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Acronyms

BPA	Bonneville Power Administration	NDRC	National Development and Reform Commission
CAISO	California Independent System Operator	NEA	National Energy Administration
CCR	Coal Combustion Residuals	NO_x	Oxides of Nitrogen
CEA	Central Electricity Authority	NPCC	Northwest Power and Conservation Council
CERC	Central Electricity Regulatory Commission	NPV	Net Present Value
CFL	Compact Fluorescent Lamp	NSR	New Source Review
CHP	Combined Heat and Power	NYMEX	New York Mercantile Exchange
CO₂	Carbon Dioxide	O&M	Operations and Maintenance
CT	Cycle (Gas) Turbine	PAC	Program Administrator Cost
CVPS	Central Vermont Public Service Corporation	PBR	Performance-Based Regulation
DISTCO	Distribution Company	PG&E	Pacific Gas and Electric Company
DR	Demand Response	PM_{2.5}	Fine particle emissions
DRIPE	Demand-Response Induced Price Effect	PPA	Power Purchase Agreement
DSM	Demand-Side Management	PT	Participant Test
DTQ NEB	Difficult-to-Quantify Non-Energy Benefits	PUC	Public Utilities Commission
EEO	Energy Efficiency Obligation	RCRA	Resource Conservation and Recovery Act
EIA	Energy Information Administration	RE	Renewable Energy
EPRI	(U.S.) Electric Power Research Institute	REC	Renewable Energy Certificate
ETS	(E.U.) Emissions Trading Scheme	RfQ	Request for Qualification
FCM	Forward Capacity Market	RGGI	Regional Greenhouse Gas Initiative
FEC	Firm Energy Certificates	RIM	Ratepayer Impact Measure (Test)
FERC	Federal Energy Regulatory Commission	RMB	Renminbi
FIT	Feed-in-Tariff	RPM	Resource Portfolio Model
GDP	Gross Domestic Product	RPS	Renewable Portfolio Standard
GHG	Greenhouse Gas	SCT	Societal Cost Test
GWh	Gigawatt-Hours	SEEAAction	State and Local Energy Efficiency Action Network
IPP	Independent Power Producer	SERC	State Electricity Regulatory Commission
IRP	Integrated Resource Planning	SIP	State Implementation Plan
ISO-NE	ISO New England	SO₂	Sulfur Dioxide
kWh	Kilowatt-Hour	SO₃	Sulfur Trioxide
LDCs	Load Duration Curves	SPC	Supercritical Coal (Unit)
LED	Light-Emitting Diode	TCE	Standard Coal Equivalent
LMP	Locational Marginal Price	TOU	Time-Of-Use
MEP	Ministry of Environmental Protection	TRC	Total Resource Cost (Test)
MW_a	Average Megawatt	T&D	Transmission and Distribution
MWh	Megawatt-Hour	UCT	Utility Cost Test
NAAQS	National Ambient Air Quality Standards		

Executive Summary

Over the past 15 years, the Chinese government has implemented a series of power sector reforms that have greatly expanded the availability of electricity and improved the efficiency, reliability, and environmental performance of the sector. But significant challenges remain: rising costs, concerns about reliability and security, high rates of demand growth, and serious threats to the domestic environment and public health, as well as global climate. The Chinese government has set ambitious energy and environmental goals in the *12th Five-Year Plan (2011–2015)* and the new *Air Pollution Prevention and Control Action Plan (2013–2017)*. Addressing these challenges and meeting these goals will require policies that reshape the power sector. International experience with power sector policy, both successes and failures, is an important point of reference for China. This paper offers recommendations for China based on that international experience, expanding on RAP's 2012 and 2011 papers on these issues.¹

We discuss several key areas we believe are at the heart of China's power sector challenges: planning, resource acquisition, generator dispatch, retail pricing, renewables integration, grid company regulation, and coal quality.

Power Sector Planning

Planning is essential in any power sector, because decision-makers need to be sure that their policies achieve their objectives, as intended, and at the lowest possible overall cost for society as a whole. For China, we recommend a broader-based and more transparent planning process, using improved analytical tools, to identify a desired mix of resources for the power sector. This planning process should directly compare demand-side resources, supply-side resources, and transmission resources in an integrated manner, considering a wide range of costs and benefits, including environmental costs. Inclusion of demand-side resources — particularly end-

use energy efficiency — into the power sector planning process is especially important. We believe that this change will lead to increased investment in end-use efficiency, as energy efficiency is typically a less expensive and cleaner alternative to new power plants.

Natural gas-fired generation is another resource that is not appropriately analyzed in China's current planning process, and, as a result, receives insufficient investment. We provide an example, using well-established international planning methodologies, showing how gas is currently cost-effective for peaking generation in China and showing too that using natural gas for peaking generation will help increase the utilization and improve the efficiency of existing coal-fired power plants.

Resource Acquisition

After the planning process determines what resources constitute the optimal mix for China, a framework is needed to acquire these resources in a cost-effective, timely, and reliable manner. Many analysts and policymakers in China are calling for rapid movement to more competitive generation as a way to achieve lower costs. We recommend a particular set of approaches, depending on the resource in question, that we believe is both feasible to implement and effective at promoting competition and lowering costs. For new coal and gas plants, we recommend the government organize competitive and transparent auctions of long-term contracts in line with the resource requirements identified in the planning process. China has had some difficulties with bidding for conventional generation resources during the 1990s and with renewables more recently. However, there is substantial recent international experience — in Brazil, India, and the United States, among other countries — demonstrating that a well-designed and well-governed

¹ See Regulatory Assistance Project, 2011 and Regulatory Assistance Project, 2012.

auction process can deliver desired resources at reasonable cost. Our view is that this type of auction mechanism is a more feasible and effective way to improve competition in China's power sector than the fully liberalized markets seen in parts of the United States and Europe.

As noted, end-use energy efficiency should also be treated as a power sector resource so that power sector policy is integrated with the ongoing national push for improved energy efficiency. We recommend that China continue to refine and expand the existing mandate on grid companies to achieve energy efficiency targets. For renewable resources, we encourage the continuation of feed-in tariffs (FITs). FITs have been very effective, even though there is some room for improvement, including more frequent reviews and adjustment of the tariffs, as well as better incentives for geographic dispersal.

Generator Dispatch

Beyond planning for and acquiring power sector resources, there are critical problems in China relating to how those resources are deployed on a day-by-day and hour-by-hour basis. Dispatch — generator operations — is an extremely important determinant of the power sector's costs and environmental performance. Moreover, problems with dispatch feed back into the planning and investment process, distorting resource choices.

The typical approach in most of the world is to rank generators according to variable costs, ideally including environmental costs, so that the system operator calls on lower-cost generators first. China has a very different approach to dispatch, with the government annually assigning the system operator a roughly equal target number of operating hours for each coal-fired generator. This is intended to give each generator an equal chance to recover capital costs but largely ignores the fact that plants within the coal fleet vary significantly in terms of efficiency and environmental performance. As a result, the overall performance of the system has suffered significantly in terms of cost, environmental performance, and distorted investment decisions. The dependence of each coal generator on running a similar number of hours has become a major barrier to reforming dispatch in China.

