning reserve. Today, these are provided by central generation capacity that is not otherwise engaged in producing electricity. These services can also be provided to customers by allowing them to participate in one of three load control programs: interruptible service, direct load control, or dynamic rate, with additional incentives and rebates. The utility reserves capacity based on the willingness of customers to participate, then loads are dispatched by the utility when necessary based on a 4-second resolution regulation signal.

Narrative (NIST 1.4)

What is being transacted?

- Customer contracts with an aggregator to allow their load or distributed assets (battery or thermal storage, dispatchable distributed generation) to be dispatched by the aggregator to provide ancillary services to the grid.

- Currently, this is primarily practiced by demand response aggregators where there are wholesale markets that allow demand participation in providing these services. However, a utility or retail service provider can also play this role.

- Ancillary services can be provided in one of two forms (although others may be defined in the future):

  1) Regulation – alternately increasing or decreasing net load in response to a signal from the grid, for short periods, by an amount up to the contractual limit, with essentially no change in total consumption in the long run.

  2) Spinning reserve – reducing net load upon command from the transmission system operator by the contracted amount for periods typically a few minutes duration, but ranging upward as high as 30 minutes on occasion. The contractual limit on the duration can be as long as 2 hours.

Why is it being transacted?

- The market prices for ancillary services can be reduced by reducing the need for overall generation capacity and increased competition to provide the services by allowing customer's load to participate in the markets.

- Customers receive incentives in the form of payments for allowing their load to be remotely controlled by an aggregator to provide ancillary services to the grid.

How is it being transacted?

- Customer signs up with a demand response aggregator to allow the aggregator to dispatch their load within capacity limits, which will to be specified by the customer periodically.

- Aggregators typically engage their customers in providing traditional demand response or net load reduction (see use cases 6.1 Interruptible Service or Direct Load Control and 5.1 Dynamic Rate, with additional rebates and incentives.

- The utility reserves the capacity needed from the aggregator.

- Loads are dispatched by the utility when necessary based on a 4-second resolution regulation signal.

- The transaction is classified as an over-the-counter (OTC) transaction.

What is the time scale of the transaction?

- Irregular, long-term ~(annual or until-further-notice) for program sign-up.

- Reserving the capacity for ancillary services generally occurs at same the time scale as the wholesale energy market interval (today 1 hour, moving to 15-min in many regions).

- Dispatch of regulation occurs at 4-second intervals. Regulation signals tend to change from positive to negative over periods of a few minutes.

- Dispatch of spinning reserve may occur any time, with full response to be delivered within 10 minutes.

Actor/Stakeholder Roles (NIST 1.5)

Who is transacting?

A. *Consumer (ratepayer)*, often but not always building owner, perhaps representing lease/rental tenants (occupants) collectively

B. *Demand response aggregator,* or less commonly a *utility or retail service provider.*

Who is the market maker?

- (B).

Who else needs to be notified or acknowledge a transaction has been made?

- N/A.

Are there other transactions associated with this?

- (B) aggregators offer to provide ancillary services from a collection of retail customers and bid it as a block into an ancillary services market.

- Aggregators also often engage their retail customers by providing energy efficiency retrofits and services via shared savings or fee-for-service contracts.

Information Exchanged (NIST 1.6)

How is the transaction verified?

- Contractual notice exchanged (paperwork or electronic) between (A) and (B).

- Regulation signal sent to customer every 4-seconds indicating fraction of the customer's capacity for net load increase or decrease that is to be dispatched.

- Notification of spinning reserve event by (B) to (A), and subsequently its termination.

How is the transacted commodity measured and verified?

- Metered 4-second interval load data is generally required.

- Establishing the baseline consumption against which the measured load is subtracted to estimate the response can be problematic.

- Willingness has been expressed by some market operators to allow metering a sub-sample of customers providing ancillary services with the same technology and end use (e.g., residential water heaters).

Activities/Services (NIST 1.7)

What equipment and technology is required?

- Very short-term interval metering (~4-second) is required (shorter than typical AMI capabilities) to provide load data time-series.

- Controls that automate the response are required due to the short allowable time lag.

- A high bandwidth/low latency network is required (e.g., broadband is typically used).

- Aggregator must have technology to forecast the resource available as a function of time-of-day, day-of-week and weather.

What is the benefit for the building?

- Payments from the aggregator – a new source of revenue can be realized from already installed building assets.

- Reduced rates result (for all customers) by lowering utility revenue requirements resulting from benefits provided to the grid.

