

NRDC WHITE PAPER

A Primer on the (Strong) Smart Grid and its Potential for Reducing GHG Emissions in China and the United States

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Introduction

In both China and the United States, the power sector is a dominant source of fossil-fuel combustion and greenhouse gas emissions.¹ Decarbonizing the power sector by both reducing the use of fossil fuels (particularly coal) and using them more efficiently, as well as integrating greater amounts of renewable, low-carbon energy sources like wind and solar, is an essential measure for reducing anthropogenic greenhouse gas emissions.

In order to do this, both countries will need to develop and build an updated electricity transmission infrastructure—a so-called *smart grid*—that can serve as a more sophisticated and intuitive framework for transmitting and using electricity more efficiently. But what exactly constitutes a smart grid, and what are the concrete mechanisms by which it would reduce greenhouse gas emissions (GHG)? The purpose of this document is to answer those questions.

It is important to note here, however, that the concept of *smart grid* in most of the world, including the United States, differs significantly from the term *strong, smart grid* (坚强智能电网) being promoted in China. In most of the world, *smart grid* refers only to the communications and information technologies that will enhance the use and delivery of electricity. In China, the emphasis on a *strong* grid reflects China's focus on developing and maintaining a stable power supply and includes its plans to build thousands of kilometers of *ultra-high voltage*² (UHV) transmission lines in the next 10 years to connect the coal, wind, hydro and solar-rich west with the high-demand east. Because the *strong* concept is an important part of China's plans, it is discussed in this paper along with the commonly accepted *smart grid* concepts. Regional integration of grids will reduce the impact of intermittent wind and solar resources, yielding more reliable generation, and will also match power supply with power demand.

As a primer on the concept of a *strong, smart grid*, this paper will explain the possible carbon reduction mechanisms that are enabled or enhanced by *strong, smart grid* technologies:

- Section I begins by defining the essential elements of a smart grid.
- Section II reviews and explains the carbon reduction mechanisms covered in two important reports published by the United States Electric Power Research Institute (EPRI) and State Grid Corporation of China (SGCC)—the larger of China's two main grid companies—that provide estimates of the GHG emissions enabled by smart grid in the United States and China, respectively.
- Section III discusses how a smart grid can help overcome challenges with integrating greater amounts of wind power into the electricity system, one of the primary hurdles to decarbonizing the energy supply.

I. What is a (Strong) Smart Grid?

A strong, smart grid is an interconnected system of (a) information and communication technologies and (b) electricity generation, transmission, distribution, and end-use technologies that will:

- enable consumers to manage their power usage and choose the most economically efficient products and services (*two-way communications*);
- maintain electricity delivery system reliability and stability enhanced by automation (*intelligent monitoring and control*); and
- integrate the most environmentally benign generation alternatives including renewable resources and energy storage (*two-way power transmission, renewable integration*).³

It is important to note here that the term *smart grid* does not require the inclusion of all of these components, and may be of even narrower scope than the descriptions herein. Actual smart grid projects may involve only one of the following components:

Two-way communications. The smart grid enables real-time, two-way communications throughout the whole electrical system, from generation to transmission to distribution to end-use consumption. This is in strong contrast to the traditional electric grid, which does not allow communication between power utilities and residential consumers, and relies on customers for reports on power outages, information that the traditional grid cannot supply.

Smart grid also allows for *real-time pricing* information, so that consumers can make decisions about when to use electricity. This does not mean that consumers must continuously monitor pricing information; a smart air conditioning unit can be set to automatically raise its thermostat setting when the electricity price goes above a certain threshold (this would be expected to happen at *peak load* times—hot summer days when most air conditioning units are running). Instead, it means that customers will no longer have to wait until billing statements in order to learn about pricing. From the utility's perspective, real-time pricing is better for business because it helps shift consumption from times of peak usage to times of lower usage.^{4,5} Consumption information can also be automatically sent from consumers' *smart meters* to utilities so that manual meter reading will no longer be necessary.

Two-way power transmission. Whereas traditional electric grid allows only one-way electricity flow from large-scale generators through transmission and distribution infrastructure to consumers, the smart grid enables two-way power flow so that consumers can also be generators. *Distributed generation* could decrease the risk of large-scale power outages; making use of distributed space for small-scale installations (*e.g.*, rooftop solar photovoltaic systems), and placing generation closer to consumption so as to reduce transmission losses and the need for new transmission capacity.

In addition, two-way electricity flow enables *plug-in electric vehicles (EVs)* to act as peak-shifting energy storage.⁶ Most EV users probably charge their vehicles at night while demand is off-peak and electricity prices are low. During the day, if charging stations are widespread, vehicles can be plugged in to provide electricity to the grid when it is most needed. In this way, EV owners can actually make money by buying electricity when it is cheap and selling it back at higher prices. From the utility's perspective, not only does this system reduce peak loads, it also maintains a higher *base load* at night, meaning its generators can run more continuously and, thus, more efficiently.⁷

Intelligent Monitoring and Control. The traditional grid has very limited ability to monitor the status of the electrical system and react to potential problems before they arise. The smart grid, with its communications infrastructure, is able to (1) detect potential problems before they become severe and (2) promptly deploy measures to solve those problems.