We recommend the establishment of a two-part pricing scheme so that generators earn (1) a capacity price (fixed cost) paid in RMB per kW per year, tied to generator

availability, and (2) an energy price (variable cost) paid in RMB per kWh, tied to generator output. This reform of compensation methods can begin with new units, and the two-part pricing scheme should be specified in the contracts issued for auction. It will facilitate national implementation of optimized dispatch, in which generators are ranked and dispatched based on variable costs. It is important to factor relative environmental costs associated with various plants into dispatch decisions. Broadly speaking, this can be achieved through dispatch rules that explicitly account for emissions or through implementation of policies such as emissions taxes or emissions trading.

Retail Pricing

Around the world, owing to the natural monopoly characteristics of the power sector (or at least segments of it), government plays an important role in setting prices. In China, retail electricity prices are not updated frequently and do not reflect the costs of the power sector. We recommend the establishment of a transparent price adjustment mechanism that gives power sector companies (the grid companies and generation companies) incentives to meet the government's core clean energy and environmental policies, including the planned investment in energy efficiency, renewables, and natural gas.

Despite these issues, China's retail pricing regime has a number of very good and innovative aspects that we recommend should be preserved. These include: tiered prices (known in other countries as inclining block prices), which charge high-consuming households with higher prices; "differential" prices, which discourage inefficient modes of industrial production; and generally higher prices for industrial electricity consumers relative to households.

One area in which we urge caution is in moving forward with the pilots that allow large users to bypass the grid companies and negotiate prices directly with generators. We believe that this is not the best way to promote competition in the power sector. In particular, allowing large retail customers to contract directly with generators may — unless the policy is carefully designed — reduce the relatively high prices paid by industrial consumers at the expense of residential and commercial consumers. It can also make it more difficult to acquire an optimal portfolio of resources, that is, the portfolio of resources that should be identified in the planning process.

Renewables

China's growth in renewable energy capacity has been impressive. It now has the most installed wind capacity in the world and will be not only a leading country in wind capacity but also in solar capacity as well. However, rapid growth of renewable energy in China has resulted in substantial grid integration problems that risk stalling further progress. Our recommendations fall into three main categories: (1) improving renewable energy policies in order to lower cost and improve efficiency; (2) integrating renewables more effectively through the creation of a flexible, least-cost mix of new conventional and renewable generation; and (3) improving power system operations and renewables integration by clarifying grid company responsibilities and accelerating certain power sector reforms. We also recommend reviewing FIT compensation levels for wind and making FITs more location-specific.

Progress is already being made on some of these issues. For example, wind forecasting and a revised grid code for wind were implemented in 2011; a solar FIT and new solar interconnection procedures have been put in place; and the renewable energy surcharge was increased in September 2013 to cover a large shortfall and to finance further expansion in renewable energy capacity. Our recommendations build on these developments. These recommendations include defining compensation arrangements to encourage more flexibility from existing generators, prioritizing flexibility when considering and approving new generation plants, stopping addition of inflexible generation to areas with high levels of wind and solar and existing inflexible generation plants, consolidating balancing areas, improving wind forecasting, transitioning to faster scheduling and dispatch, adopting generation interconnection and transmission planning practices, and implementing priority dispatch for renewables.

Grid Company Demand-Side Management

Energy efficiency is a cost-effective resource, and the integration of energy efficiency into power sector planning and operations is one of our core recommendations. Although the Chinese government has for many years

placed a high priority on improving end-use energy efficiency across all sectors of the economy, it is still at the early stages of making the efficient end-use of electricity a core concern of power sector policy. The "Demand-Side Management (DSM) Measures Implementation Rule" of 2010 was an important first step, obligating grid companies to meet end-use energy efficiency and load reduction targets. In line with our planning recommendations, we also recommend requiring grid companies to acquire all cost-effective energy efficiency before purchasing electricity from generators. This will require continuing reforms to change the grid company business model in China, possibly by implementing new incentive mechanisms for the grid companies, as has been the case in many parts of the United States. We also recommend redefining the standards by which the government assesses the performance of the state-owned grid companies and their executives, so that the success or failure of the grid company efforts to increase end-use energy efficiency in their customers' facilities becomes an important performance metric.

Coal Quality

Reducing the sulfur and ash content of coal improves power plant efficiency and lowers carbon emissions, while also reducing air pollution and coal transportation costs. Typically these benefits significantly outweigh the costs of washing and processing coal in order to reduce sulfur and ash. In China, however, coal-washing targets that date back to the Ninth Five-Year Plan (1996-2000) have still not been met. Various countries have reasonably comprehensive systems for washing, processing, and classifying coal that developed from the efforts of private firms motivated by the effect of coal quality on profits, as well as government oversight and licensing requirements. For China, we recommend a similar policy that specifies, monitors, and enforces the characteristics of the coal each plant is allowed to burn, including type, range of heating values, and sulfur and ash content. Given China's severe water constraints, we also recommend water recycling as well as consideration of processes that do not require water, such as dry additives and mechanical separation.

Chapter 1: Power Sector Planning

1.1 Introduction and Overview

Power sector planning is an essential part of providing reliable, clean electricity service at reasonable prices. Looking around the world, it is clear that planning is necessary across all models of power sector structure. Even where governments have “liberalized” the power sector, detailed planning is crucial in order to design markets to deliver desired outcomes and also to test whether existing market designs are producing optimal—and desired—outcomes.

Broadly speaking, power sector policy should have two interlocking components: one, preparation and regular updating of a comprehensive power sector plan to meet reliability, environmental, and other important goals and two, design and periodic adjustment of a mechanism, which may be competitive, to deliver the resources identified in the plan. The first component is the subject of Chapter One; we address the second in Chapter Two.

Our recommendations for China center on expanding the scope of power sector planning and improving analytic methods in order to identify a portfolio of resources — generation, transmission, and demand-side investment — that is more cost-effective, cleaner, and less risky than the business-as-usual resource mix. In brief, we recommend:

1. Integration of end-use energy efficiency as a resource into the planning process so that it is directly compared with traditional supply-side resource options. We expect that this change will lead to increased investment in end-use efficiency, as it is a less expensive and cleaner alternative to new power plants.²
2. Better analysis of generation options, which will, among other things, lead to the increased use of natural gas-fired and distributed generation, which will, in turn, improve the utilization of the existing fleet of generation assets.

3. Greater coordination of power sector planning with environmental policy design and implementation.³ We expect that this will reveal many low-cost options to reduce environmental contamination, in particular emissions of air pollutants and greenhouse gases.
4. Integration of transmission planning into power sector planning. We believe this will lead to better coordination in the development of new generation facilities and their associated transmission facilities.

These recommendations are discussed in the sections that follow. In addition, there are two appendices at the end of this chapter that go into greater detail on several important technical issues.

