The Role of the Smart Grid in Enhancing Energy Efficiency and Demand Response: An Economic Assessment of a Regional Smart Grid Deployment in the Pacific Northwest

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ABSTRACT

This paper reports on aspects of an introductory economic assessment of regional Smart Grid deployment conducted for Bonneville Power Administration. The assessment evaluated the likely beneficial roles of a full-scale regional deployment of Smart Grid functionality as well as the estimated costs of such a deployment. While a variety of benefit categories were estimated based on available data, this paper focuses on the benefits that pertain specifically to energy efficiency and demand response. An overview of the benefits assessment is presented, followed by a discussion of the mechanisms by which a Smart Grid might enable energy efficiency and demand response benefits.

The study found that, given available information, a Smart Grid buildout for the region should produce benefits estimated to be over $9B (2010 present value) through 2035, with a commensurate cost estimate of between $4B to $6B over this period. The value of energy efficiency (EE) and demand response (DR) benefits enabled by Smart Grid over this period are estimated to be $4.5B (2010 present value) for the region. To obtain these benefits, however, investments in Smart Grid *assets*—technologies applied to specific Smart Grid applications—must interact in an integrated fashion and reach a significant level of penetration extending from generation through end-use.

Definition of Smart Grid

Many Smart Grid definitions exist. Recently, published definitions have begun to converge toward the definition used by the National Institute of Standards and Technology (NIST). The Smart Grid defined in the NIST Roadmap (Von Dollen 2009) is based on the descriptions found in the energy Independence and Security Act of 2007. In this context, the term "Smart Grid" refers to:

> *A modernization of the electricity delivery system so it monitors, protects and automatically optimizes the operation of its interconnected elements – from the central and distributed generator through the high-voltage network and distribution system, to industrial users and building automation systems, to energy storage installations and to end-use consumers and their thermostats, electric vehicles, appliances and other household devices.*
>
> *The Smart Grid will be characterized by a two-way flow of electricity and information to create an automated, widely distributed energy delivery network. It incorporates into the grid the benefits of distributed computing and communications to deliver real-time information and enable the near-instantaneous balance of supply and demand at the device level.*

Definition of Energy Efficiency and Demand Response

The Department of Energy's Energy Information Agency (DOE EIA 2008) defines energy efficiency as:

> *Programs [and behaviors] that are aimed at reducing the energy used by specific end-use devices and systems, typically without affecting the services provided… savings are generally achieved by substituting technically more advanced equipment to produce the same level of end-use services with less electricity.*

The Department of Energy (DOE 2006) defines demand response as:

> *Changes in electric usage by end-use customers 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.*

Introduction

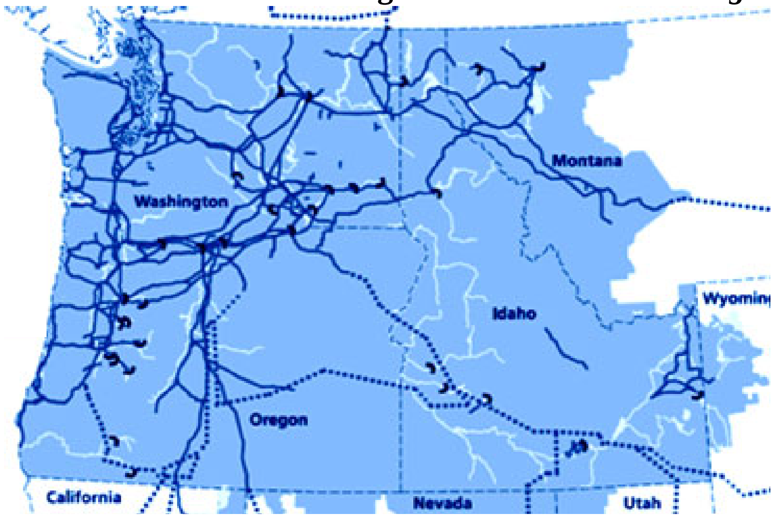
Smart Grid, as envisioned, will use new technologies and innovative methods to make the existing traditional power infrastructure more efficient and will deliver new capabilities that are not currently possible or not yet recognized. The application of these technologies aims to improve the power factors associated with infrastructure elements and extend the useful life of many capital assets.