For example, one common issue for utility companies is reactive power, which is created by some loads and generators, and congests transmission lines but does not deliver energy. Utility companies and large commercial and industrial customers have a strong incentive to optimize power factor in order to minimize reactive power. A smart grid can enhance the system's ability to sense the amount of reactive power flowing in real-time and activate equipment that provides active reactive power compensation in the correct location, clearing up congestion and increasing the flow of real power or increasing the flow of reactive power to maintain voltages, as the case may be. This capability increases distribution system efficiency and enhances grid stability.

Renewable Integration. The variable and uncertain nature of renewable energy sources like wind and solar introduces difficulties for integrating renewable energy onto the grid. For example, at times there are strong winds when demand for power is very low. To avoid shutting down the turbines (currently a common practice), the grid must be able to transmit the electricity either to areas of higher load or to energy storage facilities. And, when the wind is weaker than forecasted, smart grid may use *demand response* to reduce loads.⁸ This strong, smart grid component is discussed in greater detail in section III on wind integration challenges.

II. Estimating the GHG Emissions Reductions Enabled Through a (Strong) Smart Grid in the United States and China

Having defined the key characteristics that distinguish a smart grid from a conventional grid, the next step is to describe the concrete mechanisms by which a strong, smart grid can save energy and reduce GHG emissions, and to estimate the possible emissions associated with each mechanism. The Electric Power Research Institute's 2008 report, *The Green Grid: Energy Savings and Carbon Emissions Reductions Enabled by a Smart Grid*, provides such an estimate for the United States, while the State Grid Corporation of China's 2010 *Green Development White Paper* provides a similar estimate for China, based on the benefits of a *strong, smart grid*.^{9,10} Tables 1 and 2 summarize the reports' estimate of the possible emissions reductions in the United States and

China through various strong, smart grid mechanisms.

There is some overlap in the mechanisms examined in each report, especially those for reducing transmission loss, but for many reasons—including the different years used in the two reports, the various mechanisms examined, and contrast in assumptions—an apples-to-apples comparison of the emissions reductions from smart grid in the United States and China is impossible.¹¹

Also, it is clear from the mechanisms listed and each mechanism’s relative importance, that the two reports assume different priorities with respect to smart grid development in each country. The EPRI report, for example, attributes large energy savings to the increased feedback customers will receive on their energy usage and the accelerated deployment of energy efficiency programs, as well as savings from peak load management. The SGCC report, on the other hand, places little emphasis on the effects of energy conservation and consumer energy efficiency measures. Rather, the SGCC report assumes China has extremely aggressive plans for EV deployment, and, as evident from the gigantic savings associated with increasing the efficiency of coal-fired power generation, that China will remain heavily dependent on coal.

Table 1. EPRI: U.S. Estimated Annual Energy Savings and Avoided CO₂ Emissions¹²

Emissions-Reduction Mechanism Enabled by Smart Grid	Energy Savings, 2030 (billion kWh)		Avoided CO ₂ Emissions, 2030 (Tg CO ₂)	
	<i>Low</i>	<i>High</i>	<i>Low</i>	<i>High</i>
1 Continuous Commissioning of Large Commercial Buildings	2	9	1	5
2 Reduced Line Losses (Voltage Control)	4	28	2	16
3 Energy Savings Corresponding to Peak Load Management	0	4	0	2
4 Direct Feedback on Energy Usage	40	121	22	68
5 Accelerated Deployment of Energy Efficiency Programs	10	41	6	23
6 Greater Integration of Renewables	--	--	19	37
7 Facilitation of Plug-in Hybrid Electric Vehicles (PHEVs)	--	--	10	60
TOTAL	56	203	60	211

Table 2. SGCC: China’s Estimated Annual CO₂ Reductions From Strong, Smart Grid¹³

Mechanism	2005 Figure	2020 Figure	Difference between 2020 and 2005 figures	Avoided CO₂ emissions, 2020 (Tg CO₂)
Raising the consumption of “clean energy” ¹⁴	89 GW	411 GW	320 GW	1,018
Decrease in transmission losses	6.59%	5.7%	Save 14.17 million TCE	39
Increase Efficiency of Coal Burning for Generation	343 grams/kWh	305 grams/kWh	38 grams/kWh; save 188.859 million TCE	524
Increase in Energy Efficiency of Electricity Sector and Consumers	18% of consumer energy consumption is in the form of electricity	26% of consumer energy consumption will be in the form of electricity	N/A	Not yet calculated
Promotion of electric vehicles	0 EVs	30,000,000 EVs	35.5 million tons of petrol use will be avoided	68.7 ¹⁵
			TOTAL	1,649

Each of the strong, smart grid emissions reduction mechanisms examined by the EPRI and SGCC reports is discussed in greater detail below:

Continuous Commissioning: *Commissioning* means to size, specify, and choose settings for electrical equipment (chiller systems, refrigeration equipment, etc.) according to how it will be used in a building, considering factors like expected occupancy and weather conditions. Properly commissioned equipment will perform at optimal levels of energy efficiency, providing only the services that are most necessary. At a minimum, equipment should be commissioned when it is installed and a building is renovated. Ideally, equipment should be continuously commissioned, meaning that settings are adjusted in response to real-time changes in building usage, and performance is continuously monitored to detect equipment degradation or failure. Using a smart grid’s two-way communication capability, utilities can monitor equipment power consumption (primarily for large commercial buildings) and help facility managers adjust settings or in deciding to replace or upgrade equipment. Studies show that commissioning in large commercial buildings can yield electricity savings of 9 percent per year. EPRI’s estimates assume that large commercial buildings will consume 492 billion kWh in 2030 and that continuous commissioning will be performed in 5 to 20 percent of such buildings.¹⁶

Transmission and Distribution Losses (T&D): Traditionally, large capital expenditures are required to reduce T&D losses, and loss reduction is usually an ancillary benefit to these infrastructure upgrades. The primary reason for these investments (e.g., upgrading transformers and building new substations) is to increase T&D capacity or replace old equipment. The smart grid (which requires capital expenditures of its own) can reduce T&D losses using existing power infrastructure.

- On the transmission side, a smart grid can use voltage control to manipulate the flow of reactive power and increase transmission efficiency, as discussed above.
- On the distribution side, a smart grid can save energy by more precisely controlling consumer voltage to keep it at the low end of the tolerated range. In the United States, electrical equipment nominally runs on 120 volts, meaning that it can accept voltages from 114 to 126 volts. Most utilities keep the average voltage above 120 volts to maintain a safety margin in case of higher than expected loads. The smart grid will allow real-time monitoring and control of consumer voltage so that it can be maintained at a lower voltage without risk of going below the minimum. On average, a 1 percent reduction in voltage reduces power draw by 0.8 percent.¹⁷

EPRI's estimated energy and carbon savings are based only on the residential voltage control mechanism, assuming that voltage regulation is used in 25 to 50 percent of residential distribution substations by 2030.¹⁸

As discussed further in Section III below, China plans to build Ultra High Voltage, long-distance transmission lines to minimize transmission loss and connect resource-rich areas with distant high-demand areas.

Peak Load Management: *Peak load management* (also referred to as *demand response* and *load control*) means shifting load from periods of high electricity demand (peak) to periods of low demand (valley). This load shifting provides the direct benefits of maintaining system stability during peak periods, minimizing the need for inefficient *operating reserves*, and deferring the need to build new generation units.¹⁹ In theory, peak load management shifts electricity use but does not necessarily reduce total consumption. However, studies have shown that peak load management does actually reduce overall electricity use, saving an average of 65 kilowatt hours (kWh) per kilowatt (kW) of peak load reduction.²⁰

The smart grid will enable widespread demand response by allowing utilities to send pricing information to consumers' smart appliances, which are programmed to alter their operation according to price thresholds.²¹ *Direct load control*, whereby utilities directly alter equipment operation within consumers' contracted or pre-set limits, will also be facilitated by smart grid technology. The smart grid may also make it easier for utilities and consumers to optimally operate equipment that results in permanent peak load reductions, such as thermal energy storage systems.

EPRI's carbon reduction estimate is based on a maximum peak load reduction of 5 percent resulting from smart grid-enabled demand response programs.²²

Direct Feedback to Consumers: Smart grid will allow utilities to give direct feedback to consumers, possibly including information such as (a) current and historical consumption; (b) equivalent carbon dioxide emissions; (c) current electricity demand; and (d) real-time prices. This information may come in the form of a detailed display, audio signals, or something as simple as a glowing orb that changes color and intensity to communicate electricity-related information. Numerous studies performed in the United States, Canada, and Europe have shown that simply providing consumers with information about their energy consumption can result in significant behavioral changes, reducing energy use 5 to 15 percent.²³

Direct feedback may be implemented with or without demand response. EPRI's estimates, based on direct feedback alone, independent of demand response, assume that direct feedback will yield 5 percent energy savings for residential consumers and 2.5 percent savings for industrial and commercial consumers, with 25 to 75 percent market penetration.

It is interesting to note that this mechanism results in the highest estimated amount of CO₂ reductions in EPRI's report, but is not listed at all in SGCC's calculations. Because direct feedback appears to have significant potential for reducing carbon emissions, the impact of such feedback mechanisms on Chinese consumers' electricity usage could be an important area for further research.

Deployment of Energy Efficiency Programs: In the United States, utilities implement *negawatt* (also known as virtual power plant or *efficiency power plant*) programs that treat energy efficiency as a resource. These programs provide financial incentives to consumers and utilities who adopt practices—such as replacing appliances and lighting with more efficient models—to improve energy efficiency. Because utilities need to be able to quantify the effectiveness of their financial investment in these programs, accurate *measurement and verification (M&V)* of energy savings is extremely important to them. Currently, the energy savings of a hypothetical rebate program would be estimated *ex ante*, using laboratory data and specifications of the new equipment. This is the best that can be done because consumption cannot be measured at the end-use level. With a smart grid, however, utilities could monitor energy use for a particular end-use (*e.g.*, air conditioning) before and after replacement, thereby determining the precise amount of energy savings attributable to the program.