What is the benefit for the grid?

- Reduced need for overall generation capacity resulting from lower amount of capacity held out of markets to meet regulation and spinning reserve requirements.

- Lower market prices for ancillary services resulting from the increased competition to provide them.

- Reduced wear and tear on generators providing regulation.

- Reduced fuel costs for generators supplying regulation as a result of higher operating efficiency (heat rate).

What is the benefit for renewables?

- Penetration of renewables above ~20% is expected to result in increasing need for ancillary services.

- Reducing the need for power plants to provide these services lowers the cost of integrating renewables with the grid.

What is the benefit for energy efficiency?

- N/A.

Contracts/Regulations (NIST 1.8)

- Ancillary service markets are relatively new, are not universally present even where electricity markets exist, and are not uniform in design or rules for resources to participate.

- Current communication, measurement and verification requirements preclude use of loads smaller than large industrial loads in many cases.

Current Examples of this Transaction

- A number of markets for spinning reserve exist and allow participation by customer assets when aggregated to a significant size (e.g., PJM, ISO-New England, New York-ISO, Midwest-ISO).

- Fewer markets for regulation exist, and fewer of them allow participation by customer assets (e.g., PJM, New York-ISO, Midwest-ISO).

- Enbala, Inc. is a leader in making a business of aggregating loads to provide ancillary services.

6.5 Transactive Acquisition of Ancillary Services

Type of Transaction: Building to Grid

Brief Description (NIST 1.3)

Customer signs up with a utility, retail service provider, or demand response aggregator to provide ancillary services via transactive control in the form of (1) regulation, or (2) spinning reserve. Today, these are almost exclusively provided by central generation capacity that is not otherwise engaged in producing electricity.

Narrative (NIST 1.4)

What is being transacted?

- Customer contracts with utility or demand response aggregator to provide ancillary services for a block of time, utilizing transactive control for their demand response or net load reduction capabilities.

- Today, ancillary services can be provided by a building in one of two forms (although others may be defined in the future):

    1) Regulation – alternately increasing or decreasing net load in response to a signal from the grid, for short periods, by an amount up to the contractual limit, with essentially no change in total consumption in the long run.

    2) Spinning reserve – reducing net load upon command from the transmission system operator by the contracted amount for periods typically a few minutes duration, but ranging upward as high as 30 minutes on occasion. The contractual limit on the duration can be as long as 2 hours.

Why is it being transacted?

- The customer receives a payment for the contribution of their load or distributed assets in providing ancillary services to the grid.

- The utility or aggregator obtains a resource, in the form of a change in net load that can be aggregated with that of other customers and bid into ancillary service markets, in competition with generators that almost exclusively provide such services today.

- Alternatively, where such markets do not exist (e.g., in vertically-integrated utility systems), the resource obtained can be used to displace costs for providing such services.

How is it being transacted?

- Customer signs up with a demand response aggregator to provide ancillary services for a block of time via transactive control for their demand response

    – If practiced in conjunction with a Transactive Retail Energy Market (see use case 6.2 Transactive Retail Energy Market), the distribution utility may be the most convenient market operator so that distribution constraints can be fully taken into consideration. However, a retail service provider

or demand response aggregator can also play this role. In either case, we will use the term "aggregator" in the discussion below.

- Aggregators typically engage their customers in providing traditional demand response or net load reduction (use cases 6.1 Interruptible Service or Direct Load Control and 5.1 Dynamic Rate), with additional rebates and incentives.

- At each interval, the customer's energy management system assembles a bid curve to allocate capacity to provide ancillary services as a function of RTP.

- A price-discovery mechanism clears a price based on aggregated bids from a population of customers for ancillary services.

- Loads are dispatched by the utility when necessary based on a 4-second resolution regulation signal, within the capacity limits specified by the customer.

- The transactions can be made using a double auction approach.

What is the time scale of the transaction?

- 5 minutes for offer from customer to participate and notice from aggregator of acceptance.

- Dispatch of regulation occurs at 4-second intervals. Regulation signals tend to change from positive to negative over periods of a few minutes.

- Dispatch of spinning reserve may occur any time, with full response to be delivered within 10 minutes.

Actor/Stakeholder Roles (NIST 1.5)

Who is transacting?

A. *Consumer (ratepayer)*, often but not always the building owner, perhaps representing lease/rental tenants (occupants) collectively

B. *Utility,* or (with proper coordination to the utility), a *demand response aggregator* or *retail service provider.*

Who is the market maker?