The vision of a Smart Grid that provides these benefits contains many uncertainties. The Bonneville Power Administration (BPA) is leading an effort to advance understanding of smart technologies, applications for these technologies, and the benefits of a functioning Smart Grid. As part of this effort, BPA and Summit Blue Consulting (now a part of Navigant Consulting, Inc.) conducted an introductory economic assessment of the benefits and costs associated with a full-scale deployment of Smart Grid functionality throughout the Pacific Northwest region, which represents approximately 5% of the national electricity generation and consumption. This study will be referred to as the *regional assessment*. Figure 1 depicts the region that was considered in this assessment.

The *regional assessment* analyzed Smart Grid costs and benefits over a 25 year period,[1] through 2035. Several scenarios were evaluated based on different levels of achieved interoperability and deployment costs – the results described in this paper are based on a conservative *Expected Case* scenario. Both cost and benefit streams were analyzed to generate net-present value and benefit/cost ratio estimates for the regional deployment. This paper reports on benefit results specifically related to energy efficiency and demand response.

[1] Based on data available as of 2009.

Figure 1. Map of the Pacific Northwest Region Considered in the *Regional Assessment*



The BPA Introductory Smart Grid Economic Assessment

The purpose of the introductory Smart Grid *regional assessment* was to assess the range of costs and benefits associated with deployment of a regional smart grid in the Pacific Northwest. A framework and approach were developed to leverage the currently available data and to understand the economic factors associated with a regional deployment. The introductory *regional assessment* was intended to inform regional decision makers early in the process of Smart Grid research, development, and deployment prior to investments in large scale infrastructure upgrades. It will be updated and refined as new information becomes available. Specific objectives of the *regional assessment* included the following:

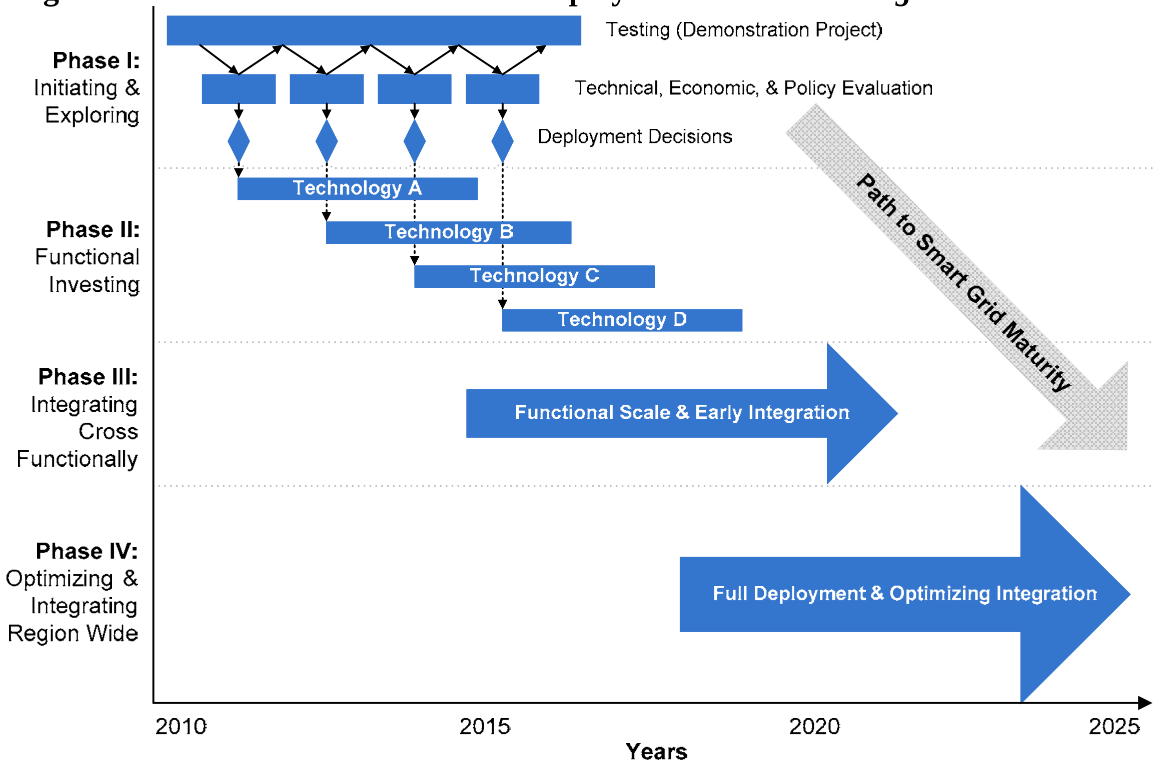
- Developing a framework for assessing regional Smart Grid deployment, leveraging information from the Pacific Northwest Smart Grid Demonstration Project.[2] The framework outlines a deployment path and an economic assessment strategy for the regional Smart Grid.
- Performing an introductory assessment of the costs and benefits associated with full scale regional Smart Grid deployment using the Northwest Power and Conservation Council's (NPCC) 6th Power Plan as a baseline. (NPCC 2009)
- Informing decision makers of the key takeaways, including economic drivers, risks, and issues associated with deploying Smart Grid region-wide.
- Recommending appropriate next steps for furthering the economic assessment and investment analysis to better inform future decisions and reduce risk as Smart Grid projects are considered.