1.2 Integration of End-Use Energy Efficiency Into Power Sector Planning

China has placed a high priority on improving end-use energy efficiency in every sector. It has set binding targets for the overall energy intensity of the economy and has implemented a broad set of policies and programs that support comprehensive investment in energy efficiency.⁴ Despite this progress, however, energy efficiency *as a cost-*

- 2 Throughout this and the other chapters, we use the terms “efficiency” and “energy efficiency” to mean measures and programs to improve the efficiency with which electricity is used—that is, end-use efficiency in customers’ homes and businesses. When we refer to other kinds of efficiency, such as economic efficiency and thermal efficiency (of generation), our meaning will be clear from the context of the discussion.
- 3 When considering generation and demand-side resource options, it is important to consider costs and benefits from the perspective of China’s overall goals. Under this approach, the costs of a supply-side or demand-side resource include an estimate of “all direct costs” over the effective life of the resource, including environmental costs and benefits directly attributable to the resource.
- 4 See Crossley, 2011 and Price et al., 2011.

effective resource to meet demand for energy service has yet to be well integrated into power sector planning.

Groundwork for this improved approach to planning has been laid. In November 2010, the National Development and Reform Commission (NDRC) issued the “Demand-Side Management (DSM) Measures Implementation Rule,” which, for the first time, assigns customer end-use efficiency obligations to the grid companies. The initial level of the obligation is low, but the policies, institutions, and associated mechanisms needed to support aggressive investment are now being put in place. Integrating DSM into power sector planning will assure that future DSM goals are scientifically and economically justified.

Modern power planning tools are able to fully evaluate the contributions that demand-side resources, including flexible demand response (load management) for efficient grid integration of variable renewable resources, can make to system operational needs in both the short and long terms.

There are numerous examples around the world of this general approach to power sector planning. To illustrate our main ideas, we here briefly describe one in particular — that of the Northwest Power and Conservation Council in the United States. More detail is given in Appendix A at the end of this chapter.

1.3 Principles of Power Sector Planning: Case Study, Northwest United States

Power sector planning is handled at the state and regional levels in the United States (US). In the US northwest,⁵ the Northwest Power and Conservation Council (NPCC or “Council”), which was created in 1980, leads the planning efforts in the region (consisting of four states: Washington, Oregon, Idaho, and Montana).

The Council’s current planning methods have developed from years of experience. The challenges that confront China’s power sector are in many ways unique, but the planning methods developed by the NPCC are adaptable and can help China address those challenges.

The national law that established the NPCC sets out several aspects of the planning process that are relevant to China:

- The plan must achieve an “adequate, efficient, economical and reliable power supply” at the “least cost.” Here, “cost” is defined to include all costs associated with a resource over its life, including

the costs of the impacts of pollution and other environmental damage to society.⁶

- The plan must treat end-use energy efficiency as a resource — that is, it must compare energy efficiency directly to conventional generation resources and establish that mix (portfolio) of resources that will meet demand for energy service at the lowest cost over the long term.
- Energy efficiency is declared to be a “priority” resource. The law defines the concept of a “loading order,” a protocol to guide new investment decisions. The loading order gives preference to resources for their environmental and economic benefits. Resource acquisition must begin with end-use energy efficiency and is followed in turn by renewable resources, resources with high fuel conversion efficiencies (such as combined heat and power [CHP]), and finally other, more traditional resources, such as natural gas-fired plants.

The main steps of NPCC’s planning process — which together make up a regularly repeated cycle of activity — are as follows.

Stakeholder input given: The first step in the planning process is a request for comments from the public and stakeholders on the key issues that a power plan should address. For example, for its recent Sixth Power Plan, the Council expressly sought comments on how to improve system flexibility in order to integrate wind, solar, and other variable output (i.e., non-dispatchable) resources into system operations.

Estimation of a baseline demand forecast with “frozen efficiency”: The initial demand forecast serves as a baseline. It is called the “frozen efficiency” forecast because it assumes that no new end-use efficiency improvements will be made over the planning period. Demand forecasts

5 See Northwest Power and Conservation Council, 2011 for more detail.

6 Environmental damage costs are one type of “external” cost or “externality.” They are called “externalities” because their costs are not reflected, either fully or in part, in the market for the good or service in question. But there is no question that they constitute real costs to society—through illness, reduced productivity, destruction of natural resources, and so on—and these costs should be accounted for during the planning process.

that account for planned investment in end-use efficiency are developed in relation to this “frozen efficiency” baseline.

Assessing costs of various generation and energy efficiency options: The Council estimates the costs of all possible generation and energy efficiency options. Council analysts evaluate both well-established technologies and newer technologies that are relatively expensive or immature. The cost estimates include adjustments for uncertainties about how costs will increase or decrease over the planning horizon. Costs also include quantifiable environmental costs associated with the mitigation of adverse impacts on air, water, and land.⁷ The costs of other, less easily quantified externalities, such as climate change, are captured in the risk analysis performed in the preparation of the overall resource strategy (described below). The costs of upgrading or building new transmission to interconnect the plants to the grid are also included. Lastly, the costs of each are put into a format—levelized dollars per megawatt-hour (MWh) over the life of the resource—that allows for easy comparison but which is not a sufficient basis on which to make investment decisions. It is the final step of the planning process—the development of the overall “resource strategy”—that determines the most cost-effective means of serving energy needs.

Preparing the overall “resource strategy”: Calculating the costs of resource options is only the beginning of the economic analysis. Cost alone cannot reveal the value of a resource to the system. How a plant runs, what needs it meets, how it affects other plant operations, and risks that it imposes on the system are among the factors that combine with direct cost to determine whether a particular investment is cost-effective. In developing the resource strategy, the Council tests the various resource choices against the demand scenarios and determines the mix of resources that most economically serves load, while meeting reliability and other policy goals (e.g., renewable energy targets, emissions reductions, and so on).

In this final step, the Council assembles a cost-effective portfolio of resources to meet expected demand. By “cost-effective,” the Council means the lowest total cost over the long term. In making this assessment, the Council adjusts its analysis by two sets of factors that will affect outcomes: resource operational characteristics and risk.

- **Operational Characteristics:** The Council’s planning models consider how each option operates in the overall power system. This step takes into account all of a power plant’s characteristics, particularly

flexibility (i.e., the degree to which a resource can be dispatched to help balance demand and supply and contribute to reliable system operations). (Note that this step is an example of the type of analysis discussed in section 1.4.)

- **Risk:** The risks associated with each option and with the system as a whole are also assessed. They include, among others, the risks associated with booms or busts in economic growth, fluctuations in the relative fuel costs, demand uncertainty, construction cost overruns, construction delays, and environmental risks not already reflected in the monetized costs of the resources (such as, for example, the failure to comply with environmental regulations, failure to reasonably anticipate changes in those regulations, accidents, and the effects of climate change on resource availability and demand). The riskiness of a resource, and of the portfolio as a whole, is then reflected in its cost: the riskier it is, the more it costs.

The Resource Portfolio Model (RPM) is the computational tool that the Council uses to identify the optimal portfolio of resources. The RPM compares resource choices under many “future scenarios.” Each scenario presents a different but plausible forecast of the future, each with different expectations for economic growth, fuel prices, capital costs, demand, and so forth. Out of that comparison emerges the resource portfolio that best meets the region’s demand, environmental protection objectives, and other policy goals, reliably and at lowest total cost, across the many possible futures—that is, the portfolio that is most versatile or “robust.” This is economic analysis in its truest form: from the “societal” perspective wherein all costs and benefits are accounted for.