- (B).

Who else needs to be notified or acknowledge a transaction has been made?

- Distribution utility, if they are not serving as (B), needs to verify the feasibility of the transaction.

Are there other transactions associated with this?

- (B) aggregates offers from multiple consumers (A) to provide ancillary services and bids these as a resource into an ancillary services market (where such markets exist).

Information Exchanged (NIST 1.6)

How is the transaction verified?

- Electronic exchange of consumer offer from (A) and aggregator's acceptance of offer from (B) are exchanged.

- Regulation signal sent to customer every 4-seconds indicating fraction of the customer's capacity for net load increase or decrease that is to be dispatched by the consumer's control system.

- Notification of spinning reserve event by (B) to (A) to be dispatched by the (A)'s control system, and subsequently its termination.

How is the transacted commodity measured and verified?

- Metered 4-second interval load data is generally required.

- For regulation services, a payment is made for the degree to which their load matches the control signal.

Activities/Services (NIST 1.7)

What equipment and technology is required?

- High-bandwidth/low-latency network (e.g., broadband or radio broadcast) to get 4-second control signal to the consumer.

- Very short-term interval metering (~4-second) (shorter than typical AMI capabilities) to provide load data time-series.

- Advanced AMI processing capability to compute the incentive based on the integral of the control signal and the managed net load.

- A home/building energy management system and local area communications network capable of assembling the demand bid curve, implementing control, and/or broadcasting the RTP to the appliances and equipment (e.g., a smart thermostat, an AMI meter, a personal computer).

- Controls that automate the response of the consumer equipment resulting from the short allowable time lag.

- (Desired) Aggregator may need technology to forecast the resource available as a function of time-of-day, day-of-week and weather.

What is the benefit for the building?

- Payments from the aggregator.

- Reduced rates result (for all customers) by lowering utility revenue requirements as a result of benefits provided to the grid.

What is the benefit for the grid?

- Reduced need for overall generation capacity due to lower amount of capacity held out of markets to meet regulation and spinning reserve requirements.

- Lower market prices for ancillary services resulting from the increased competition to provide them.

- Reduced wear and tear on generators providing regulation.

- Reduced fuel costs for generators supplying regulation as a result of higher operating efficiency (heat rate).

What is the benefit for renewables?

- Penetration of renewables above ~20% is expected to result in increasing need for ancillary services.

- Reducing the need for power plants to provide these services lowers the cost of integrating renewables with the grid.

What is the benefit for energy efficiency?

- N/A.

Contracts/Regulations (NIST 1.8)

- Ancillary service markets are relatively new, are not universally present even where electricity markets exist, and are not uniform in design or rules for resources to participate.

Current Examples of this Transaction

- None. The closest example of this use case is the response to the magnitude of wind generation in the Pacific Northwest Smart Grid Demonstration. This is an example of a potential new type of ancillary service for balancing fluctuating output from renewables that is commonly called *ramping*.

6.6 Rate Dependent Priority for Cold Load Pickup

Type of Transaction: Building to Grid

Brief Description (NIST 1.3)

The distribution utility leverages demand response programs at its disposal to mitigate very large loads that result after an outage because of pent-up demand for electricity by thermostatically-controlled loads (cold load pickup). This use case is an extension of the previously described use cases 5.1 Dynamic Rate, 6.1 Interruptible Service or Direct Load Control, and 6.2 Transactive Retail Energy Market. Only key differences will be noted in this section.

Narrative (NIST 1.4)

What is being transacted?

- Interruptible services, critical peak price, and direct load control events are called to activate maximum demand response. Real-time prices are similarly raised to very high levels to trigger demand response.
- RTP customers receive a rebate for the difference in their energy bill resulting from such events.

Why is it being transacted?

- Distribution utility utilizes demand response mechanisms at its disposal to reduce load temporarily immediately following power restoration to mitigate cold load pickup, making it easier to restore power to larger groups of customers. This speeds restoration time.

How is it being transacted?

- Any excess charges resulting from the artificially high rates are rebated to customers on RTP plans.

What is the time scale of the transaction?

- Customer rebates are received on their monthly bill.

Activities/Services (NIST 1.7)

What is the benefit for the building?

- Faster power restoration after an outage.

What is the benefit for the grid?

- Utilities can avoid the expense of crews energizing small sections of feeders individually after an outage to avoid overloads and protection re-trips caused by motor inrush currents and loss of load diversity.