EPRI's estimation is based on a study showing that energy efficiency programs can potentially decrease energy consumption by 7 percent (realistic achievable potential) to 11 percent (maximum achievable potential), and then attributing 5 to 20 percent of the difference between the two achievable potentials to improved M&V facilitated by smart grid.²⁴

The SGCC report mentions increasing consumer energy efficiency as a mechanism for carbon reduction, but the report lacks estimated figures for these reductions, indicating that further work remains to be done in this area. At present, several provinces and cities, including Jiangsu,

Hebei, Sichuan, Beijing, Shanghai, and Chongqing have implemented some form of a demand side management (DSM) energy efficiency program aimed at reducing energy use and emissions through large-scale investments in efficiency. The State Grid Corporation also intends to pursue *integrated resource strategic planning*, which would promote investment in *efficiency power plants* alongside investments in expanding power generation.

Another potential area of research is China's standard-setting process for interoperability among components of communication and control infrastructure, and among smart end-use devices. Open standards are preferred because they allow the greatest participation in the market and will facilitate widespread adoption of reliable, trustworthy M&V.

Renewable (Wind) Integration:²⁵ In its carbon reduction calculation for wind integration, EPRI assumes that there will be 100 gigawatts (GW) of additional renewable capacity by 2030—half from biomass, the other half from wind. Assuming an average capacity factor of 61 percent, and half of the renewable generation coming from wind, there should be 267 terawatt-hours (TWh) of wind-generated electricity in 2030.²⁶

EPRI then limits the carbon savings attributed to smart grid to its ability to mitigate wind *variability*, and estimates that the smart grid attribution is 25 to 50 percent.²⁷ EPRI's calculation stands in contrast with the calculations by SGCC, which attribute *all* carbon emission reductions from the use of *clean* energy sources to the *strong, smart* grid. An argument can be made that EPRI's estimate is likely more accurate because some level of variable renewable generation can be integrated into the grid without smart grid technology.

Plug-in Electric Vehicles:²⁸ EPRI assumes that, on the aggressive side, 50 percent of new-car sales, and 40 percent of all on-road vehicles, will be plug-in hybrid EVs in 2030.²⁹ While a smart grid is not absolutely necessary for charging EVs, EPRI attributes 10 to 20 percent of EV carbon savings to smart grid because it would ease EV adoption by enabling distributed storage, regulation services, and other potential business models such as battery leasing.³⁰ Again, SGCC's estimate attributes 100 percent of carbon reductions resulting from EV adoption to smart grid technology. SGCC also assumes that there will be 30 million EVs on the road in China by 2020.³¹ In 2010, SGCC plans to build 75 EV charging stations consisting of 6,209 charging columns.³²

Increase Efficiency of Coal Burning for Generation: After increased use of “clean” energy, the second most important mechanism for carbon reductions in China is to increase the efficiency of coal burning for power generation—in other words, decreasing the number of grams of coal needed to generate each kWh. Unfortunately, while this mechanism is important, it is not well explained in the SGCC report. Two important aspects of this mechanism appear to be that: 1) smart grid allows more effective priority dispatch that favors energy efficient plants, which will incentivize generators to operate more efficiently and invest in technologies to increase their efficiency; and 2) smart grid will allow coal-fired power plants to increase capacity factors by increasing dispatch of those units. Research shows that for each percentage point increase in *load factor*, 2.3 grams less coal is required to produce one kWh.^{33,34,35}

The first aspect may have minimal effect because China's energy consumption growth is constantly leading its generation capacity growth. As a result, in many regions, all available generation must be dispatched. The second aspect can be quite complicated. For example, better wind forecasting combined with regional grid integration will allow utilities to plan further ahead and more precisely regarding which coal plants need to be operated at which times. In this way, coal plants can be operated closer to their optimal operating efficiency, as less capacity must be maintained as operating reserves.³⁶ Load factors can also be raised with improved peak load management.

Additional emissions reduction mechanisms enabled by a strong, smart grid. Additionally, smart grid will help minimize curtailment, which is not just a problem for wind energy alone. According to a recent news article, coal plants in Inner Mongolia are also curtailed because there is nowhere to send the power that the province is capable of generating.³⁷ *Regional grid integration*, primarily a *strong* grid concept, will solve this problem and allow coal plants in low-demand regions to operate more efficiently.³⁸ *Energy storage*, which will be enhanced by smart grid, may also increase the efficiency of coal plants by reducing the amount of operating reserves necessary and absorbing extra power in times of low demand so as to avoid curtailment.³⁹ Finally, effective peak load management and demand response will enable utilities to run a higher 24-hour base load, which also increases operational efficiency.⁴⁰

III. Strong, Smart Grid Solutions to Integrating Greater Wind Energy Resources

Three characteristics of wind generation (which are shared by other forms of renewable energy) make it difficult to integrate into the grid: (1) its *variability*; (2) its tendency to have strong day-night swings; and (3) its location in areas that are far away from areas of high demand. This section discusses in detail four solutions (improved wind forecasting, demand response, storage, and regional grid integration) either enabled or enhanced by a smart grid, which can counteract these challenges and ease grid integration.