In the 30 years since the NPCC was created, it has issued six plans. Each has been an improvement on its predecessor, in its scientific methods and in the

7 Some of the costs may in fact be benefits. For example, the Council credits end-use efficiency for its quantifiable environmental benefits—that is, it reduces the cost of efficiency (for the purpose of the analysis) to reflect the value of those benefits (e.g., avoided pollution). The Council also awards end-use efficiency an additional cost advantage—it increases the cost of generation alternatives by 10 percent—to reflect efficiency’s designation as the “priority resource.” In so doing, the Council is “internalizing” real benefits (or costs) that traditional financial analysis would overlook.

sophistication with which it addresses the complicated interactions of the many elements of the economy, environment, and power sector itself. NPCC is the national leader in power planning.

1.4 Improved Economic Analysis of Generation Options

Long before energy efficiency, the environment, or risk were considerations for power sector planners, the primary goal of planning was merely to find the optimal mix of different types of generation. There are well-tested methods for doing so, in use widely around the world, but they are not used in China. Improving the way China analyzes generation options and makes investment decisions is especially important today, because the country's broad policy goals, which call for increased diversity of supply—renewables and natural gas, in particular—are unlikely to be met if it continues to rely on analytical methods that fail to reveal the true value of such resources.

Currently, China chooses between gas-fired and coal-fired generation by comparing the levelized cost per MWh of a natural gas plant operating for a given number of hours per year with that of a coal plant operating for its own specified number of hours per year. As noted in the discussion about the NPCC planning process, this approach, by itself, does not provide a sufficient basis on which to make a reasoned resource decision, because it fails to reveal the true economics—the true value—of these very different types of generation. This explains why some Chinese analysts conclude—wrongly, in our view—that natural gas-fired generation is not cost-competitive.

Appendix B describes the ways in which internationally accepted planning methods reveal how power plants with very different capital and operating costs can combine to meet electricity demand in an optimal way. The analysis shows that natural gas is already cost-competitive for peaking generation in China and that using natural gas for peaking generation will help to improve the efficiency of existing coal-fired power plants. (Improved planning methods will uncover the true economic and environmental value [or costs] of particular resources and resource portfolios; but in order for that value to be captured in real-world investment and operational decisions, several reforms to generation pricing and dispatch will be necessary. These are taken up in Chapter 3.)

1.5 Increased Integration of Power Sector and Environmental Planning

Environmental protection and improved air quality are high priorities in China, particularly in light of the severe and large geographic scope of the air pollution events of early 2013. Recent research estimates that air pollution causes about 2.1 million premature deaths each year worldwide, predominantly in India and China.⁸ In 2007, the World Bank calculated that the health costs of air and water pollution amount to about 4.3 percent of China's gross domestic product (GDP).⁹ PM_{2.5} from coal-fired power plants has adverse health impacts on people of all ages, but it especially affects the health of children, with long-term effects on cognitive functions, which also will constrain China's future economic health. Addressing the air pollution problem requires a nationwide effort in every sector of the economy, particularly power, which is a major polluter. Power sector planning will play a key part in the national efforts to improve the environment.¹⁰

Making emissions a critical consideration in the planning process will allow China to make well-informed power sector decisions in two ways. First, it will require planners to identify and address costs associated with expected environmental policies over the lives of the generation options. In recent years the Chinese government has issued important new air quality management policies, including the NO_x and SO₂ emission reduction targets (mentioned previously) and requirements for 113 cities to develop air pollution control plans by 2015. China's current ambient air quality standards are less stringent than those in the United States or Europe, however, and are likely to be revised again in the near future. Power system planners should anticipate these revisions to air quality standards and account for the effects that implementation of the more stringent policies will have on the costs of power plants. By way of example, the costs of installing emissions controls should be factored into a power plant's resource cost, even if the controls are only required by policies expected to be implemented and enforced several years in the future. This

8 Lancet, 2012.

9 World Bank, 2007.

10 For more discussion of the strong connection between energy and environmental policy, see Ma et al., 2013.

approach will lead to increased reliance on clean resources and increased investment in pollution control equipment, simply as a matter of risk management. But, perhaps more important, it will reduce the total cost of compliance with environmental regulations by encouraging investment control equipment at the time of power plant construction rather than through more expensive retrofits later.

Second, the planning process will reveal the total costs and emissions of different resource scenarios. This information will allow power sector, environmental, and other policymakers to see the real tradeoffs between cost and improved air quality (see Text Box 1).

1.6 Include Transmission Planning in the Power Sector Planning Process

China's grid companies are world leaders when it comes to designing and building infrastructure. Yet three of the major power sector challenges China faces today relate to shortcomings in transmission policy and planning: (1) addressing the need for greater interprovincial power trade, (2) interconnecting and integrating renewable energy into the grid, and (3) addressing the problem of generation curtailment.¹¹ Coordinated grid and generation planning may have suffered when China separated generation from

Text Box 1

Assessing the Connections Between Energy and Environmental Planning

A recent study by Ma et al., 2013 illustrates how China's environmental goals can be a significant driver of energy choices in the power and other sectors. The report discusses the financial implications of addressing (or not addressing) China's air pollution problems. In so doing, it also illustrates the connections between energy and environmental planning. The following excerpt summarizes the findings:

... to reduce urban average PM_{2.5} to 35 [micrograms per square meter] by 2030, China should sharply reduce its coal and car consumption growth, and massively increase investments in clean energies and subways/railways. We propose a policy package that can achieve a reduction in the annual urban average PM_{2.5} to 35 by 2030, a target that is a political imperative. This package will require the following changes to current policies or plans, among others:

- 1. Reduce the annual average coal consumption growth by half (to 2%) from the current forecast of a 4% CAGR for 2013-17, and cut coal consumption by 22% from 2017-30. This means that China's coal consumption should peak in 2017, vs. the consensus projection of a peak around 2025.*

- 2. Reduce coal-related emissions by about 70% in the coming 18 years via clean coal technologies.*
- 3. Reduce emissions per car by more than 80% by enforcing high standards for gasoline and car emission and improving fuel efficiency.*
- 4. Increase the annual growth rate of clean energies (gas, nuclear, hydro, wind and solar) by another 4ppts for 2012-20 vs. the current forecast.*
- 5. Reduce the 2030 target for passenger vehicles to 250mn from current expectation of 400mn. This implies a reduction in annual average car sales growth to 5% during 2013-30 from 20% p.a. in the past five years.*
- 6. Increase the length of railways and subways by 60% and four-fold, respectively, from 2013-20, and further increase the length of railways and subways by 60% and 230%, respectively, from 2020-30.*

Our analysis shows that these new targets are technically achievable, and their impact on economic growth, fiscal balance, and inflation is manageable. It does, however, require a strong government to overcome the opposition from interest groups.