The assessment framework developed for this effort leverages information available at the time the study was conducted from the *demonstration project*, along with other publicly available studies and information to assess potential costs and benefits over a 25-year period. The *demonstration project* serves as the first phase of regional deployment where learning

[2] The *Pacific Northwest Smart Grid Demonstration Project* refers to Battelle's proposal submitted to the U.S. DOE in response to the funding opportunity announcement for Smart Grid demonstrations (DE-FOA-0000036).

occurs and technology deployment decisions are made. The framework then extends Smart Grid functionality through four of the five levels of the Carnegie Mellon Smart Grid Maturity Model (CM SEI V3.1), with 80% of the Pacific Northwest regional grid achieving Level-4 maturity by 2025. The regional Smart Grid deployment considered in this assessment proceeds in four broad phases that align with the first four maturity levels of this model, as shown below in Figure 2. Note that the labels on the y-axis correspond to the four deployment phases.

Figure 2. Framework for Smart Grid Deployment used in the *Regional Assessment*



Definitions of the four deployment phases are outlined below:

- **Phase I. Initiating and Exploring** – Developing a Smart Grid vision and supporting experimentation. Testing and pilot programs serve this role and anchor the path through subsequent phases.
- **Phase II. Functional Investing** – Aligning investments to an integrated vision, acting on individual investment decisions, and deploying technologies to achieve specific functions based on specific costs and benefits to stakeholders.
- **Phase III. Integrating Cross-Functionally** – Creating an integrated Smart Grid "backbone," merging deployed technologies into an integrated system, and deploying individual technologies and functions based on costs and benefits in the context of the integrated system, rather than as stand-alone efforts.
- **Phase IV. Optimizing & Integrating** – High-penetration deployment of Smart Grid technologies with integrated and interoperable functions that can be optimized across the system.

Five scenarios were developed as part of the assessment to demonstrate the range of possible economic outcomes. The most likely of these scenarios, the *Expected Case*, uses generally conservative assumptions about technology adoption and achievable benefits. This scenario does not include benefits that are difficult to quantify and assumes that integration is achieved by the fourth phase. It also excluded the anticipated effects of region wide optimization and widespread innovation. The benefits findings for this case are discussed below and provide insight into the expected benefits breakout over the deployment period.

