Transition Plan - the Grid

CLEAN ENERGY VISION PROJECT

Modernizing the Grid: How Our Electric System Can Welcome New Resources, Improve Reliability and Reduce Costs

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Over the next several decades, we can expect most new homes and businesses to generate as much power as they consume. We can expect appliances and equipment to be much more energy efficient; much of our auto travel to be in electric vehicles; and most electricity to be produced by geothermal, solar, wind and other clean resources. We can expect investment in these new technologies to replace fossil fuel costs, risks and liabilities.

The electric system that integrates all these capabilities is likely to be much more intelligent, decentralized and flexible than grids are today. The technologies and markets to create an advanced energy economy — one more secure, healthful and prosperous — are already in place or rapidly emerging. The large capital investment required can drive innovation and regional economic development. And once that investment is paid down, we will be left with a lower cost, lower risk electric system.

In *Western Grid 2050: Contrasting Futures, Contrasting Fortunes* (2011), Western Grid Group compared Business As Usual electricity supply to clean energy development trajectories. Study findings document economic, security, health and environmental benefits of transition away from fossil fuels — the framework for a Clean Energy Vision for the American West.

This paper outlines ways we can modernize our electric system to support a clean energy future. It explains how grids organized around clean resources might operate and how they might be structured. It identifies key challenges to organizing electric service to deliver greater long-term social value for less cost. Notes and references at the end provide citations and background information to help explain and guide further investigation of key concepts.

But first, it summarizes a few straightforward changes that can add significant flexibility to the grid right now. These will improve reliability, reduce costs and allow large amounts of clean resources to be added.

1. Adding Flexibility to the Western Grid Today

Electric systems must continuously balance demand for and supply of electricity. Demand for electricity follows predictable daily and seasonal patterns but is inherently variable, as consumers turn equipment and appliances on and off, and as weather changes the need for heating and cooling. Meanwhile, electricity supply is uncertain. Thermal generators routinely fail to start, trip offline or stop operating unexpectedly, and produce less or more power than scheduled. Disruptions in fuel supply and fuel storage complicate generation performance. Fires, icing and tower collapses cause transmission line outages.

System operators manage these everyday uncertainties as statistical probabilities, using well-developed engineering practices and analytical tools. These same practices allow operators to manage the incremental variability and uncertainty that wind and solar power add to system operation today, in the relatively small amounts required by current state renewable energy standards. As variable resources provide larger amounts of power, systems will need more operational flexibility. Simple mechanisms can minimize the cost of providing it.

Most of our electricity is supplied by relatively inflexible generators — large coal, nuclear and combined-cycle gas generating plants. Operational flexibility needed to meet constantly changing load is provided mainly by gas-fired plants, along with hydroelectric generation in some regions. In most of the West, power is bought and sold in bi-lateral transactions, and markets that would enable power to be provided most efficiently do not exist. Grid operation doesn't take full advantage of readily available digital communications and energy management technologies. These factors make it much more expensive than necessary to add clean but variable resources like wind and solar.

Some states and some utility companies impose grid integration charges on wind generation, in an attempt to account for costs of adjusting system operation to accommodate the variability of wind (and solar) output. The reality, however, is that all generation sources require adjustment of system operation to integrate the characteristics and patterns of their output. The output of nuclear generators, for example, cannot vary. When these units were added to the grid in the 1960s-70s, system operation had to be restructured to ensure that local and regional grids could accept their unvarying output in all hours, planning and operating reserves had to be greatly increased and transmission system operation had to be redesigned to accommodate outages of these large plants. Much coal power is also sold as blocks of unvarying output. It is difficult and expensive for system operators to match such unvarying output to the constantly changing demand for power. But neither coal nor nuclear generators are charged for the integration costs they impose on regional grids. Discriminatory integration charges disadvantage wind and solar power and increase the cost of adding renewable energy to the grid.

Instead of imposing added costs on variable energy sources, a better approach is to reduce system operating costs for everyone. A few straightforward changes in industry practices and policy can increase grid flexibility, improve reliability, reduce costs to consumers, and accommodate larger amounts of clean power. These include:

- **Faster scheduling and dispatch** . Allowing generators to change the amount of power they provide to the grid every five minutes, instead of once every 30 minutes or once every hour (the current practice in most of the western US), enables energy markets to supply operational flexibility at lower cost than is possible with hourly dispatch.
- **Flexible generation.** Procurement of new generation should focus on providing capacity and system flexibility, not energy. Laws in most states require renewable energy to be added, and almost all regions of the West have ample existing gas generators that can be called on to produce energy when needed. As a result, there is little or no need to build more gas generation to supply energy. Instead, any new gas generation should increase flexibility — able to start fast, ramp quickly and operate efficiently across a broad range of conditions. Flexible renewable generators that can help meet system reliability needs should be compensated for such service.
- **Better weather forecasting.** Electricity use is driven in large part by weather. Better forecasting improves reliability, while inadequate anticipation of extreme temperatures has led to blackouts. Gas pipelines and compressors, thermal generators and electrical substation equipment sometimes fail to operate in freezing conditions; extreme high temperatures reduce gas generator output and stress system capabilities. More accurate forecasts allow operators to schedule and balance wind and solar generation in ways that save money. Revolutionary changes in forecasting now underway can supply vastly improved information to system operators.
- **Balancing Area consolidation.** Balancing Areas (BAs) match generation with load to keep system frequency stable and meet reliability requirements. Larger BAs give operators many resources to call on to keep electricity supply and demand in balance. In the West, system operation is siloed into 37 Balancing Areas, many of them very small. Consolidating them can improve reliability and reduce costs.
- **Energy Imbalance Market.** Actual demand for electricity in each hour is usually larger or smaller than forecast, and actual power generation is often less or more than scheduled. Creating a western regional market to supply these imbalances allows the most efficient generators to run more, the least efficient to run less or not at all, and makes much more efficient use of existing transmission.
- **Improved generation siting.** New software allows power buyers to choose wind and solar projects whose location-specific output matches their hourly power needs and complements the output of other system resources. This minimizes the challenges of adding variable renewables.