11 There are a number of complex issues that influence interprovincial power trade, including cost allocation and pricing, provincial and municipal taxation policies (that may favor in-region production over imports), and wholesale generation pricing terms (that put out-of-region production at a disadvantage). Addressing these questions is well beyond

the scope of this part of the chapter. Some of them will be discussed in Chapter 4. It is worth noting at this point, however, that breaking down barriers to investment and increased trading is very important and should be considered in the transmission planning process.

the grid companies, after which planning for both was no longer the responsibility of one entity. Whether this is the case or not, it is nevertheless clear that more coordinated planning—and the analytical tools to support it—are needed.

The need to connect transmission and generation planning is clear. Planners should use their analytical tools to calculate the economic trade-off between, on the one hand, low-cost but remote generation that requires more transmission investment and, on the other hand, more costly generation closer to load centers requiring less transmission investment. They can also analyze how transmission investment can be shaped to meet not only reliability requirements but other public policy objectives as well (e.g., a coal consumption cap, local air quality goals, and renewable energy targets). We recommend a routine, institutionalized transmission planning process that is overseen by government regulatory authorities. Two examples from the United States may be helpful in this respect.

1.6.1 NPCC and Transmission Planning

In developing its resource plan (discussed earlier and in Appendix A), the NPCC pays close attention to the costs and risks associated with the transmission requirements of each resource option. The Council is not directly responsible for transmission planning, but it does provide input to federal, state, and utility transmission planning processes. Although the NPCC doesn't have final authority over the details of transmission planning, its resource plan strongly influences transmission planning decisions. The NPCC recognizes that transmission has costs and benefits. Consideration of these costs and benefits is well integrated into the NPCC's own planning process.

Two characteristics of transmission in the Northwest make this region's experience especially relevant to China. First, like China, the Northwest has a large government-owned grid company, the Bonneville Power Administration (BPA), which is empowered to construct and operate transmission facilities to serve all users in the region. It is obligated to provide transmission service to all who request it. Second, by law, BPA's mission and priorities are closely aligned with those of the NPCC. BPA must comply with the Council's plan (or seek approval from Congress to take an action that is deemed inconsistent with the plan). BPA is thus obligated to consider efficiency

and renewable resources as options for its own resource acquisition needs. And, as mentioned earlier, transmission planning (by BPA) is closely coordinated with power supply planning (by the NPCC). In addition, as a matter of law, BPA cannot discriminate against any power plant that seeks interconnection to the grid. When new power plants are built by any entity (public utility, private utility, or independent power producer), BPA is obligated to provide transmission service. As a result, planned generation resources seldom face transmission-related construction delays or constraints.

1.6.2 California and Transmission Planning

Every year the California Independent System Operator (CAISO) produces a plan that identifies new transmission needed to meet California's reliability and policy mandates. California's renewable energy goal (33 percent by 2020) has become the principal driver of transmission planning and investment.

Key components of the transmission plan include:

- Identification of transmission investments needed to support meeting the renewable energy goal. Planners vary assumptions and prepare a range of forecasts of new renewable resource portfolios over a ten-year planning horizon, including type and location.
- Analysis of transmission needs for a range of these possible renewable resource portfolios.
- Identification of transmission upgrades and additions needed to reliably operate the network.
- Economic analysis of transmission upgrades or additions to determine whether they provide additional ratepayer benefits, beyond mere reliability.

CAISO has also taken steps to better integrate generation interconnection procedures into the transmission planning process. The principal changes aim to assure that the addition of new generation is better coordinated with new transmission needed to integrate the capacity with the system.

1.7 Conclusion

Improving power sector planning in China is partly organizational in nature and partly technical. The organizational question—who should be responsible for planning?—can be answered a number of ways. Institutional roles and responsibilities vary around the

world. In many countries, for instance, grid companies are responsible for detailed planning, while the government sets goals and oversees the grid company efforts. Given the unique features of China's power sector, the government may want take on a larger and more direct role in planning than governments do elsewhere. But, whatever the precise role of government in developing the plan, the lesson to learn from successful efforts elsewhere is that the planning process—and thus the plan itself—will be better off if a single government entity is given authority for it. Other government agencies will of course be involved—this is necessary if the plan is to truly integrate supply, end-use efficiency, transmission, and environmental considerations—but ultimately a single entity should be made responsible for the process and the plan that comes out of it. That entity should also have authority to see the plan implemented (which means, among other things, that it should oversee competitive acquisition procedures and pricing; see Chapters 2 and 3). The recent decision to merge the State Electricity Regulatory Commission into the National Energy Administration can be seen as a significant step in the right direction.

As for the technical question—how should the plan be developed?—this chapter makes four recommendations. In summary, they are:

- 1. Expand the scope of planning to include comprehensive consideration of all resources and impacts.** Planning should directly compare demand-side resources, supply-side resources, and transmission resources in an integrated process. It should account for all the costs of the various options, including their environmental costs.
- 2. Recognize the value of natural gas-fired, distributed, and combined-heat-and-power generation.** If planners improve their analysis of these resources, then it will become clear that greater investment in them can lower total power system costs and reduce emissions.
- 3. Coordinate energy policies with environmental policies.** The integration of power sector policymaking with environmental policies (such as caps on coal consumption, emissions trading schemes, and regional air quality management plans) will allow for more rapid, less expensive, and smoother reductions of emissions and other pollutants. The failure to do so risks adoption of

policies in both arenas that will work at cross-purposes or even render them ineffective altogether.

- 4. Coordinate transmission expansion and renewable development.** This will help to better connect renewable resources located in areas far from electric demand and will allow for more power to be transmitted between regions.

1.8 Appendix A: Power Sector Planning in the Northwest United States

Power sector planning is handled at the state and regional level in the United States. In the US northwest, planning is well developed and comprehensive.¹² The Northwest Power and Conservation Council (NPCC or “Council”), which was created under federal legislation adopted in 1980, leads the planning efforts in the region (consisting of four states: Washington, Oregon, Idaho, and Montana). A regularly updated plan identifies a targeted mix of resources; state governments then use competitive mechanisms to acquire the resources.¹³

The Council's current planning methods have developed from years of experience and may, in detailed form, be too ambitious—at least in the near term—for China to consider implementing. The basic elements of the NPCC planning cycle are quite applicable to China, however, and can be viewed as the basis of a scientific planning process.

The federal legislation that established the NPCC includes several directives:

- The Council is required to create and regularly update a long-term (20-year horizon) strategy for meeting the region's power sector needs.
- The plan must consider all costs and benefits from a societal perspective, including pollution costs.
- The plan must achieve an “adequate, efficient, economical and reliable power supply” at the “least cost.” System cost is defined to include all costs of a resource over its useful life, including quantification of the impact of pollution on society.
- The NPCC is required to treat energy conservation (that is, end-use energy efficiency) as a resource and

12 See Northwest Power and Conservation Council, 2011 for more detail.

13 Strictly speaking, the plans are “advisory” to the states.

to directly compare that resource with conventional resources (e.g., thermal power plants). In fact, the legislation emphasizes energy efficiency as a “priority” resource. It establishes the concept of a “loading order,” which begins with energy efficiency, followed by renewable resources, then resources with high fuel conversion efficiency, and finally other resources.