Costs were estimated based on averages from available resources for a wide range of technologies and systems. The assessment did not attempt to predict winning or losing technologies, but rather assumed averages from all technologies where applicable cost information was available. Cost estimates were developed based on a variety of factors:

- Deployment timing consistent with the overarching assessment framework
- *Demonstration project* costs (containing a wide range of technologies and systems)
- Current technology costs from various vendors
- Learning curve and cost curve factors consistent with analogous past technologies
- Scalability of technologies throughout the region (fixed and variable costs)

For all of the scenarios, six primary benefits categories were established based on several factors, including: the list of Smart Grid roles developed as part of the *demonstration project* effort; the information currently available for analysis and projection; and the feasibility of developing or leveraging a reasonable methodology for each selected benefit category.[3] The six benefits categories evaluated in the assessment are shown in Table 1.

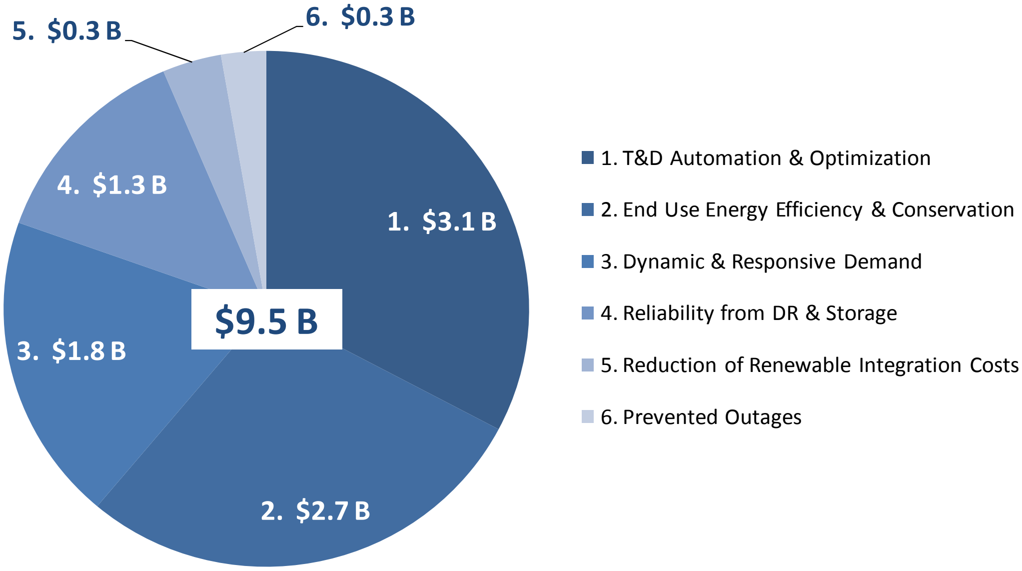
Table 1. List of Smart Grid Benefit Categories Used in the *Regional Assessment*

Smart Grid Role	
1. T&D Automation & Optimization	4. Reliability from DR & Storage
2. End Use Energy Efficiency & Conservation	5. Reduction of Renewable Integration Costs
3. Dynamic & Responsive Demand	6. Prevented Outages

The breakout of benefits for the *Expected Case* scenario is shown below in Figure 3, which includes benefits resulting from the six primary benefits categories outlined. The figure shows an overall benefits estimate (2010 present value) in the conservative *Expected Case* of $9.5B.[4]

[3] Potential “externality” benefit categories such as environmental impact would have required in-depth research and sophisticated modeling and were considered beyond the scope of this assessment.
[4] An annual nominal discount rate of 9% was selected for this assessment based on BPA’s internal financial evaluation and review process. Rates of 6% and 12% were evaluated in a sensitivity analysis. Future inflation rates were applied as 3% annually.