- **Greater use of demand resources.** Electricity used by customer-sited resources — motors, pumps, air conditioners, electric vehicles — can be temporarily reduced and restored to quickly respond to changing system conditions. In some parts of the country, these resources are already paid to provide both capacity and operational flexibility to the grid, at lower cost than generation.
- **Targeted energy efficiency savings.** Energy savings programs targeted to specific locations on the transmission system can counteract transmission congestion, in effect relieving constraints to help reduce regional power cost while avoiding new transmission construction. Geographically-targeted savings are an often overlooked source of system flexibility.
- **Added renewables.** The most effective way to reduce the aggregate variability of wind and solar generation is to install more of it. While the output of a single wind or solar project can be highly variable, the combined output of many such projects is orders of magnitude less variable. Further, wind and solar generation often complement each other, providing power across all hours. And facilities spread across larger geographies can take advantage of different weather patterns to the same end. Geothermal and biomass resources provide other options for meeting reliability needs with clean resources.

Together, these practices can improve the efficiency and reduce the cost of operating our existing grid. Balancing Area consolidation by itself could save consumers hundreds of millions of dollars per year — just in the western U.S. — by enabling system operators to draw on resources from wide regions and by eliminating the need for each utility system to carry its own operating reserves. By making grid operation more flexible, these practices also lay the groundwork for electric systems organized around non-fossil resources and advanced communications and control technologies.

2. 21st Century Electricity

The flexibility mechanisms outlined above can improve the reliability of our existing grid, and have potential to save consumers hundreds of millions of dollars each year in the process. But centralized fossil generation and long-distance transmission have inherent vulnerabilities and costs that limit the value existing grid structure and operations can deliver.

Opportunities to better align electric service with the needs of modern economies, customer preferences and environmental goals are too compelling to justify continued investment in 20th century patterns of reliance on centralized, inflexible fossil-based generation.

Goals for Electric Service

New technologies and power market fundamentals make it feasible to set new goals for electric service. Energy security and environmental imperatives make it urgent that we do so. There is ample basis for expecting 21st century grids to be:

- Lower cost. Fuel accounts for about 75% of electricity cost. International competition and supply fundamentals make it highly likely that these costs will rise. After investments in non-fossil technologies are paid back, clean electric systems can have lower operating costs than today — indefinitely.
- More secure, and less vulnerable to outages and attack, with less fuel supply and price risk, and fewer environmental liabilities. Modernized grids can be more reliable, as a result of decentralized operation revolving primarily around indigenous and inexhaustible resources instead of fossil fuels.
- More efficient. New technologies and maturing energy efficiency programs make it feasible to reduce wasted energy 40%-60% by 2050.
- Supplied primarily by non-fossil resources, with only small amounts of flexible and efficient gas-fired generation needed to maintain system balance.
- Sustainable. Grids built around energy efficiency and clean resources provide cleaner air, reduced water use, reduced carbon emissions, and as a result help mitigate ecosystem degradation. We no longer have to be resigned to living with the enormous health and environmental impacts fossil-based systems create.

Working toward new goals will change how the grid is structured and operated, and the ways utility companies are regulated. A sustained, orderly transition can be fair to investors in the existing grid while it expands markets across a broad range of dramatically more efficient products and services.

Characteristics of More Secure and Capable Grids

Grids capable of meeting these goals are defined by three key characteristics:

- They are decentralized into local networks built around two-way flows of both power and information;
- They make much greater use of information technologies to manage these flows; and
- They are organized primarily around non-fossil resources.

Our existing grid was designed for one-way flows of power, from central generators to consumers. Information about real time power usage is available only long after the fact, when utilities read consumers' meters. Even with smart meters there is limited communication from customer facilities back to the grid. Operators have relatively little information about system conditions at granular levels.

Rooftop photovoltaics and other new technologies are changing this, as power from customer locations flows back to the central grid. Two-way flows, of both power and information, are essential for taking advantage of both small-scale local generation and of Demand Resources (DR) on the customer's side of the meter. Two-way flows provide much more information about system conditions and electricity usage, and more options for both system operators and customers. This real-time information enables more efficient use of resources and allows local problems — transmission constraints, equipment failures — to be anticipated and resources dispatched to avoid outages.

Small-scale, clean distributed generation has potential to add many thousands of resource locations to the electric system. Although only a few pilot projects are in operation, considerable engineering has been done on conceptual system architectures for grouping local generators and loads into local networks. Digital communication and control technologies to manage these networks and their interaction with wide-area grids are already available. Standards are being developed to ensure cyber security and consumer privacy. Other key design considerations include making it easy for new products, services and suppliers to be added; and making it possible for customers to have as much control over their electric generation and consumption as they want. Standardized and simplified interconnection procedures and plug-and-play system designs support continuous improvements in efficiency, power quality, reliability, grid resilience and security.

Demand Resources are another core component of intelligent local supply. DR includes smart appliances and electric vehicles whose electricity use can be turned up, down or off to help keep both local networks and the wide area system balanced. They can respond to system control instructions faster than generators, and add great flexibility to the grid at low cost.

Developing local intelligent networks requires cooperation with utility distribution companies. There are technical, political, financial and regulatory issues to be resolved. Some distribution grids can accommodate only limited amounts of local generation flowing back onto the centrally-dispatched grid. Many neighborhood and substation transformers, for example, may not be able to withstand around-the-clock use that two-way flows of local generation and EV charging impose. Some distribution circuits may have to be upgraded or rebuilt. Both the costs and economic and social benefits of developing intelligent local networks have to be made clear. How investments in these systems are financed and how utility companies can earn reasonable returns on such investment must be defined.

Utility companies stand to lose revenue as distributed generation and more efficient homes and appliances make customers more energy self-reliant and displace operation of utility-owned generators. Hundreds of non-utility companies, fueled by venture capital investments, are eager to supply advanced electric services. These forces create huge opportunities for innovation. Utilities can adopt new business models to become providers of high-value electric services or integrators of clean resources rather than sellers of commodity kilowatt-hours. Regulators can devise incentives and adjust allowed returns on investment to support such a transition. City councils and local boards of directors can do the same to encourage publicly-owned utilities and electric cooperatives to meet new goals for 21st century electric service.