1.8.1 NPCC Planning Process

Before the NPCC was established, the individual electric utilities conducted power sector planning, which was in many ways very simple. Planners would make one forecast of the demand for electricity and then draw up a list of resources to meet that forecasted demand. The relative costs of various generation options were a consideration, but, at that time, end-use energy efficiency was not considered as a resource. There was inadequate consideration of the risks (such as cost-overruns and construction delays) associated with different generation options. In addition, there was no attempt to consider the flexibility of generation options because the region’s hydroelectric resources provided considerable flexibility, and integration of variable renewables had not yet become an issue.

Since the early 1980s the Council has been a leader in developing increasingly sophisticated planning methodologies, in line with the directives set out in the legislation. These methods—as well as the general philosophy of the Council’s approach—have been influential in other states and countries, many of which now require an integrated resource planning process.

The Council uses several models in its planning process to assess each of the following:

- electricity demand and the scope for energy conservation (end-use energy efficiency);
- natural gas, oil, and coal prices;
- the levelized cost of generating (i.e., supply-side) resources;
- the levelized costs of efficiency (i.e., demand-side) resources;
- electricity market prices at different points in the region;
- the overall adequacy and reliability of the regional electricity system; and
- most important, the overall costs, benefits, and risks of the various resource portfolio options.

The main steps of the planning process—which together

make up a recurring cycle—are as follows.

1.8.1.1 PUBLIC INPUT

A first step in the planning process is a request for comments from the public and various stakeholders on the key issues that a power plan should address. For example, for the recent Sixth Power Plan, the Council requested comments on various issues, including improving system flexibility in order to integrate wind and other variable output resources. More broadly, the process is highly transparent and open to public scrutiny throughout the planning cycle. The Council regularly publishes updates and holds public hearings on its findings.

1.8.1.2 ESTIMATION OF A BASELINE DEMAND FORECAST WITH “FROZEN EFFICIENCY”

The Council makes some initial forecasts of wholesale electricity prices, based on assumptions about fuel prices, economic growth, and so on. These forecasts of electricity prices eventually change later in the planning process, once energy efficiency investments are identified and the demand-lowering effects of the investments are taken into account. However, the initial demand forecast serves as a baseline. Crucially, it assumes that no technical efficiency improvements are made over the planning period. For this reason it is called the “frozen efficiency” forecast. It serves as a comparison for demand forecasts that come later in the process and take account of planned investment in energy efficiency. All demand forecasts and efficiency assessments are based on “bottom-up” analysis of end-uses of energy and the various technical possibilities for efficiency improvements. This “inventory” method also helps assess the potential for efficiency as a resource.

1.8.1.3 ASSESSING COSTS OF VARIOUS RESOURCE OPTIONS

The Council puts careful effort into estimating the costs of all possible options—on both the supply and demand side—and calculates the results in terms that are directly comparable across options. Council analysts look at well-established technologies, as well as technologies that are still expensive or immature. For the latter, the estimation of costs may include adjustments for uncertainties about how fast costs will decrease over the planning horizon.

When assessing resource costs, the Council looks at costs from a “societal” perspective. Under this approach,

the costs of a supply-side or demand-side resource include an estimate of “all direct costs” over the effective life of the resource, including environmental costs and benefits directly attributable to the resource.

For power plants, total resource cost includes capital costs and operation costs (which typically in the Pacific Northwest system fall directly on end-users in the form of rates) as well as the externalities associated with pollution and carbon emissions. The cost of upgrading or building new transmission associated with the new plant is also included.

The same cost principles are applied to energy efficiency. The total resource costs of a given efficiency measure include the costs of purchasing, installing, and maintaining the new, more efficient equipment. These costs are included, regardless of who pays them. (In some programs, the utility may pay part of the cost while the facility owner pays the remainder. Both costs are included in the overall cost of the efficiency measure.) Costs of evaluation and program administration are included. However, energy efficiency also includes non-energy benefits. In particular, the Council adjusts the cost of efficiency to take account of avoided natural gas, petroleum, water, wastewater, and similar costs and the associated benefits in terms of reduced pollution.

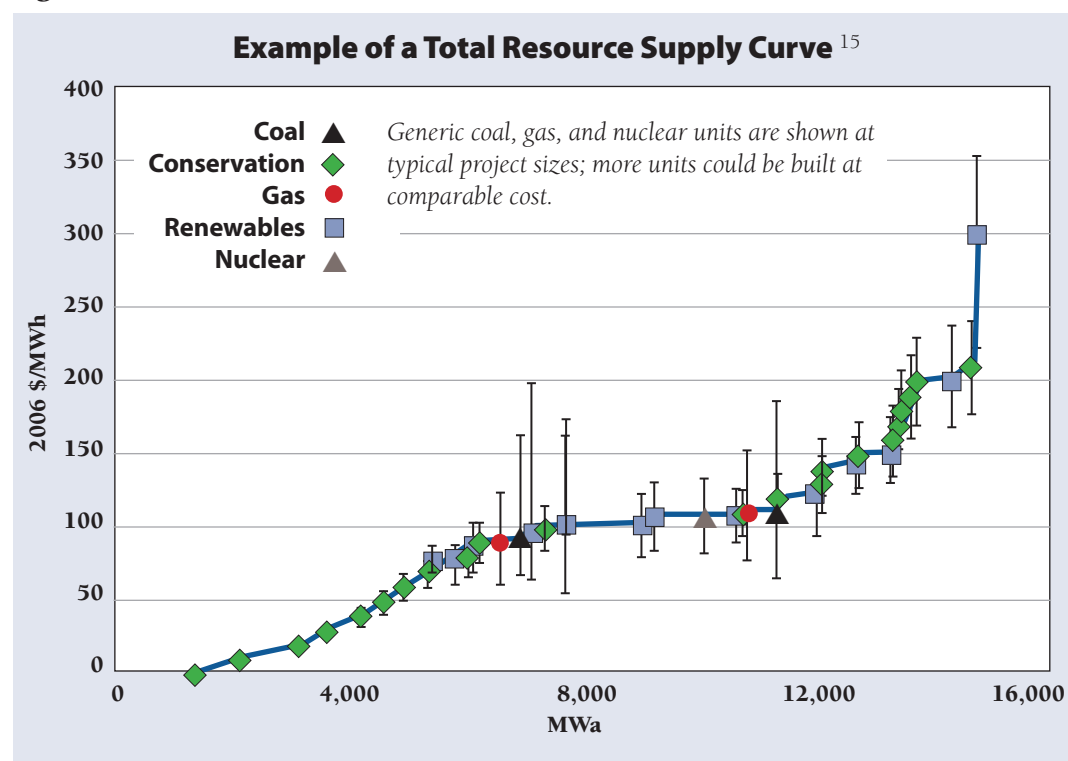
The Council analyzes its “inventory” database of energy end-uses and considers all technically feasible efficiency measures. The possible efficiency measures include retrofits of existing equipment and appliances. However, the Council also considers the scope for upgrading the efficiency of facilities that have not yet been constructed. For example, the Council considers the costs and benefits of upgrading machinery in a facility to a level beyond that which the facility owner would normally install. This becomes particularly important during periods of rapid

growth when many new facilities are under design.