Figure 3. Breakdown of Estimated Benefits by Category (2010 present value)[5]



The *Expected Case* benefits are expected to produce large economic value totaling $9.5B (2010 present value). The benefit categories that are specifically related to energy efficiency and demand response are shown below with their respective estimated benefits:

- End-Use Energy Efficiency & Conservation - $2.7B
- Dynamic & Responsive Demand - $1.8B

The specific mechanisms by which Smart Grid could create these energy efficiency and demand response benefits are discussed in the following section.

The *regional assessment* concluded that regional deployment of Smart Grid functionality has high potential upside benefits when system-wide interoperability, region-wide optimization, and innovation in electric devices and technologies are achieved. There is also some downside risk in the scenarios where Smart Grid system integration costs turn out to be higher than expected and interoperability and resource optimization are slow to materialize. In summary:

- It is likely that regional deployment will produce a net positive value to the region, but there is some possibility that regional deployment could produce a negative net value to the region.[6]
- Regional Smart Grid benefits over the next 25 years could be as much as three times the costs if a high level of interoperability is achieved and regional optimization of resources is largely successful.

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[5] This breakdown of estimated benefits by category looks only at the benefits of a functioning Smart Grid and does not consider costs associated with the deployment of Smart Grid assets.

[6] A negative net benefit could result from inadequate reduction of risks, higher than expected integration costs, and an overly time consuming integration process.

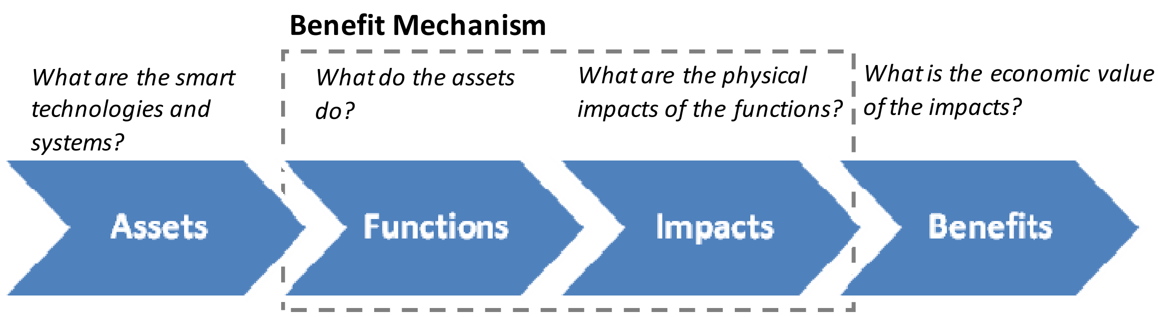
Smart Grid Benefit Mechanisms for Ee & Dr

Smart Grid is expected to provide large economic benefits related to energy efficiency and demand response. This section focuses on the mechanisms by which these benefits can be created.

What Is a Benefit Mechanism?

A benefit mechanism is the mode by which an asset (technology, system, or application) creates economic value. Figure 4 depicts the role of a benefit mechanism.

Figure 4. Illustration of the Mechanism by which an Asset Produces a Benefit



A benefit mechanism consists of two components – *functions* and *impacts*. Functions may be thought of as the capabilities that a technology or system enables. For example, advanced digital meters may enable time-stamping of energy consumption measurements and the ability to enact more effective temporal or dynamic pricing structures. Impacts may be thought of as the physical effect of a function, and can usually be measured in real units (e.g., MW, kWh). A likely impact of a dynamic pricing structure would be a reduction in the peak demand, since peak energy would have higher prices. This reduction is an impact that can be measured in real terms, peak megawatts reduced. The ultimate economic benefit of this impact is the dollar value of the reduction in peak load. Of course, advanced digital meters would likely enable other benefits by other mechanisms as well.