Improved Wind Forecasting

In general, the goal of every utility company is to provide uninterrupted service to its consumers. Thus, it must always maintain *operating reserves* in case of higher than predicted demand. Operating reserves can be *spinning* or *non-spinning*. Spinning reserves refer to additional generation capacity that can be almost immediately added to the power supply by speeding up generators that are already on-line. Because generators generally operate most efficiently at close to maximum speeds, utilities aim to keep the amount of spinning reserves to the absolute minimum needed to compensate for possible shortages. Non-spinning reserves are often provided by *peaking plants*, generators (usually burning natural gas) that can be powered up very quickly (on the order of 10 minutes) to meet higher than expected demand. Because these plants are of relatively small size and do not operate many hours per year, they operate at low efficiency and high cost. Hence, utility companies try to minimize their use.

The addition of intermittent wind resources adds to the uncertainty of power supply and thus requires utilities to increase the amount and dispatch (utilization) of operating reserves. If, for example, a wind farm expected to be producing 500 megawatts (MW) suddenly reduces output to 100 MW because of an unforeseen decrease in wind speed, then operating reserves must be able to account for the 400 MW deficit. When wind generation is added to a grid, utilities must add reserves to compensate for generation intermittency as well as unexpectedly high demand. This problem becomes more severe with higher levels of wind penetration.

Thus, accurate daily wind forecasting and the grid intelligence to use that forecast data to minimize the amount of reserves needed will improve utilities' ability to maintain continuous service in the most energy and economically efficient manner. For example, utilities can use forecast data to plan demand response measures, re-route energy to and from storage facilities, and more accurately determine when it will need to buy or sell power to and from other regions. Moreover, accurate hourly forecasting will allow wind generators to participate in real-time energy markets, potentially making them more profitable.

Demand Response

The smart grid will also enhance a utility's residential demand response capabilities. When improved wind forecasting falls short and demand exceeds supply, the smart grid will send signals to consumers' equipment telling them to reduce their power usage. Large-scale demand response reaching all consumers (residential, commercial, and industrial), will allow utilities to avoid calling on their *interruption supply contracts* with large industrial consumers, and will decrease the risk of blackouts and other failures.⁴¹

Demand response can be effective in mitigating both the intermittency of wind and its tendency to generate more electricity at off-peak times. For example, the smart grid can shift smart appliance use to off-peak times and can optimally control thermal storage systems, advanced air conditioning systems that use electricity to create ice at off-peak times, using it to cool indoor air during peak times.

Storage

An unfortunate reality is that electrical storage is inefficient and expensive, so in most situations, electricity must be used as it is generated. Therefore, utilities often curtail wind power because it often generates more electricity than can be used at that moment. Another reality is that consumer activity can not be completely controlled or predicted, even with effective demand response, so utilities must constantly adjust supply to match the load as it changes throughout the day. This continuous adjustment is called *regulation* and is usually done by adjusting the output of thermal turbines, which decreases energy efficiency and increases wear and tear on the turbines. As the ratio of wind power increases in the total power supply, more regulation is needed because of the intermittent and unpredictable nature of wind. Even when daily forecasts are accurate, sudden gusts and lulls can create changes in supply that require regulation services. Large-scale storage technologies such as pumped hydro, batteries, and flywheels are potential solutions to reduce curtailment and ancillary service requirements, but smart grid

technology may provide a less expensive and more effective solution through the integration and control of *distributed storage*.⁴²

Distributed storage refers to small-scale energy storage that is dispersed throughout the geographic area of an electrical grid, for example battery systems integrated with residential solar installations and plug-in EVs. Eventually, an EV owner may charge his car at home at night and plug the vehicle into the grid at his workplace during the day. Whenever the vehicle is plugged in, the battery can be used as a regulation device, providing and absorbing power to and from the grid instantaneously as required.

In some cases, wind generation is higher at night—a time of low demand—so large numbers of EV owners charging at night could reduce the amount of night-time curtailment. In the future, EV owners may be able to make money through two mechanisms: (1) charging the battery when prices are low and selling back to the grid when prices are high; and (2) providing regulation services.⁴³ Building-based battery systems (*e.g.*, residential solar systems with batteries) can perform the same services these services as well.

Regional Grid Integration

Regional grid integration, primarily a *strong grid* concept, provides two solutions. First, it mitigates wind intermittency by integrating wind generation across a large geographic area. The larger an area that a grid operator can monitor and control, the more geographic diversity can be leveraged to smooth aggregate wind output. In other words, the larger an area that a grid covers, the more likely it will be able to compensate for generation peaks and valleys in one region by using corresponding valleys and peaks in other regions. Second, regional grid integration makes it possible to transfer power over long distances to areas of high demand, thereby easing regional congestion and reducing wind curtailment.