Large-Scale Renewable Energy and Transmission

Greater deployment of small-scale distributed generation outlines a trajectory for gradually decentralizing electricity production. Beyond 2050, it may be possible to have an appreciable amount of US electricity generated by small-scale, local systems. But for the next few decades, it appears physically and economically impossible to deploy small photovoltaic systems fast enough and on a large enough scale to make more than a small change in overall power mix. Even if western states achieve aggressive energy efficiency savings goals, the volume of power needed to meet state Renewable Energy Standards and replace retiring coal plants is simply so great that power from large-scale geothermal, solar, wind and biomass generating projects will be required.

Some in the West are skeptical of the impacts and potential costs of climate disruption. Moving to a clean energy economy does not depend on climate considerations — there are too many other compelling economic, security and environmental reasons to transition away from fossil fuels. Nevertheless, scores of western cities and some states are already implementing measures to mitigate or adapt to effects of a changing climate. There is also wide recognition that if increasing costs of damage from more violent weather and other climate disruptions are to be avoided, international carbon reduction goals will have to be met. These effectively require at least 80% of electricity — everywhere — to be generated by non-fossil resources by 2050. The technologies and resources required are already available. Supplying such an enormous volume of electricity will require continuous development of large-scale renewable energy generation.

The U.S. Department of Energy's Renewable Electricity Futures Study (June 2012) shows that renewable electricity generation from technologies that are commercially available today is more than adequate to reliably supply 80% of U.S. electricity by 2050. The abundance and diversity of renewable resources makes this feasible across a broad range of conditions and uncertainties. If environmental, health and emissions costs and liabilities are neglected and fuel costs stay in forecasted ranges, the total cost of an 80% renewable energy future may be modestly more expensive than Business as Usual development. The small cost premium for an 80% renewable energy future may be able to be reduced by expected improvements in the efficiencies of renewable generating technologies.

The two major requirements for achieving such a future — in addition to political will — are increased electric system flexibility and new transmission facilities to make renewable electricity generation available to customers in every part of the country. Regardless of any specific goal, developing renewable energy on a scale large enough to change US generation mix will require substantial investment in expanding and modernizing the U.S. transmission grid.

This investment can be good for consumers. Here's why: The marginal cost of geothermal, solar and wind power is very low or zero. Access to such power reduces consumer costs both directly and indirectly, by putting downward pressure on regional wholesale power prices. This runs counter to the interests of utilities and other generators who benefit from higher wholesale prices. The main opposition to new transmission construction, in fact, comes from those utilities whose more expensive generation would be displaced if there were access to lower cost power. Even though the cost of individual large-scale transmission projects can range up to $1 billion, the added cost of new transmission paid by individual consumers is usually very small, a fraction of one cent per kilowatt-hour. For individual consumers as well as for society as a whole, the benefits of access to lower cost power are much larger than the costs of the transmission necessary to deliver that power.

Transmission cost, on average, makes up only about 7% of customers' bills. From an economic development perspective, this means that relatively small investments in transmission leverage much larger investments in lower cost generation: a $1 billion transmission project can support $15 billion-$20 billion of investment in wind, solar or geothermal projects. Such large investments stimulate and sustain local and regional economies, and lay foundations for an electric system that has much lower operating costs than ours today.

Expanding our transmission system provides social and environmental benefits as well as electrical and economic ones. Like the internet, air travel and the interstate highway system, added transmission increases the connectivity that allows our interdependent economy to prosper. It supports greater reliance on indigenous and inexhaustible renewable resources, to make energy supply more secure. U.S. military strategy of making every military base energy self-reliant, for example, revolves around the energy security advantages of renewables. And greater utilization of renewables is the only way we can reduce the enormous, accumulating and pervasive effects on our health and ecosystems created by producing, transporting and burning fossil fuels — coal mining, gas drilling, pipeline explosions and leaks, toxic emissions.

Connectivity, security and public health benefits of renewables and transmission accrue not just to individual utility companies that may join together to build new transmission facilities, but to broad regions and the country as a whole. Federal Energy Regulatory Commission (FERC) rules now allow states and utilities to identify regional and inter-regional benefits of new transmission.

These benefits include improved reliability. Added transmission connections make the grid more resilient and provide operators with more flexibility to avoid outages. And replacing large thermal plants with large aggregations of wind and solar projects can itself improve overall system reliability. The aggregate output of geographically-dispersed geothermal, solar, wind and biomass generation can reliably supply a large percentage of the power needed by western states in all or most hours of the year. With power production spread across hundreds of small machines, the grid is not as vulnerable to the large, instantaneous outages that thermal power plants create when they trip off line.

Large-scale renewables also remove fuel supply and price risks from consumers and mitigate the many environmental liabilities of obtaining and burning fossil fuels. However, they bring other environmental impacts and challenges, including habitat fragmentation, and negative impacts on flora, fauna and viewsheds. Associated transmission facilities add to the impacts of wind and solar project siting. To minimize both environmental impacts and the amount and thus the cost of transmission required, wind and solar development can be focused into small geographic zones. Zones can be defined to include high quality resources and to minimize environmental and social conflicts. Efforts to identify appropriate zones are underway across the West.

Building System Operation Around New Resources

The grid today evolved to accommodate the characteristics of relatively inflexible thermal generators. From this perspective, accommodating the different characteristics of new resources — distributed generation, demand resources, energy efficiency programs, large-scale wind and solar projects–looks difficult and expensive. Current practices limit deployment of these resources and the benefits they can deliver. Faced with having to integrate large amounts of variable resources, utilities and regulators familiar with fossil-based systems first look to add gas generation to keep the system balanced.

A lower cost and higher reliability approach is to build system operation around non-fossil technologies capable of providing more efficient, responsive and lower cost service. Engineering practices that have been used for decades to manage the grid can be applied to new technologies to guide this development.

Smart buildings and appliances, electric vehicles and other new resources can be controlled to provide large amounts of operational flexibility to the grid. Interaction between intelligent networks that manage local generation, storage and consumption can provide additional flexibility. Geographically-dispersed wind and solar power can be operated to contribute to system balancing, minute-by-minute and hour-by-hour, taking advantage of the spatial and temporal diversity in wind and solar output across large regions. Output from large solar thermal generating plants can be stored in molten salt to provide solar power across more hours of the day. Output from wind plants can always be turned down or off; new technologies allow wind output to be increased under system dispatchers' control, and to supply inertia, reactive power and regulation services. Utilities like Xcel already manage wind plants using Automated Generation Control, the same system they use to control fossil power plant operation.