Total resource costs for each resource option are calculated in a fashion that allows direct comparison of the various resources.¹⁴ In particular, costs for plants and efficiency measures are calculated as levelized costs, adjusted for inflation. Varying cost patterns over a resource’s lifetime are converted to present values or levelized costs to compare resources with different time patterns of cost. (As noted earlier, however, resource options are not simply compared on the basis of levelized cost; a more comprehensive analysis is necessary.)

The costs of the various resource options are assembled in a cost curve. Figure 1 shows a supply curve of generating and efficiency resources, including cost-uncertainty ranges. It is an illustration of how resource alternatives are developed for the plan.

Figure 1



14 The Council awards energy efficiency a 10-percent cost advantage (i.e., the cost of generation alternatives is increased by 10 percent) to reflect its designation as the “priority resource.” This is in addition to providing credit for the quantifiable environmental benefits.

15 Northwest Power Planning Council, 2011.

1.8.1.4 PREPARING THE OVERALL “RESOURCE STRATEGY”

The Council proceeds to assemble a cost-effective portfolio, based on the cost curve comparison of all options. The cost curve, however, is not the only consideration in preparing the portfolio:

- The Council also emphasizes reduction of uncertainty, considering how to identify and mitigate risk. Risk factors include:
 - The risk of acquiring “too many” or “too few” resources due to booms or busts in economic growth;
 - Fluctuations in the relative fuel costs;
 - Construction costs that exceed expected costs (“cost overruns”);
 - Construction delays; and
 - Potential environmental costs not already quantified in the direct costs of resources, such as those associated with climate change or the failure to comply with environmental legal requirements.
- The planning process also considers various power plant characteristics, particularly flexibility. The term “flexibility” refers to the degree to which a resource can be shaped to help meet loads on an hourly basis and its suitability to provide within-hour reserves.

The Resource Portfolio Model (RPM) is the computational tool that the Council uses to identify the optimal portfolio of resources. The RPM assesses thousands of potential resource choices. For example, two potential resource options might be:

1. a gas-fired combined-cycle turbine that could be fully designed and licensed and ready for construction by 2016; and
2. an efficient lighting incentive program that could be ready for implementation by 2013.

These two illustrative resources have different time horizons for construction, different measure lives, different capital and operating costs, and different load shapes. The next task is examining how the entire portfolio of options fits together in terms of reliability, cost, and risk.

The RPM compares thousands of such resource choices under hundreds of “future scenarios.” Each future scenario presents a different hypothetical version of the future, with a different economic growth path, different fuel prices, capital costs, and so on. According to the Council, “[t]he key to assessing risk is a model structure that makes

resource decisions without assuming knowledge of future conditions.”

Essentially, the RPM helps the Council identify a resource portfolio that works best across the many possible futures that it forecasts. No one resource mix is the best for *all* futures, but the RPM helps the Council identify the portfolio that has a reasonably low average (“expected”) cost and the lowest risk of producing high-cost results, should future conditions be particularly challenging. In general, resources with small unit size, short lead times, and little pollution are found to mitigate risk; all of these tend to favor end-use energy efficiency over conventional supply options.

Because electricity prices in the region vary depending on the day of the week, time of day, and season, the shape of efficiency savings is an important part of the analysis. Measures that save energy during peak demand hours, such as space heating, will have more value to the power system than a measure that saves energy during off-peak hours, such as streetlights.

In the Council’s experience, the RPM tends to recommend portfolios that emphasize energy efficiency: “[Energy efficiency] is low cost, uses no fuel, emits no carbon, and can defer or eliminate transmission expansion. Because of its low cost and risk relative to other resources, the chosen resource portfolios typically put a premium on efficiency. . . . Efficiency turns out to be a low-cost insurance policy against high market prices, rapid unexpected growth, as well as high fuel and carbon prices.”

The RPM also tends to favor natural gas-fired generation over other types of plants. Although natural gas suffers from the risk of uncertain future fuel prices, it has the advantages of relatively low capital costs, short lead time, and high flexibility. Appendix B gives a specific example of how natural gas can be analyzed in the Chinese context.

Strictly speaking, the Council’s plan is not actually a mandatory set of rules for any retail electricity provider in the region, but it significantly influences all in two principal ways. First, the Bonneville Power Administration, a federal wholesale power supplier to more than 100 electric utilities, is obligated to follow the plan in its own resource acquisition (or seek Congressional approval to choose another option). Second, each of the state regulators tends to give great weight to the Council Plan in evaluating the actions of the utilities subject to their oversight.

1.9 Appendix B: Planning for Natural Gas-Fired Generation in China

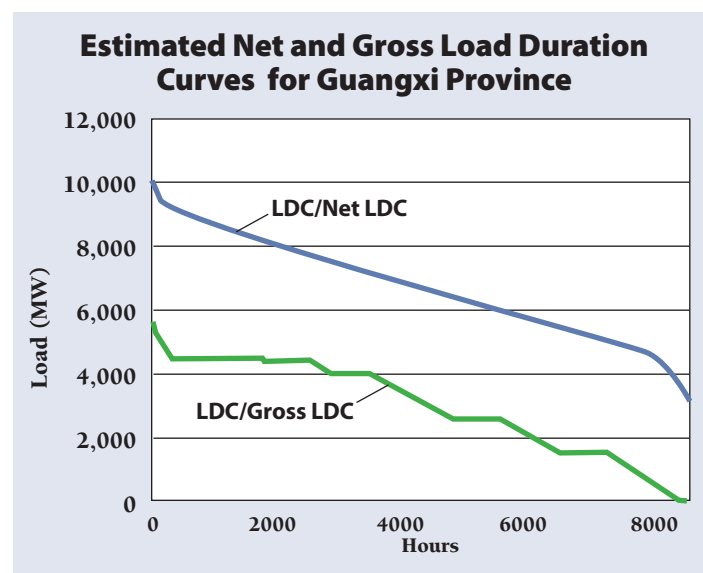
There has been debate over the cost-competitiveness of gas-fired generation in China. This section argues that existing economic comparisons between natural gas and coal-fired generation in China typically do not account for the value of the roles that gas-fired generation can have in the power sector. The analysis in this appendix shows that natural gas is already cost-competitive for peaking generation in China, and that using natural gas for peaking generation could help to improve the energy efficiency of existing coal-fired power plants.

1.9.1 Using Screening Curves and Load Shapes to Evaluate Generator Economics: Guangxi Case Study

In other countries, generation planning often makes use of two analytical tools: load duration curves (LDCs) and screening curves. An LDC is an ordered ranking of electricity demand over time, usually a year, with peak demand in hour 1 and the lowest demand in hour 8,760.

Figure 2 shows an estimated LDC for Guangxi Province, calculated using monthly peak demand and typical daily load shapes. The LDC can be converted to a “net thermal” LDC by subtracting out nuclear power, wind power, and hydropower in each hour and then reordering demand from largest to smallest hour. The net thermal LDC shows the amount of thermal generation required to meet demand in each hour. For Guangxi, which primarily uses coal

Figure 3



and hydropower and uses hydropower as baseload in the summer monsoon season, an estimated net thermal LDC is shown alongside the original LDC (Figure 3).