What is the benefit for renewables?

- N/A.

What is the benefit for energy efficiency?

- N/A

Contracts/Regulations (NIST 1.8)

- Scheme may require approval by public utility commission or board of directors' approval.

Current Examples of this Transaction

- N/A.

7.0   Societal Services

Chapter 2 describes societal services as energy and energy-related services that have a value agreed upon and acknowledged by society, and provided to all involved or affected parties, and whereby settlements may be made by the larger governing entity. The responsibility of monetizing the societal value, in most cases, would be performed by the governing entity, as well. Examples of societal services may include participation by utilities, and third party provided into emissions cap-trade markets etc., using energy efficiency certificates (white tags), acquired from customers (buildings) using transactive mechanisms. The value (monetary or other) gained from providing societal services would be shared between the involved parties. Examples of use cases with details on the transactive mechanisms that could be employed for providing societal services that are described here are:

- Emergency Power Rationing
- Efficiency Incentive Payment
- Air Shed Management

Each of these is described in more detail, below.

7.1 Emergency Power Rationing

Type of Transaction: Building to Grid

Brief Description (NIST 1.3)

Customer signs up with retail service provider to receive power rationing services under global emergency conditions (i.e., blackouts). The retail service provider owns distributed energy resources (DERs) that can be coordinated to provide constant service to consumers with critical loads, within limits and capabilities, to minimize impacts to well-being of the people involved and impact to businesses. This assumes that automated metering infrastructure (AMI) with remote disconnect capability is deployed and used in the case of a blackout to reduce the load that must be served. First priority of course to restore the service goes to the premium customers. There could also be an alternate provision of a forward market set up to allow customers to trade for long-term capacity rights between premium customers (see for example, the use case described in Section 6.3, *Trading Allocated Capacity Rights*).

Narrative (NIST 1.4)

What is being transacted?

- Customer signs up with load serving entity (LSE) to receive highest quality of electricity service possible that will optimize social welfare of all consumers involved during an emergency situation (i.e., blackout). The customer agrees to pay a monthly premium for the service.

Why is it being transacted?

- Power outages cause over $100 billion in economic losses, annually. Power rationing based on social welfare can be used to minimize impacts to well-being of the people involved (impact to health, businesses, economy, etc.). For example, higher priority should be given to supply critical load in a hospital treating patients in critical condition than in a residential building where a healthy young adult resides because the former could result in loss of life without electricity service.

How is it being transacted?

- Customer fills out a load assessment questionnaire.

- LSE offers the customer quotes on different premium plans that specify the capacity rights the customer is eligible for during an emergency, based on the responses given in the questionnaire. The questionnaire ensures that the capacity rights granted are limited to the specific needs of the individual customers and that customers with money are not the only consumers that will receive power during emergency situations.

- Customer signs up for one of the premium plans that specifies the capacity limits during emergency situations.

- During an emergency situation, the LSE will immediately notify customers of an emergency situation via text, email, pager and/or two-way communications with EMS. The customer will have several seconds to minutes to reduce loads within capacity limits given. The LSE will provide the highest quality of electrical services within capability and customer limits.

- If the customer exceeds the capacity limits at any time, electricity supply to the entire building will be cut.

- Reports are provided by the LSE, explaining the emergency situations if any and plans were executed within the terms and conditions of the policy contract.

What is the time scale of the transaction?

- Irregular, long-term (~annual or until-further-notice) for program sign-up depending on changes in customer critical loads. For example, if critical loads are replaced by more efficient loads or are no longer used, customers may want to consider a plan with a lower premium.

- Emergency situations are typically unpredictable and occur irregularly.

- Customers respond to notification of an emergency situation within seconds to minutes.

- Premiums are paid monthly by customers.

- Irregular reports, explaining service provided within contract terms and conditions during emergencies.

Actor/Stakeholder Roles (NIST 1.5)

Who is transacting?

    A. *Consumer (ratepayer)*, often but not always building owner, perhaps representing lease/rental tenants (occupants) collectively.

    B. *Utility, retail service provider,* or a *third-party aggregator*.

Who is the market maker?

- (B).

Who else needs to be notified or acknowledge a transaction has been made?

- N/A

Are there other transactions associated with this?

- N/A

Information Exchanged (NIST 1.6)

How is the transaction verified?

- Contractual notice exchanged (paperwork or electronic) between (A) and (B).

How is the transacted commodity measured and verified?