Digital communication and control technologies make it possible to coordinate the operation of these resources to ensure system reliability while also minimizing the amount of gas generation required. Grids will require flexible gas generation, to fill in around variable and non-fossil resources. In addition, gas-fired Combined Heat and Power plants may provide the most efficient, least-impact ways to power dense urban areas. Some of the needed gas may be able to be supplied by biogas, to reduce carbon impacts. Beyond 2050, and with new technologies, it may be possible to further reduce the amount of gas generation in electric portfolios.

3. Guiding Grid Evolution

Three opportunities outline a path for migrating our existing electrical system toward greater reliance on clean resources and advanced communication and control technologies:

- Basing system operation around capability resources instead of capacity resources;
- Supplying intelligent services rather than bulk power; and
- Organizing generation and consumption into local intelligent networks to the greatest extent possible.

These new approaches are likely to take years to put into practice, because they require changing the ways utilities are regulated and make money. Challenges include evolving regulatory structures that take obsolete assets off the books and that give utilities new incentives to deliver continuous improvement in system efficiency, reliability and cost savings. If decision-makers begin to address these opportunities now, the framework for more secure and capable electric service may be able to be in place by 2030.

From Capacity Resources To Capability Resources

Electric systems today are built around mostly fossil-fueled capacity resources. This paradigm is increasingly at odds with efficient new technologies and lower demand growth. It carries high levels of vulnerability, liability, costs and risks.

Transition to greater reliance on clean resources changes the focus of system needs from generator capacity to electrical capabilities. Systems can now be planned to take advantage of diverse portfolios of demand and supply technologies — capability resources — better able to supply all the electrical characteristics needed to provide more secure, higher quality power.

Limits of the Focus on Capacity Resources

Electric systems need three kinds of resources: capacity, energy, and ancillary electrical services. Capacity resources have the ability to generate electricity whenever needed. This ability makes them valuable even if they operate very little or not at all. The value of energy resources, by contrast, is tied to how much they operate. Many generators can also be operated to increase or decrease their output quickly, and to provide ancillary services that support power flow and help keep frequency and voltage stable.

Large, centralized fossil, nuclear and hydro plants are the dominant capacity resources. Planning system operation around them — current practice today — keeps baseload units operating most or all hours of the week; dispatches intermediate units as demand increases each day; and then dispatches peaking units when demand can no longer be met with baseload and intermediate units running at their full output. This operating regime cannot easily accommodate energy efficiency, demand resources, distributed generation or variable renewables.

Building electric systems around capacity resources served us well as we electrified the country. Large fossil, hydro and nuclear plants (and transmission projects to access them), while expensive, offered economies of scale. Assumptions that electricity use would increase rapidly and indefinitely made centralized generators look like good investments. Still today, both system planning and engineering practice continue to assume that traditional fossil-fired capacity resources will be operated to provide most of our electricity. It is an assumption that blocks efforts to take advantage of new, more efficient resources.

Variable renewables are incompatible with baseload resources and capacity-centric system dispatch. Adding renewable energy to the grid reduces the amount of energy that must be supplied by fossil generators. This residual quantity, called net load, is the total demand for electricity minus the power supplied by wind and solar generation. System operation has traditionally been geared to follow daily and seasonal patterns of consumer demand. As variable wind and solar power is added, the net amount of power to be supplied by traditional resources becomes less predictable. Baseload and some intermediate generators are poorly equipped to follow new patterns of net demand. Already on some utility systems today, lower net loads drive baseload units off the system, or into intermediate duty, where their limited mobility raises system costs compared to more efficient ways of providing operational flexibility.

With no fuel expense, the operating cost of wind and solar generation is very low or zero. The least-cost approach is to utilize as much of the power they produce as possible, before turning to resources that have much higher production costs. But inability to turn baseload generators off or to reduce their output by more than relatively small amounts is already causing wind power to be curtailed in some regions, especially during low-load hours. In these situations, higher cost, inflexible generation prevents lower cost, emission-free generation from being used. This raises costs for all consumers in the region.

System capabilities are also defined by emissions. Emissions are a function of energy — pounds of pollution per megawatt-hour of electricity generated. As a result, concerns about emissions focus system planning and operations on energy rather than capacity. Traditional capacity resources, because they are expensive to build, are generally designed to operate as many hours as possible to provide energy. In the case of coal plants, the emissions associated with this energy are carbon-intensive. Meanwhile, grids are evolving to include diverse sources of low-carbon energy, and lower cost sources of capacity. The combination of limited operational flexibility, carbon intensity and expensive capacity appears to leave little place for new baseload plants. And it raises immediate questions about whether retrofitting old coal plants makes economic sense for investors or for utility customers.

More fundamentally, continued reliance on fossil resources increases vulnerabilities, costs and risks of electricity generation rather than reducing them. This paradigm is increasingly out of sync with current realities and opportunities for the future.

Today, demand growth is low — and energy efficiency programs and utilization of demand resources have potential to reduce it significantly. New options enable customers both to produce electricity and to manage their consumption. Non-fossil technologies are available to provide capacity and the electrical attributes needed to ensure reliable power in all hours.

And the energy needed by homes and businesses can be supplied by renewables and other clean technologies — at lower costs than new fossil or nuclear generators, even with very low gas prices, and with no or much lower emissions. Wind turbines and solar panels take advantage of the significant economies of modular, factory-built manufacturing. They can be deployed much more quickly than thermal generators. As a result, they can be added in increments in response to local and regional power needs, thus greatly reducing the risk that new generation won't be fully utilized. They can be sited to decentralize power production, to reduce system vulnerabilities. There are strong economic and strategic arguments against building fossil-fueled capacity resources to supply system energy.

To summarize: environmental and financial constraints, clean variable generation, fast-response customer resources and new communications and control technologies make the capacity resources paradigm itself obsolete. Basing system operation around large blocks of inflexible power limits utilization of our most cost effective resource, energy efficiency. It limits grid flexibility. It restricts ability to add clean variable power and frustrates efforts to diversify and modernize electric service.