The current situation in Inner Mongolia illustrates a problem that is common in both China and the United States. Inner Mongolia currently has 34 GW of total generation capacity, but demand within Inner Mongolia is only 18 GW. Of the extra 16 GW, Inner Mongolia can only export 4 GW (to the Northern China grid company), so there is an overcapacity of 12 GW. This problem will only get worse as more wind farms are built. By the end of 2010, the province will have over 7 GW of wind capacity, only to increase to 8.5 GW by the end of 2011. An additional 1.5 GW of projects have secured funding but have not been approved by the NDRC.⁴⁴

The problem is so severe that even coal plants are curtailed to an average of 4,000 operational hours a year, when ideally they should be operating 6,000 hours a year.⁴⁵ As discussed below, more coal plants will likely be built in Inner Mongolia in the coming years. Thus, China must develop its transmission capabilities simultaneously with its capacity additions in order to most efficiently use its resources—both renewable and conventional.

Inner Mongolia has requested the following grid expansions for China's Twelfth Five-Year Plan: seven 600 kV AC lines, one 660 kV DC line, and one 800 kV Ultra High Voltage Direct Current (UHVDC) line—capable of bundling hydro, thermal and, wind power and transmitting 30 GW

outside of the province.⁴⁶ Unfortunately, these projects, if approved, will not be completed until several years from now.

In China, 80 percent of coal resources and virtually all wind resources are in the west and north. Eighty percent of hydropower resources are in the west, and 75 percent of demand is in the eastern and central areas of the country. Resources and demand are separated by 800 to 3000 kilometers, and existing 500 kilovolts (kV) transmission lines can only economically transmit power over distances of 800 kilometers.⁴⁷ 1000 kV UHVAC lines can economically transmit power over 3000 kilometers, and +/- 800 kV UHVDC lines can transmit power over 2500 kilometers.⁴⁸ Thus, one of China's priorities is to build a network of long-distance UHV lines.

China has invested over 580 million RMB in UHV trial projects and currently has at least two UHV transmission lines in operation. One is an 800 kV UHVDC trial project that connects Xiangjaba (向家坝) in Sichuan to Shanghai and provides clean energy to the World Expo.⁴⁹ The other is a 1000 kV UHVAC line that connects Jindongnan (晋东南) in Shanxi to Nanyang (南阳) in Hunan to Jingmen (荆门) in Hubei— across a distance of 640 kilometers.⁵⁰ It has been in operation for over a year and has transmitted over 9 TWh.⁵¹ China is currently building a 2,100 kilometer +/- 800 kV UHVDC line, from Jinping (锦屏) in Sichuan to Suzhou (苏州) in Jiangsu.⁵² It is also working to develop new +/- 1000 kV UHVDC technology.⁵³

Along with building long distance UHV lines to bring renewable energy to load centers, China also plans to build many large coal plants (dubbed *mine-mouth power plants*) near wind farms in the north and west. China's coal resources happen to be located in the same areas that have abundant wind resources. The advantages of building coal plants in the west are:

- (1) SGCC claims it is cheaper and less energy intensive to transmit coal-fired electricity over UHV lines than to ship coal via railroad to be burned at coal plants in the east;
- (2) electricity from coal plants can be “bundled” with wind and hydro power before it is transmitted so that the intermittently generated power will be of higher quality while it is transmitted and when it reaches the distribution level; and
- (3) bundling coal, hydro and wind power will make optimal use of transmission line capacity which would otherwise be wasted because UHV transmission lines are designed to handle peak loads that exist only tens of hours per year.^{54,55,56}

China's goal is to decrease the ratio of coal shipped out to electricity transmitted out (in TCE equivalent) from 20:1 in 2006 to 4:1 in 2020, for the “Three Wests” (Shanxi, Shaanxi, Mengxi).⁵⁷

SGCC also claims that building coal plants in the west will benefit western China economically because transmitting power contributes six times more to GDP than shipping coal, and also employs twice as many people.⁵⁸ Though it is unclear why this is so, SGCC also claims that building coal plants in close proximity to each other will make it easier to recover and reuse coal byproducts and other associated resources, including carbon dioxide, water, ash, and cinder.⁵⁹ In

building and operating these mine-mouth power plants, China must be sure to strictly regulate the amount of pollution created by the coal extraction process and the power generation process. It would be disastrous to ruin western China with acid rain and other coal-related pollution.

An even more difficult task in the United States might be convincing the numerous and independent regional grid operators to share the costs of building inter-regional transmission lines and setting up a fair system for buying and selling power among the regional utilities.⁶⁰

IV. Conclusion

Expanding, strengthening, and innovating the infrastructure which transmits electricity from generator to end-user is an essential component of efforts to combat climate change and decarbonize our energy supply—improving the efficiency with which we use electricity and integrating greater and greater amounts of renewable generation. As we build a stronger, smarter grid in both China and the United States, it is important that we continue to research and examine the mechanisms by which a strong, smart grid will enable increased reductions in greenhouse gas emissions.

Additional Resources for Information on Strong, Smart Grid

The American Wind Energy Association and Solar Energy Industries Association, *Green Power Superhighways: Building a Path to America's Clean Energy Future*, February 2009, available at www.awea.org/GreenPowerSuperhighways.pdf.

Electric Power Research Institute, *The Green Grid: Energy Savings and Carbon Emissions Reductions Enabled by a Smart Grid*, June 2008, available at: my.epri.com.