The following sub-sections explain the energy efficiency and demand response benefits (cited previously from the BPA economic assessment) in terms of their benefit mechanisms.

Increased End-Use Efficiency

This section focuses specifically on the benefit mechanisms associated with end-use reductions in energy consumption.

Assets

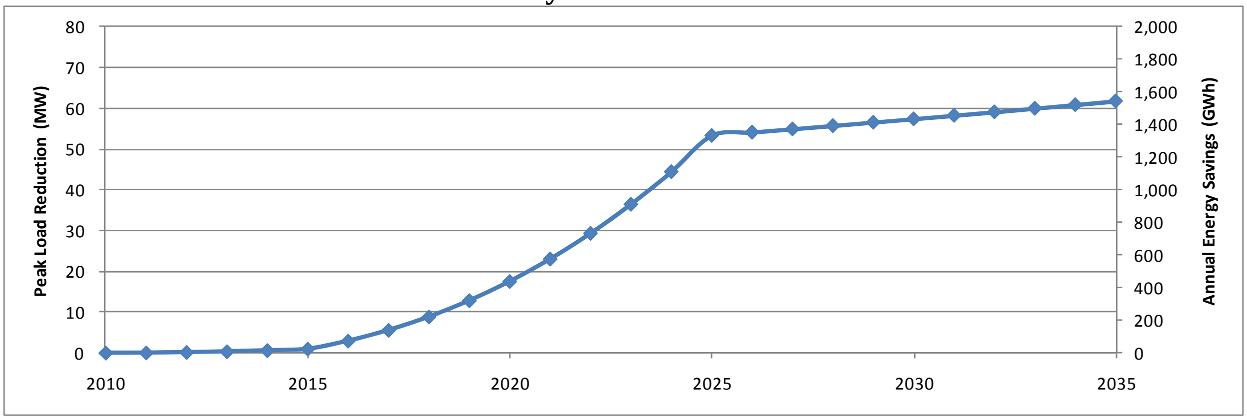
- Digital meters
- End-use energy information displays
- Digitally enabled end-use devices/appliances
- Meter data management systems & applications

Functions

- **Consumption Awareness** – Advanced digital meters will enable time-stamping of energy consumption measurements. In-home or web-based energy information displays can enable end-use customers to view their consumption patterns providing them a better understanding of how energy is used on site. This would lead to a conservation effect by end users.
- **Active Energy Diagnosis** – Advanced digital meters and digitally enabled end-use devices enable identification of equipment that is not running properly, requires maintenance, or should be replaced. By analyzing data coming from end-use technologies through meter data management systems and applications, utilities and customers can be made aware of problem equipment that is consuming excess energy and can address these problems more quickly. Improved maintenance and retirement of inefficient equipment will reduce excessive energy consumption.
- **Reduced EM&V Effort** – Availability of higher fidelity data should accelerate the evaluation, measurement and verification (EM&V) process, while increasing the precision and certainty of savings estimates. Not only will this improve the quality of these analyses, but would also reduce the data collection costs of EM&V efforts.

Impacts. Smart Grid assets and functions that are enabled will create real, physical impacts. Functions like "consumption awareness" and "active energy diagnosis," as well as many others, are expected to lead to reduced consumption. This reduction would lower the peak demand for energy, allowing the most expensive plants to be taken offline. It would also result in less energy consumed. Figure 5 shows the estimated reductions in annual peak demand and annual energy savings resulting from reduced consumption from the *regional assessment*. The inflection seen in 2025 is the result of the completion of the primary build-out of the Smart Grid.

Figure 5. Estimated Peak Load Reduction and Avoided Energy due to Increased End-Use Efficiency and Conservation[7]



[7] The inflection in the year 2025 indicates the assumed end of Smart Grid deployment with an achievement of 80% technology penetration.