Capability Resources: Framework for 21st Century Electricity

To take advantage of today's opportunities, a more practical approach dispatches the diverse range of new supply and demand-side resources to take advantage of their unique reliability, flexibility, environmental and cost characteristics as well as their electrical capabilities.

A capability-resource paradigm allows procurement to focus on achieving system performance goals. These may include, for example, saving energy, reducing the costs of electric services, deploying more distributed generation, reducing emissions and water use, improving power quality, engaging customers, and ensuring reliable service across a range of contingencies. With goals for reducing emissions, system operation might seek to utilize low-carbon resources first, to provide as much energy, capacity and system balancing services as possible, and deploy gas-fired generation and other resources to fill in around the preferred clean resources to meet cost and reliability requirements.

Grids continue to need capacity, energy and operational flexibility to ensure voltage and frequency stability in all hours at all locations. If the constraints of basing system operation around baseload capacity resources are removed, these attributes can be supplied at lower cost from the more diverse range of non-fossil technologies and flexible gas generation now available. Automated energy management systems and modern communications technologies enable portfolios of these resources to be operated to provide highly reliable and high quality electricity. Resource portfolios having such diverse capabilities give system operators great latitude for meeting hourly system needs at least cost.

From Bulk Power to Intelligent Services

Electrifying the U.S. required large amounts of power, and most utility business models still revolve around selling electricity in volume. Wholesale power, meanwhile, has become a relatively low value commodity. In an economy based increasingly around advanced information technologies, there are many opportunities for electricity suppliers to provide intelligent services rather than, or in addition to bulk power.

The centralized structure and limited flexibility of the grid today, however, frustrates the ability to provide customers with value-added services. Non-utility suppliers of intelligent networks, energy management systems, smart appliances and low-carbon generation now compete to supply customers with advanced services. This competition may influence utility grids to modernize and develop capabilities to deliver power having specific attributes — high power quality, low emissions, greater control over usage, ease of adding third-party energy services — increasingly required by customers.

Linking Local Intelligent Networks

Reasonable system performance goals include continuous improvement in efficiency, power quality and customer control, and continuous reduction of risks, liabilities, operating costs, emissions and environmental impacts. Centralized grids appear to have limited ability to achieve such goals. They have limited flexibility and frustrate introduction of value-added services, more efficient technologies and new suppliers.

Decentralized networks are now being designed to achieve such goals. These networks include local clean generation, storage, demand resources and the communications and control systems to manage local supply and demand and interact with other local networks and wide area grids. The US Department of Defense provides one example. Its energy security strategy includes making military bases energy independent, so they can function even if cyber attacks disable the interconnected grid. This goal, which revolves around energy efficiency and renewable energy, suggests a new form of service in which grid power can be combined with stand-alone local networks to supply reliable power in all conditions. We may be able to look to DOD to stimulate the investment, technology and markets that will help define how intelligent local grids interact with today's wide area grids.

As decentralized grids play larger roles in providing electric service, wide area grids can evolve to coordinate interaction of local networks and integrate large-scale renewable generation, flexible gas generation and system-scale storage.

4. Summary

Today and over the next several years, a few straightforward changes can add significant flexibility to the existing grid. These require little more than widespread adoption of the best system engineering practices now being pioneered by industry leaders. Adding flexibility will reduce the cost of integrating clean resources and support development of efficient new technologies.

Incremental improvements in grid flexibility today can help lay the groundwork for decentralizing system operations into intelligent networks built around two-way power and information flows and advanced communications and control technologies. Networks can be designed to have the operational capabilities necessary to take full advantage of localized energy efficiency savings and customer-sited generation and demand resources. Central grid coordination can integrate local intelligent networks together with large-scale renewable generation and flexible gas generation needed to ensure reliable service in all hours and at all locations.

Orderly transition will require large investments in distribution networks and clean resources. A new generation of power system engineers and operators must be trained. Utility business models and the public interest regulation of utilities must be adjusted to encourage necessary investments to be made. Much of this investment may be made by the many non-utility companies wanting to compete to provide electric services. As this investment is paid back and fossil fuel use is minimized, vigilant private sector management and far-sighted public officials can ensure that communities and the country are left with higher quality, more secure and lower cost electric service.

Notes and References

Introduction, p. 1.

Over the next 20 years, western states will invest more than $200 billion to maintain and enhance the electricity system. *Western Grid 2050: Contrasting Futures, Contrasting Fortunes* challenges decision-makers to invest that money in ways that support orderly transition to a clean energy economy. The report was prepared by Carl Linvill, John Candelaria and Ashley Spalding of Aspen Environmental Group and published by Western Grid Group in August 2011. It is available at: www.westerngrid.net. A video with former Colorado governor Bill Ritter introducing the report and media stories about the report and other materials are available at: www.cleanenergyvision.org.

The Clean Energy Vision Project for the western U.S. is a joint effort of Western Grid Group and the Western Clean Energy Advocates coalition. Western Grid 2050 and Goals for Clean Energy Grids are the first of several Clean Energy Vision Project documents. Transition to Clean Energy: Policy and Investment Decisions for Western States and supporting materials will be released in 2012.

1. Adding Flexibility to the Western Grid Today, pp. 1-3.

Costs of Integrating Renewables: A study sponsored by the Western Governor's Association, "Meeting Renewable Energy Targets in the West At Least Cost: The Integration Challenge" (June 2012) explains nine approaches states and utilities can implement to reduce costs of adding variable renewables. Several of these are the same mechanisms briefly summarized here in "Goals for Clean Energy Grids." The WGA study is available at: www.westgov.org.

Two papers from the National Renewable Energy Laboratory (NREL) provide helpful background and analysis: Milligan, M.; Hodge, B.; Kirby, B.; Clark, C. "Integration Costs: Are They Unique to Wind and Solar Energy?" 12 pp.; NREL Report No. CP-5500-54905 (2012); and Milligan, M.; Ela, E.; Hodge, B.; Kirby, B.; Lew, D.; Clark, C.; DeCesaro, J.; and Lynn, K., "Cost Causation And Integration Cost Analysis for Variable Generation." NREL/TP-5500-51860 June 2011. This paper explains how the complex interactions of electricity put on and taken off the grid in every moment make it effectively impossible to attribute added costs of keeping the system balanced to any specific generator or type of generators.