John Douglas, "Putting Wind on the Grid," EPRI Journal, Spring 2006, available at: mydocs.epri.com/docs/public/00000000001013289.pdf.

The National Energy Technology Lab, Smart Grid Implementation Strategy Reference Shelf, available at: www.netl.doe.gov/smartgrid/refshelf.html. In particular, the White Paper section provides detailed but accessible information about many aspects of smart grid, including monitoring and control and storage.

R.G. Pratt et al., *The Smart Grid: An Estimation of the Energy and CO₂ Benefits*, January 2010, Pacific Northwest National Laboratory, available at: energyenvironment.pnl.gov/news/pdf/PNNL-19112_Revision_1_Final.pdf

State Grid Corporation of China (SGCC), SGCC Green Development White Paper (in Chinese) (国家电网公司绿色发展白皮书), April 2010, available at: www.sgcc.com.cn/bps/index.shtml

State Grid Corporation of China, *Opinions on Speeding up Construction of the Strong, Smart Grid* (in Chinese) (关于加快推进坚强智能电网建设的意见), SGCC Office No. 1 (2010), available at: www.sgcc.com.cn/ztl/2010ngs_lh_/hywj/01/215426.shtml

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ENDNOTES

¹ In China for example, the power sector consumed 1.40 billion tons of coal in 2009, or 45.6 percent of the total 3.07 billion tons of coal equivalent energy consumed nationwide. See State Electricity Regulatory Commission, 2009 Electricity Regulation Annual Report (电力监管年度报告 (2009)), May 2010, available at: www.serc.gov.cn/zwgk/jggg/201005/t20100514_13055.htm and National Bureau of Statistics, "About China's Energy Consumption Situation in 2009" (关于 2009 年中国能源消费情况的说明), August 12, 2010, available at: www.stats.gov.cn/tjdt/zygg/sjxdtzgg/t20100812_402664717.htm.

In the U.S., the power sector constituted 34 percent of total U.S. greenhouse gas emissions in 2008. U.S. EPA, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2008*, April 15, 2010, available at: epa.gov/climatechange/emissions/usinventoryreport.html.

² Defined by State Grid Corporation of China as +/-800 kV DC and higher or 1,000 kV AC and higher.

³ Adapted from Roger Levy, Smart Grid Technical Advisory Project, Lawrence Berkeley National Laboratory, as used in presentation "Smart Policies for a Smart Grid", Richard Sedano, Regulatory Assistance Project (February 1, 2010), available at: www.raponline.org/docs/RAP_Sedano_SmartPoliciesForASmartGrid_2010_02_01.pdf

⁴ Peaking plants, which sometimes run for only tens of hours per year, are the most costly and inefficient plants to operate and maintain.

⁵ In general, the concept of reducing demand at peak times is called "demand response," in contrast to supply response, which means operating peaking plants, calling on operating reserves, or building additional generation capacity.

⁶ Note, however, that this will require that EVs themselves be equipped for bi-directional power flow, which is not currently a priority for EV manufacturers.

⁷ The use of EVs for peak load shifting may not be realizable in the near term. An intermediate technology may be using EVs to provide ancillary services like frequency regulation.

⁸ See footnote 5 explaining demand response and discussion below on "Peak Load Management."

⁹ Electric Power Research Institute, *The Green Grid: Energy Savings and Carbon Emissions Reductions Enabled by a Smart Grid*, June 2008, available at: my.epri.com.

¹⁰ State Grid Corporation of China (SGCC), *SGCC Green Development White Paper* (in Chinese) (国家电网公司绿色发展白皮书), April 2010, available at: www.sgcc.com.cn/bps/index.shtml.

¹¹ EPRI estimates smart grid-related emissions reductions for the year 2030, SGCC for 2020

¹² EPRI, *The Green Grid*, pp. 10-4. Note: 1 Tg = 1 million metric tons. All energy savings and avoided emissions figures are provided on an annual basis.

¹³ SGCC, *SGCC Green Development White Paper*, pp. 54-55.

¹⁴ The *SGCC Green Development White Paper* defines "clean energy" as including hydro, wind, nuclear and solar. Annual operating hours are assumed to be 3,500 for hydro, 2,000 for wind, 7,500 for nuclear, and 1,400 for solar.

¹⁵ The *SGCC Green Development White Paper* assumes that each car travels 20,000 kilometers per year, each

EV consumes 10 kWh per 100 kilometers, and each gasoline vehicle consumes eight liters of gasoline per 100 kilometers. The following methodology is used to calculate CO₂ reductions from EV displacement of gasoline vehicles: CO₂ reduction = number of EVs on the road that year * (CO₂ emissions per km traveled by a gasoline vehicle – CO₂ emissions per km traveled by an EV) * km traveled that year by each EV.

¹⁶ EPRI, *The Green Grid*, pp. 4-2 – 4-3

¹⁷ EPRI, *The Green Grid*, 5-2.

¹⁸ EPRI, *The Green Grid*, 5-3.

¹⁹ See subsection below titled “Improved Wind Forecasting” for a discussion on operating reserves.