- Reports are provided after each emergency to verify that actions were taken within the customer agreement.

- If terms of the agreement are not met by the LSE, penalties will be due to the customer.

Activities/Services (NIST 1.7)

What equipment and technology is required?

- Interval metering (AMI/AMR) is required to provide load data time-series

- Optimization algorithms and reconfiguration schemes used to coordinate emergency distributed energy resources to maximize the time that electricity services can be provided to critical loads.

- A home/building energy management system and local area communications network capable of automatically switching off non-critical loads within capacity limits when notified of an emergency situation.

What is the benefit for the building?

- Reliable service delivered to critical loads that will have a major impact on either health or business, if the loads are lost during emergency situations.

What is the benefit for the grid?

- Reduced economic losses from power outages of critical loads.

- Revenue streams for owning distributed energy resources.

What is the benefit for renewables?

- N/A

What is the benefit for energy efficiency?

- N/A

Contracts/Regulations (NIST 1.8)

- Contracts should include the following

  – Capacity rights in an emergency situation

  – What constitutes an emergency situation

  – LSE responsibilities

  – Guarantees and disclaimers during an emergency situation

  – Customer responsibilities

  – Consequences for LSE for not meeting terms of the agreement

  – Consequences for customer for not meeting the terms of the agreement

- Further regulations may be necessary to ensure that some elderly and poor citizens can also receive electricity during emergency situations if there is an absolute need for it.

Current Examples of this Transaction

- N/A

7.2 Efficiency Incentive Payment

Type of Transaction: Building to Grid

Brief Description (NIST 1.3)

Customer signs up with a utility that provides an incentive payment for the efficiency achieved, and uses the resulting savings to meet regulatory obligations or in a secondary market for generation for carbon market and for meeting renewable portfolio standards (RPS).

Narrative (NIST 1.4)

What is being transacted?

1) In traditional programs, a utility (or retail service provider) subsidizes the cost of increasing the energy efficiency of a building or facility.

2) In a new alternative, the utility creates a market-like incentive program paying a bounty for customer-financed and implemented energy efficiency measures that can be translated into capacity.

Why is it being transacted?

- Often the utility or retail service provider is incentivizing efficiency costs because it must meet regulatory societal goals for deploying efficiency or as part of an RPS, set by a state, a public utility commission, or its board of directors.

- The utility or retail service provider can sell the resulting energy efficiency into a) a RPS market, or b) a carbon market where such markets exist and allow participation of energy efficiency.

- Customer obtains a lower energy bill and a payment for the efficiency achieved.

How is it being transacted?

- Customer signs up for program.

- Customer installs efficiency measures at their expense.

- Customer applies to utility for bounty (incentive payment) for savings achieved.

- Utility verifies savings and sends payment to customer.

What is the time scale of the transaction?

- Sign-up occurs once or irregularly.

- Payment may occur once after verification, or annually as persistence is re-verified over some period of years.

(The latter is particularly useful for behavior-driven efficiency measures such as diagnostics and commissioning, equipment and system tune-ups, thermostat setback programs, etc.)

Actor/Stakeholder Roles (NIST 1.5)

Who is transacting?

   A. *Consumer (building owner).*

   B. *Utility/load-serving entity.*

Who is the market maker?

- (B).

Who else needs to be notified or acknowledge a transaction has been made?

- N/A.

Are there other transactions associated with this?

- See secondary transaction by utility to a market, noted above under *Why is it being transacted?*

Information Exchanged (NIST 1.6)

How is the transaction verified?

- Application from (A) to (B) for incentive payment.
- Payment of incentive (B) to (A) subsequent to verification of savings.

How is the transacted commodity measured and verified?

- Utility verifies savings, either by stipulation via an engineering calculation, spot measurements, or analysis of metered data, or some combination thereof.

Activities/Services (NIST 1.7)

What equipment and technology is required?

- (Desirable) AMI meter.
- (Desirable) Continuous or spot end-use metering can improve targeting of efficiency measures and support savings verification.
- (Desirable) Data from commercial building management and control systems or smart residential thermostats and appliances can likewise support improved targeting and measurement.

What is the benefit for the building?

- Reduced utility bills and direct payment from utility.

What is the benefit for the grid?

- Increase efficiency from end uses that contribute to peak loads and reduce the need for capital investment for generation, transmission, and distribution capacity.
- When utilities are subject to a RPS requirement, they can earn credit for efficiency where allowed.
- When utilities are subject to a carbon market or tax, they can save money by reducing their need to purchase credits or pay taxes.