Faster Scheduling. On June 20, 2012, the Federal Energy Regulatory Commission (FERC) issued a rule on treatment of Variable Energy Resources. This rule requires transmission service providers to offer 15-minute scheduling to transmission customers, including wind and solar power generating companies. It does not, however, require generators to be dispatched at 15-minute intervals. More rapid generator dispatch increases system flexibility and makes wind and solar power easier to fit into grid operations. Regional Transmission Organizations (RTOs) that supply power to much of the country all operate their grids using

5-minute scheduling and dispatch. The wind and solar industries and clean energy advocates had requested FERC to establish 5-minute scheduling and dispatch as national standards. The cost savings of faster scheduling are well established.

Flexible Generation. Background on the amount of gas-fired generating capacity in in the western US, its low rate of utilization and the increasing need for more flexible capacity is found in the agenda materials for the October 26-27, 2011 meeting of the Committee on Regional Electric Power Cooperation, available at: http://www.westgov.org/wieb/meetings/crepcfall2011/10-11agen.htm. See, e.g., Dave Olsen, "Changing Role of Gas Generation in WECC;" and "Best Utilization of the Gas Fleet Under an EIM."

Better Weather Forecasting. FERC's Variable Energy Resources rule, Order 764 (June 20, 2012) requires wind and solar generators to supply project meteorological and forced outage data to transmission providers. It does not, however, require transmission providers to utilize this data. That task remains for state Public Utility Commissions, since better forecasting can improve reliability and reduce costs. NREL's Western Wind and Solar Integration Study found that State of the Art wind and solar forecasts would reduce WECC production costs by $5 billion per year.

Energy Imbalance Market (EIM). A brief description of the purpose and operation of such a market, "What Is An Energy Imbalance Market," is available at: www.westerngrid.net. "Why An Energy Imbalance Market Will Make the Western Interconnection More Reliable," a paper by WECC board member John Stout, is also available at that site. Detailed exploration of a western EIM is being organized (2012) by commissioners from all western state Public Utility Commissions, in cooperation with the Western Interstate Energy Board of the Western Governors' Association. Information about proposed market design, benefits and costs is available from this PUC-EIM Group at: www.westgov.org/PUCeim/index.htm. A National Renewable Energy Laboratory (NREL) paper discussing reduction in flexibility reserves (and associated cost savings) attributable to an Energy Imbalance Market by is available at: http://www.nrel.gov/docs/fy12osti/54660.pdf. The first phase of NREL's more comprehensive study of EIM benefits and costs, "NREL/Plexos Analysis of the Proposed EIM in the Western Interconnection: Results" (May 10, 2012) is available at: www.nrel.gov. A second phase study will identify costs and benefits to specific Balancing Areas in the West.

Improved Generation Siting. The National Renewable Energy Laboratory (NREL) has developed a Renewable Energy Load Matching (RELM) model to enable utilities to match the output of wind and solar generating projects to the specific daily and hourly demand for electricity they must supply. The model is described in an NREL presentation by model authors Walter Short and Victor Diakov, "Renewable Energy Load Matching for the Western U.S.," November 29, 2011. Northrop Grumman and LS Power Corporation have independently developed other models that enable siting of wind and solar projects to be optimized to produce a variety of economic and environmental benefits.

Demand Resources. FERC Order 745 requires Regional Transmission Organizations (RTOs) to compensate demand response resources for the service they provide at the market price for energy when the demand response resource has the capability to cost-effectively balance supply and demand as an alternative to a generation resource. Order 745-A (December 2011) reiterated the value of DR as a system resource and reaffirmed that compensating it at the same rate as generation would help reduce barriers to its wider development.

Targeted Energy Efficiency Savings. See for example, Chris Neme and Rich Sedano, "US Experience with Efficiency As a Transmission and Distribution System Resource," Regulatory Assistance Project, February 2012. It is available at: www.raponline.org.

2. 21st Century Electricity

Goals for Electric Service, p. 4.

Need for a 21st Century Grid. Costs and risks of the U.S. electric system today are summarized in, Jay Stuller, An Electric Revolution: Reforming Monopolies, Reinventing the Grid and Giving Power to the People, Galvin Electricity Initiative (2011). These include brownouts and power spikes estimated to cost the economy $150 billion a year; up to 90% of the thermal energy used to generate electricity being wasted; and more than a trillion dollars lost to the U.S. through businesses moving to nations having higher quality power. Electricity produces more pollution than any other single industry, and more carbon dioxide than the entire transportation sector.

Efficiency. See for example the January 2012 report by the American Council on an Energy Efficient Economy (ACEEE), "The Long-Term Energy Efficiency Potential: What the Evidence Suggests." This study shows how energy use can be reduced 40% to 60% by 2050 through highly cost-effective efficiency investments. Programs to save that amount of energy could generate up to 2 million jobs while saving all residential and business consumers a net $400 billion per year, or the equivalent of about $2,600 per household annually.

Characteristics of More Secure and Capable Grids, pp. 5-6.

New Utility Business Models. In his 2010 book, Smart Power: Climate Change, the Smart Grid and the Future of Electric Utilities, Peter Fox-Penner proposes two new business models that could enable utilities to take advantage of energy efficiency savings, demand resources, other new technologies and decentralized generation. As a "Smart Integrator," utilities could operate a regulated smart grid offering independent power and other services at regulated prices. Or, if they adopt an Energy Services Utility model, utilities would change from a pipes-and-wires business to a customer service-centric business emphasizing energy efficiency savings. State Public Utility Commissions would have to change the ways they regulate utilities to support such changes in the ways utilities earn money. Commissioners may have reason to do so. Fox-Penner provides data suggesting that selling energy services instead of kilowatt-hours could relieve upward pressures on utility costs.

Large-Scale Renewable Energy and Transmission, p. 6-8.

Deployment of Distributed Generation: Kevin Sweeney's annotated slide presentation, "Acres & Watts: Considering Scales of Change" (April 2011) graphically illustrates the challenge of deploying rooftop photovoltaics on a scale sufficient to make any appreciable change in U.S. power mix. It is available at: www.climateofhope.net/Climate_of_Hope/Acres_&_Watts.