Benefits. The impacts of increased energy efficiency will lead to economic value according to these formulae:

*annual energy benefits = energy savings (MWh) * avoided energy cost ($/MWh) * discounting factor*
*annual demand benefits = peak reduction (MW) * avoided capacity costs ($/kW-yr) * discounting factor*
*annual EE implementation cost benefits = total EE reductions (MWh) * cost of implementing EE ($/MWh) * cost reduction (%) * discounting factor*

Avoided energy was valued as the forecasted wholesale price of electricity, $32.97/MWh in 2010. [8] Avoided generation, transmission and distribution capacity was valued at $153.85/kW-yr. Reductions in demand and energy were assumed to scale by the penetration fraction of Smart Grid technologies. Energy projections, peak load projections and cost assumptions were based on the NPCC's 6th Power Plan. (NPCC 2009) The cost of implementing energy efficiency was applied as $36.00/MWh. The total benefit (2010 present value) estimated for increased end-use efficiency and conservation for the region through 2035 is $2.7B.

Increased Demand Response Capacity

This section focuses specifically on the benefit mechanisms associated with increases in utilities' capacity to affect electric consumption patterns by end-use customers.

Assets

- Digital meters
- Home area networks
- Energy management systems
- Digitally enabled end-use devices/appliances
- End-use energy information displays

Functions

- **Pricing Incentives –** Advanced digital meters may enable time-stamping of energy consumption measurements and the ability to enact a variety of pricing structures. These pricing structures can be used to incent customers to reduce consumption during peak hours or during periods when likelihoods of reliability events are at unacceptable levels. An impact of incentive pricing structures would be a reduction in the peak demand since peak energy would have higher prices.
- **Automated Device Optimization –** Home area networks (HAN) and energy management systems (EMS) that control digitally enabled end use devices such as water heaters, HVAC systems, and appliances can automatically control usage of these devices. These systems could optimize utilization of these devices based on customer preferences, electricity prices, weather forecasts, and a variety of other factors. Such optimization

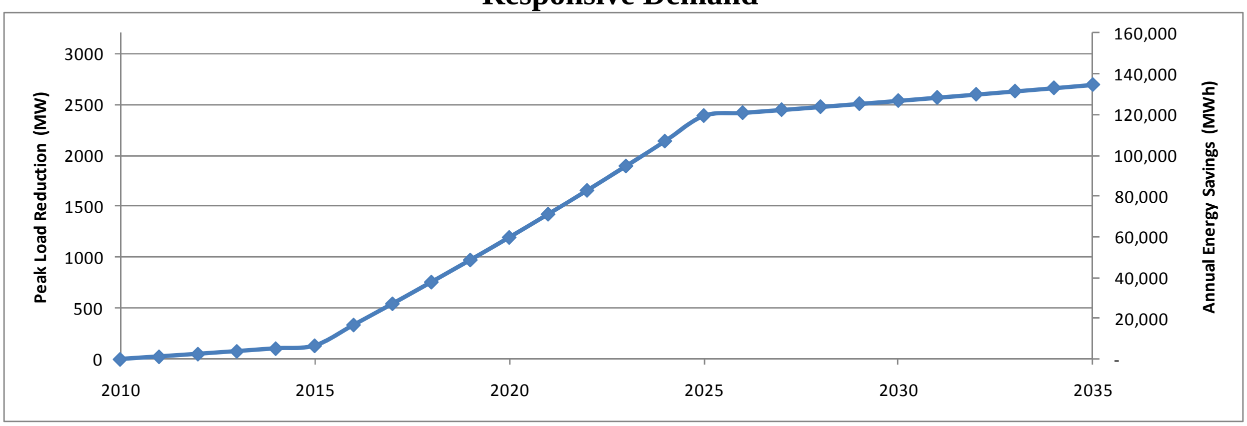
[8] O&M costs were also included for generation, transmission and distribution.

would render incentive schemes even more effective than if devices were not digitally controlled.