What is the benefit for renewables?

- No direct benefit.

- Program could be expanded to include renewable generation.

What is the benefit for energy efficiency?

- Opportunity for incentive payment spurs penetration of efficiency measures.

Contracts/Regulations (NIST 1.8)

- Where a regulated utility is involved, public utility commission approval must be sought to offer such services.

Current Examples of this Transaction

- Seattle City Light has just announced this type of program to meet their energy efficiency goals.

7.3 Air Shed Management

Type of Transaction: Building to Other

Brief Description (NIST 1.3)

An air shed management authority created to improve air quality in a "smog basin" receives the authority to manage pollution levels in its district on declared "smog alert" days via an air quality surcharge on electricity and natural gas rates. These variable real-time surcharges may be zero or near zero under normal circumstances, but rise during such events, to reflect discharges from 1) generation used to power electric end uses and 2) gas and oil end uses, to encourage the following:

- load curtailments, particularly for customer segments and end uses that have high contributions of local pollutants

- shifting of electricity generation to cleaner and extra-regional sources, including curtailment of distributed generation and combined cooling-heating-power systems in the air shed district.

The surcharges are applied to existing utility rates, whether flat or time-varying dynamic rates, via the utility billing infrastructure.

Narrative (NIST 1.4)

What is being transacted?

- A real-time surcharge to all customers existing utility rates in the air shed district is applied to all customers' consumption.

- Customers can respond to the variation in total price by curtailing their consumption during surcharge periods.

Why is it being transacted?

- The air shed management authority wants to reflect the costs of shifting electricity generation to cleaner and extra-regional sources, and thereby encourage curtailment of end-use loads (gas, electric, and other fuels), and of fuel-powered distributed generation and combined cooling-heating-power systems in the district, in proportion to the benefit that doing so provides to air quality.

- Customers receive a lower energy bill if they respond to the surcharges by curtailing consumption during surcharge periods or shifting their consumption to lower surcharge periods.

How is it being transacted?

- The utility (or retail service provider) applies the surcharge from the air shed authority to all customers existing utility rates in the air shed district based on the fuel type (and perhaps the rated conversion efficiency of the generation or end-use equipment), and delivers the prices to the customers.

- As an alternative, the air shed management authority itself could deliver notice of the surcharges to the customers.

- Customers can respond to the variation in price by curtailing their consumption during surcharge periods.

What is the time scale of the transaction?

- Surcharges are sent out with hourly granularity, a 48-hour look-ahead, and updated on a regular (e.g., daily or hourly basis).

- Savings appear on the customer's regular (e.g., monthly) utility bill.

Actor/Stakeholder Roles (NIST 1.5)

Who is transacting?

A. *Air shed management authority*

B. *Utility/load-serving entity.*

C. *Consumer (building owner).*

Who is the market maker?

- (A).

Who else needs to be notified or acknowledge a transaction has been made?

- N/A.

Are there other transactions associated with this?

- Presumably there is an associated re-dispatch of central generation to reflect their contribution to the district's air pollution as well. This may be conducted using the LMP-style computation of marginal costs, with the surcharges incorporated there as well.

Information Exchanged (NIST 1.6)

How is the transaction verified?

- Receipt for notification of surcharge prices from customer to utility (or air shed management district if it is the sender).

How is the transacted commodity measured and verified?

- No verification is required. AMI electric and gas meters simply measure consumption.

Activities/Services (NIST 1.7)

What equipment and technology is required?

- AMI electric and gas meter.

- (Desirable) Means of defining and communicating conversion efficiencies allows incentive to naturally target "dirtier" loads.

- (Desirable) End-use metering for non-electric loads can improve accuracy of surcharges.

What is the benefit for the building?

- Reduced surcharges on their utility bills.

What is the benefit for the grid?

- The construction of cleaner, but potentially more expensive power plants receive an additional incentive.

What is the benefit for renewables?

- Surcharges encourage the expansion of distributed and centralized renewable generation.

What is the benefit for energy efficiency?

- Surcharges spur the penetration of efficiency, especially for fuel-consuming end-use loads and distributed generation.

Contracts/Regulations (NIST 1.8)

- Where a regulated utility is involved, public utility commission approval may be required.

Current Examples of this Transaction

- We are not aware of any current examples of this transaction. In some instances, air shed management districts do have authority to curtail loads (usually industrial) and order shifting of generation outside the district.

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