80% Renewables, U.S.: The U.S. Department of Energy's Renewable Energy Futures Study is available at: http://www.nrel.gov/analysis/re_futures/. The three-year study involved collaboration among more than 110 contributors from 35 organizations including national laboratories, industry, universities, and non-governmental organizations.

80% Renewables, California: California law (AB 32, Statutes of 2006), requires the state to reduce its greenhouse gas emissions 80% below 1990 levels by 2050. To this end, a federal-state collaborative called the Desert Renewable Energy Conservation Plan (DRECP) is planning for an 80% renewable future by 2050 in California. Its intent is to site large solar, wind and geothermal generating projects in ways that minimize ecosystem impacts, including those of the transmission needed to access and deliver the large quantities of renewable energy.

Renewables Drive Electricity Costs and Prices Down: NREL's Western Wind and Solar Integration Study (May 2010) investigated effects of having 30% wind and 5% solar in the generation mix of a six-state area of the West. Adding that amount of wind and solar was found to reduce operating costs for the entire WECC region by $20 billion per year. The report is available at: www.nrel.gov/wind/systemsintegration/pdfs/2010/wwsis_final_report.pdf; see Section 6.2.

A study by Synapse Energy Economics, "The Potential Rate Effects of Wind Energy and Transmission in the Midwest ISO Region" (May 22, 2012) explains how low marginal cost renewables reduce wholesale electricity prices. The study found that adding wind power can save Midwestern consumers $3 billion — $9.5 billion annually by 2020. New transmission to access and deliver the wind power would increase retail electric rates by 0.1 to 0.5 cents per kWh, but that small increase would be dramatically offset by driving wholesale power prices down between $3 and $10 per MWh by 2020 and by $50/MWh (5¢/kWh) by 2030. The study, however, does not address the facts that many utilities pay fixed prices for wind power that are not affected by wholesale market prices, and that utility customers pay utilities to recover those fixed costs. On some utility systems, this may reduce the economic benefits of adding wind power. The study and additional information is available at www.cleanenergytransmission.org.

Energy Security: General Martin Dempsey, Chairman of the Joint Chiefs of Staff, told a Pentagon Energy Security Forum (October 2011) that: "The Army is answering and leading the call to the nation to face one of the great challenges of our time: confronting our dependence on foreign oil, addressing the moral, economic and environmental challenge of global climate change, and building a clean energy future that benefits all Americans." Gen. Dempsey's speech is at: http://www.jcs.mil/speech.aspx?id=1656.

Military Energy Goals: According to the U.S. Army Energy Initiatives Task Force, "Energy security is operationally necessary, financially prudent, and mission critical." The mission of the Task Force is, "Securing Army installations with energy that is clean, reliable and affordable." The goals that drive the Army's Energy Security Implementation Strategy include reducing energy consumption; increasing energy efficiency; reducing use of fossil fuels; relying on renewable energy; and reducing adverse impacts on the environment — all to make bases net-zero installations, that use only as much energy as they produce. See www.armyeio.com/

FERC Order 1000 (2011) requires public utility transmission providers to work together to develop regional and inter-regional transmission plans, and to take public policy requirements into account in those plans. It directs that the costs of projects proposed in those plans be allocated in line with project benefits, and allows utilities and states significant latitude to identify benefits broadly. These reforms support efforts of states and other non-utility stakeholders to plan transmission to meet public interest goals in addition to electrical ones. See Order 1000, Docket No. RM10-23-000 at: http://elibrary.FERC.gov.

Minimizing New Transmission: The amount of transmission needed to access and deliver large-scale renewables can be minimized by first utilizing existing infrastructure efficiently. Outside of the California Independent System Operator area, most power in the West is sold in bilateral transactions, details and timing of which are not known to other users of the grid. This makes it difficult to schedule power flows efficiently and in fact, many major western transmission paths have large amounts of capacity available for many hours of the year. Implementation of an Energy Imbalance Market would greatly improve transmission system utilization.

Renewable Energy Zones: Six western states have identified development areas intended to minimize both environmental conflicts and new transmission. The Western Renewable Energy Zone (WREZ) initiative of the Western Governor's Association is working to identify priority development areas across the entire West. The Environmental Data Task Force formed by the Western Electricity Coordinating Council is developing habitat and species information necessary to improve identification of development zones. For Arizona's

Restoration Design Energy Project: The Bureau of Land Management-Arizona is preparing an environmental impact statement to identify lands suitable for renewable energy development while also establishing baseline environmental protection measures for such projects. In California, a joint federal-state effort, the Desert Renewable Energy Conservation Plan (DRECP) is identifying zones based on Natural Community Conservation Planning (NCCP) requirements. Projects sited in such zones will be afforded expedited permitting. All these efforts require collaboration among diverse interests. Structure and operation of one successful Renewable Energy Zone initiative is described in David Olsen et. al., "Collaborative Transmission Planning: California's Renewable Energy Transmission Initiative," IEEE Transactions on Sustainable Energy, 2012; available at: ieeexplore.ieee.org.

Building System Operation Around New Resources, pp. 8-9.

Solar Thermal Storage: Concentrating Solar Power (CSP) with thermal storage increases the amount of total solar generation that can be utilized by utility systems. See Paul Denholm and Mark Mehos, "Boosting CSP Production with Thermal Energy Storage," Power, Vol. 156, No. 6, June 2012, pp.46-50.

Variable Renewables As System Resources: In addition to using Automated Generation Control to dispatch wind turbines, improvements in forecasting now enable utilities like Public Service Company of Colorado to turn off coal plants when system operators expect sustained wind output: https://www2.ucar.edu/atmosnews/impacts/bringing-wind-to-the-grid. Modern wind turbines provide a range of electric system services. See, e.g., Cardinal, M.E; N.W. Miller, "Grid Friendly Wind Plant Controls: WindCONTROL — Field Test Results," in Proceedings of the American Wind Energy Association WindPower Conference 2006, Pittsburgh, PA.

Combined Heat and Power. Denmark, for example, is retrofitting its Combined Heat and Power plants with electric boilers to provide storage and flexibility, and CHP plants there are responding to flexibility signals in power and regulation markets.