- **Increased Customer Appeal for Demand Response –** Digitally enabled appliances and systems could provide opportunities for utilities to enroll more customers in direct load control programs. Rather than only offering on/off control of air conditioners, for example. The utility could remotely increase thermostat settings by only a couple of degrees, an outcome that would be more acceptable to a broader base of customers than having their units shut off completely.
- **Direct Communication Pathway** – Digital displays and web interfaces will provide utilities a communication pathway into end-use customer sites. This communication pathway can be used for targeting customers with direct marketing, decreasing the cost of recruiting and communicating with EE & DR program participants.

Impacts. Smart Grid functions like pricing incentives, automated device optimization, increased customer appeal for demand response, and others are expected to lead to an increase in demand response capacity. This reduction would lower the peak demand for energy, allowing the least cost efficient plants to be taken offline and would lower energy prices for customers. Figure 6 shows the estimated increases in annual demand response capacity resulting from reduced consumption from the *regional assessment*.

Figure 6. Estimated Peak Load Reduction and Avoided Energy due to Dynamic and Responsive Demand[9]



Benefits. The impacts of increased demand response capacity will lead to economic value according to this formula:

*annual demand benefits = peak reduction capacity(%) * peak demand (MW) * avoided capacity costs ($/kW-yr) * discounting factor*
*annual fixed DR implementation cost benefits = total DR capacity (MW) * fixed cost of implementing DR ($/kW-yr) * cost reduction (%) * discounting factor*
*annual variable DR implementation cost benefits = total DR called (MWh) * cost of calling DR ($/MWh) * cost reduction (%) * discounting factor*

[9] The inflection in the year 2025 indicates the assumed end of Smart Grid deployment with an achievement of 80% technology penetration.

Avoided energy was valued as the forecasted wholesale price of electricity, \$32.97/MWh in 2010.[10] Avoided generation, transmission and distribution capacity was valued at \$153.85/kW-yr. The actual annual reduction in peak load was assumed to scale by the penetration fraction of smart grid technologies. Peak demand projections and cost assumptions were based on the NPCC's 6th Power Plan. (NPCC 2009) The fixed levelized cost of implementing DR was applied as \$50.20/kW-yr and the variable cost of calling DR was applied as \$150/MWh. The total benefit (2010 present value) estimated for increased demand response capacity for the region through 2035 is \$1.8B.

Conclusions

The future Smart Grid promises valuable benefits from increased energy efficiency and increased demand response capacity. An introductory economic assessment by Bonneville Power Administration and Summit Blue Consulting for Smart Grid deployment in the Pacific Northwest estimates the value of EE & DR benefits through 2035 to be \$4.5B for the region. To obtain these benefits, however, investments in Smart Grid *assets*—technologies applied to specific Smart Grid applications—must create value through well functioning benefit mechanisms to produce real impacts.

Benefit mechanisms for increased energy efficiency and conservation that have been examined here include:

- Increased consumption awareness – consumers viewing their energy consumption patterns leads to a conservation effect.
- Active energy diagnosis – where appliances communicating with utility or third party systems can be diagnosed remotely and proactively maintained to reduce excess energy consumption.

Benefit mechanisms for increased demand response capacity may include:

- Pricing incentives – smart devices and loads that can respond to dynamic or marginal cost pricing signals.
- Automated device optimization – central energy management systems automatically controlling end-use devices to best suit the preferences of the customer when balancing cost, comfort, and other variables.
- Increased customer appeal for demand response – new levels of flexibility making demand response programs more attractive to customers.

These mechanisms and possibly many others will allow investments in technologies, systems, and applications to produce both financial investment returns and societal benefits such as carbon emissions reduction.

The introductory economic assessment, which served as the basis of this report, will be revised and updated with lessons learned from the Pacific Northwest Smart Grid Demonstration Project and as additional information becomes available. The goal of this effort is to provide a useful tool to help inform utility executives as they make Smart Grid investment decisions.

[10] O&M costs were also included for generation, transmission and distribution.

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