²⁰ EPRI, *The Green Grid*, 6-3.

²¹ Refer to the above subsection titled “Two-Way Communications” for additional discussion on demand response.

²² EPRI, *The Green Grid*, 6-3 through 6-4.

²³ EPRI, *The Green Grid*, pp. 7-1 – 7-2.

²⁴ EPRI, *The Green Grid*, 8-2 through 8-4.

²⁵ Please refer to the section below titled “Smart Grid Solutions to Wind Integration Challenges” below for a discussion on smart grid’s role in overcoming challenges to wind integration.

²⁶ This calculation appears to be incorrect. A 50/50 mix for wind and biomass capacity does not mean that generation will also be 50/50. EPRI should have multiplied 50GW wind capacity times the average capacity factor for wind, which would probably be between 30 percent and 40 percent, to obtain the number of TWh generated by wind.

²⁷ EPRI, *The Green Grid*, 9-1 through 9-3

²⁸ Please refer to the subsection below titled “Storage” for a more in-depth discussion on plug-in EVs.

²⁹ EPRI, *Plug-in Hybrids on the Horizon: Building a Business Case*, available at mydocs.epri.com/docs/CorporateDocuments/EPRI_Journal/2008-Spring/1016422_PHEV.pdf

³⁰ EPRI, *The Green Grid*, 9-4.

³¹ *SGCC Green Development White Paper*, 54.

³² *SGCC Green Development White Paper*, 49.

³³ More efficient automated dispatch is commonly raised by Chinese smart grid experts as a useful smart grid improvement, but it is unclear how smart grid will improve dispatch operations because utilities can already dispatch power plants according to each plant’s efficiency.

³⁴ Also known as capacity factor, load factor is the ratio of a generator’s actual generation to its maximum nameplate generation.

³⁵ *SGCC Green Development White Paper*, 51.

³⁶ See below subsection titled “Improved Wind Forecasting” for a discussion on operating reserves.

³⁷ Eastmoney.cn, “Rapid increase in wind energy causes thermal power plants to stop production: The story behind the blocking of transmission from Inner Mongolia” (in Chinese) (风电激增火电停产：内蒙古电力外运受阻背后), July 8, 2010, available at: finance.eastmoney.com/news/1355,2010070882611094.html.

³⁸ See below subsection titled “Regional Grid Integration” for a more detailed discussion.

³⁹ See below subsection titled “Storage” for a discussion on distributed storage.

⁴⁰ See above subsections titled “Two-Way Communications” and “Peak Load Management” for discussions on demand response.

⁴¹ Utilities often sign interruptible supply contracts (also called “curtailment contracts”) with large

industrial users, which allow utilities to shut off the power supply to those customers when demand greatly exceeds supply, in exchange for compensation to those customers. As one can imagine, these contracts are only called in extreme circumstances when the potential cost of a complete system collapse outweighs the cost of paying contract compensation.

⁴² For a primer on energy storage technologies, see The Pew Center on Climate Change, *Energy Storage*, available at www.pewclimate.org/technology/factsheet/EnergyStorage.

⁴³ There is some disagreement about whether EVs will be able to profitably provide regulation services and energy storage/load shifting. Reasons for this disagreement include potential oversaturation of the market and the cost of battery degradation effects from participating in these services.

⁴⁴ Eastmoney.cn, “Rapid increase in wind energy causes thermal power plants to stop production.”

⁴⁵ *Id.*

⁴⁶ *Id.*

⁴⁷ *SGCC Green Development White Paper*, pp. 14.

⁴⁸ *SGCC Green Development White Paper*, pp. 28.

⁴⁹ *SGCC Green Development White Paper*, 44.

⁵⁰ See SGCC, “The 1000kV Jindongnan – Nanyang – Jingmen AC UHV Experimental Demonstration Project (1000kV 晋东南 — 南阳 — 荆门特高压交流试验示范工程)”, available at: www.sgcc.com.cn/yw/gk/yxxm/tgyjl/index.shtml.

⁵¹ *SGCC Green Development White Paper*, 51.

⁵² See SGCC, “Introduction to the Jinping – Sunan ±800 kV DC UHV Transmission Project” (锦屏—苏南±800千伏特高压直流输电工程简介), available at: www.sgcc.com.cn/yw/gk/jsxm/jstgyzl/index.shtml.

⁵³ *SGCC Green Development White Paper*, 44.

⁵⁴ Currently, coal shipments (mostly for electricity generation) take up 50% of railroad capacity. *SGCC Green Development White Paper*, pp. 13.

⁵⁵ According to a researcher at the State Grid Energy Research Institute.

⁵⁶ *Id.*

⁵⁷ *SGCC Green Development White Paper*, 13.

⁵⁸ *SGCC Green Development White Paper*, 35.

⁵⁹ *Id.*

⁶⁰ For a discussion on the policy obstacles that stand in the way of regional grid integration in the United States, see American Wind Energy Association and the Solar Energy Industries Association, *Green Power Superhighways: Building a Path to America’s Clean Energy Future*, available at: www.awea.org/GreenPowerSuperhighways.pdf.