100% Renewable Electricity: PriceWaterhouseCoopers joined with the International Institute for Applied Systems Analysis and the European Climate Forum to compile a comprehensive study of the feasibility, cost and pre-requisites of such a future in its report, "100% Renewable Electricity: A Roadmap for Europe and North Africa" (2010). It is available at: www.pwc.com/climateready and www.supersmartgrid.net.

In Reinventing Fire: Bold Business Solutions for the New Energy Era, Amory Lovins and the Rocky Mountain Institute present scenarios showing the kinds of technological developments that could enable non-thermal technologies to provide more than 80% of US — and world — electricity needs, beyond 2050.

3. Guiding Grid Evolution

From Capacity Resources to Capability Resources, pp. 9-12.

Capacity and Energy. Electric systems need both capacity resources and energy resources. Capacity resources have the ability to provide power whenever needed. This capability is measured in kilowatts (kW) or megawatts (MW). Electrical energy runs our lights, appliances and equipment; it is measured in kilowatt-hours (kWh) or megawatt-hours (MWh). Fossil, nuclear, geothermal and those hydroelectric plants that can store water provide system capacity approximately equal to the nameplate rating of their generators. When they operate, they also supply energy. Wind and solar power provide more energy than capacity. The weather-driven capacity they provide is location-specific and may vary by season. Energy efficiency savings and Demand Resources can provide both capacity and energy.

Baseload, Intermediate and Peaking Units: the Capacity Resources Paradigm. Current operating practice sorts generating resources into three categories: baseload resources, which supply power 24/7; intermediate resources, which supply power for several hours each day; and peaking units, which supply power for short periods and when needed on a fast-start basis. Coal, nuclear, geothermal and some large hydro plants are baseload resources. They generally supply the lowest-cost power but have little or no operational flexibility and have limited ability to be dispatched down or off at night or on weekends. Older, smaller coal plants are commonly used in intermediate service, because their place in the baseload order has been taken by newer, larger coal plants. These plants become even less efficient when required to ramp up and down. Gas-fired combined-cycle plants have more operational flexibility and can be turned down or off nights and weekends. Peaking units include some hydroelectric generators, and gas-fired combustion turbines which can be started quickly and can ramp up and down to meet minute-by-minute changes in demand. Because they are operated only for short periods, their power is the most expensive in the supply stack

Net Load: Wind and Solar Displace Capacity Resources. The graphs below, from NREL's Western Wind and Solar Integration Study (2010), illustrate that traditional generators run less when wind and solar power is added. They show 30% wind (green) and solar (red and orange) being added to the generation mix of a six-state area of the West during one week of July (top) and one week of April (bottom). The blue line is net load. This is total demand for electricity minus power produced by solar and wind.

In the July week, there is much more demand for power than in April and the system can easily accommodate the added wind and solar. In the April week, the added renewables displace all or almost all baseload generation on several days. Inflexible baseload generators make it challenging to manage the system in such conditions.

Inflexible Capacity Resources: A paper by Meg Gottstein and Simon Skillings of the Regulatory Assistance Project, "Beyond Capacity Markets: Delivering Capability Resources to Europe's Decarbonised Power System," provides a succinct explanation of how zero marginal cost renewables change the dynamics on the grid, and why "…inflexible generation increasingly constitutes a threat to resource adequacy." It was written to explain that, using data from NREL's Western Wind and Solar Integration Study, the UK's proposed capacity market is unlikely to deliver the flexible resources needed today. The paper, to be published by IEEE (May 2012) is available at: www.raponline.org/document/download/id/4854

A complementary slide presentation (Gottstein/RAP, May 10, 2012) explains why paying capacity that is inflexible or not flexible enough increasingly threatens system reliability, imposes larger costs on consumers and creates pressures to curtail or restrict use of renewables: www.raponline.org/document/download/id/5006

Linking Local Intelligent Networks, p. 12.

Gridwise Alliance, "Realizing the Value of An Optimized Grid," (February 2012) provides a detailed overview of smart grid implementation and value proposition, along with case studies of deployment efforts. www.gridwise.org/ Alliance members include utilities, major IT companies, venture capital investors, universities and manufacturers around the world. It is an excellent source of information on the many dimensions of grid modernization. Its mission is: "To transform the electric grid to achieve a sustainable energy future."

The Electric Power Research Institute's IntelliGridSM initiative is working to create a technical foundation for a smart power grid that links electricity with communications and computer control to achieve large improvements in reliability, capacity, and customer services. IntelliGrid Architecture is an open-standards, requirements-based approach for integrating data networks and equipment that enables interoperability between products and systems. http://intelligrid.epri.com/.

The National Energy Technology Laboratory is developing US DOE's Smart Grid Implementation Strategy (previously the Modern Grid Initiative). Its mission is to "Accelerate Grid Modernization in the United States." Its Smart Grid vision has been widely accepted as a foundation for Smart Grid planning. Today, 140 DOE-supported Smart Grid projects are in various stages of implementation across the US. www.smartgrid.gov

Jay Stuller summarizes characteristics of intelligent grids in the Galvin Electricity Initiative publication, An Electric Revolution: Reforming Monopolies, Reinventing the Grid and Giving Power to the People (2011), pp. 10-11. Chapter 4, "Microgrids: Where Technology and Consumers Connect," describes architecture and capabilities of intelligent local networks. Chapter 8, "Grains of Sand," summarizes intelligent grid demonstration projects and state policies that are supporting them.

Energy security, affordability, environmental and productivity benefits of decentralizing wide area grids into local intelligent networks are detailed in Perfect Power: How the Microgrid Revolution Will Unleash Cleaner, Greener, and More Abundant Energy. Robert Galvin and Kurt Yeager, McGraw-Hill, 2009.

The Pecan Street Project, a leading smart grid demonstration project, is a community-wide collaboration in Austin, Texas to fully reinvent the energy delivery system. It is being developed by local companies, NGOs and the University of Texas, with the strong support of Austin Energy, the city's municipal utility. To build support for new energy system goals throughout the city, Pecan Street offers courses in "Smart, Clean, Energy." www.pecanstreet.org/.