1.9.1.1 SCREENING CURVES

A screening curve shows the total operating (fixed and variable) costs of generating technologies for a given number of operating hours. Screening curves can be used to guide investment decisions for new generation by evaluating the range of operating hours in which each technology is economical. The screening curve in Figure 4 shows total operating costs for a simple cycle gas turbine

Figure 2

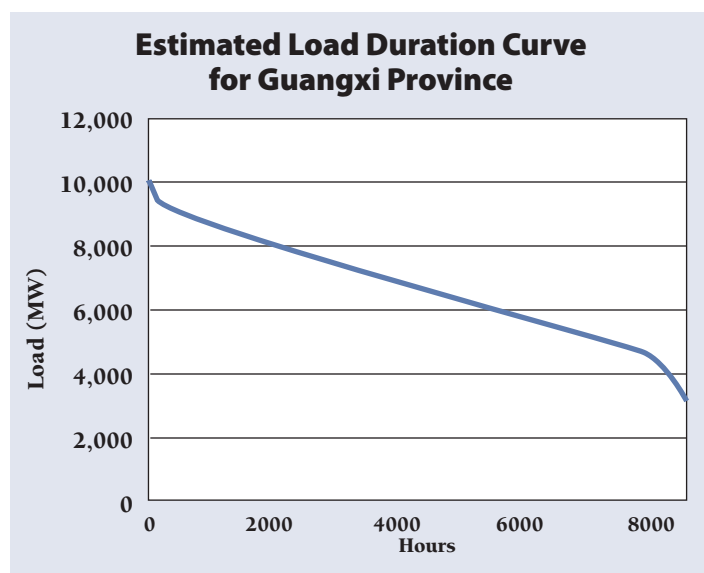


Figure 4

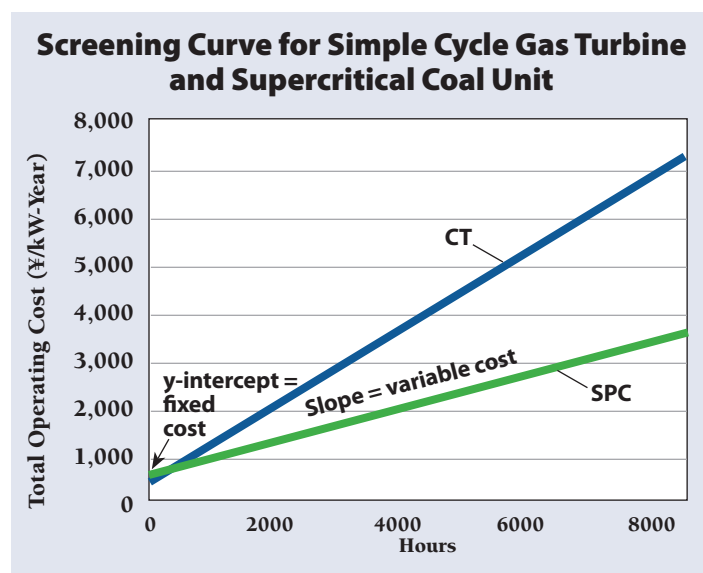
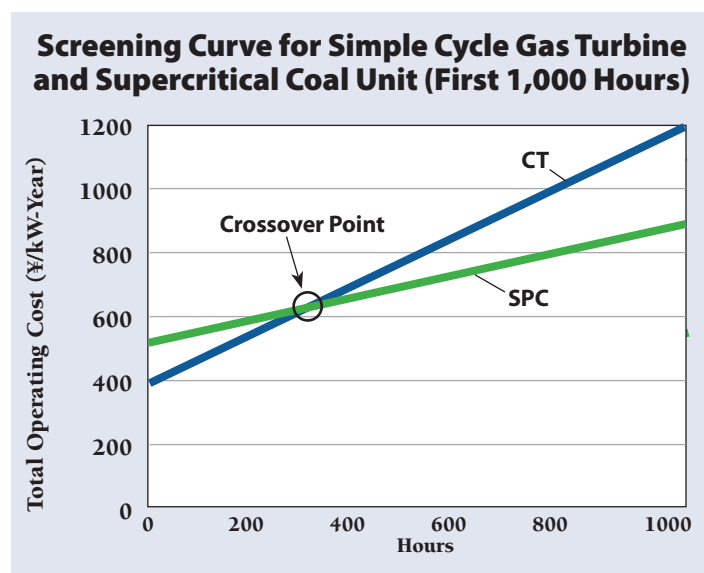


Figure 5



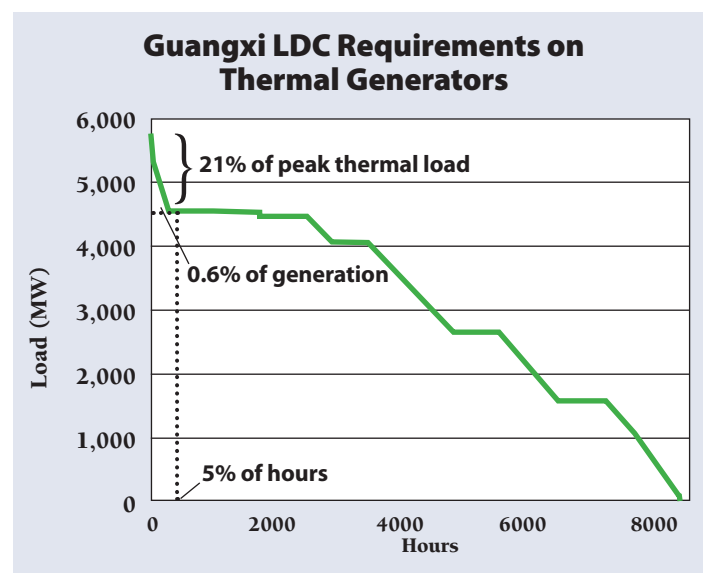
(CT) and a supercritical coal (SPC) unit in China, based on a detailed model of costs for different types of thermal generation in China.¹⁶ In the figure, the y-intercept represents the total fixed costs for each technology; the slope of each line is the technology's variable cost, and each point on the line is the technology's total annual operating cost, in yuan per kW, for the corresponding number of operating hours on the x-axis.

The screening curve shows which technologies are cost-effective for a given range of operating hours. Crossover points show the number of operating hours in which one technology becomes more economical than another. In Figure 4, these crossover points are difficult to see; Figure 5 shows crossover points for only the first 1,000 hours, which makes the crossover points more visible. At the fixed and variable costs used in this screening curve, a CT would be cost-effective if it is operated for less than about 300 hours.

1.9.1.2 COMBINING LOAD DURATION CURVES AND SCREENING CURVES

In almost all electricity systems, a large amount of generating capacity is needed to meet demand in a small number of hours. In Guangxi, the estimated net thermal LDC shows that more than 20 percent of thermal generation capacity is needed to meet demand that only occurs in 5 percent of hours (Figure 6). However, the generating capacity used to meet this demand accounts for less than 1 percent of total generation. For these peak

Figure 6



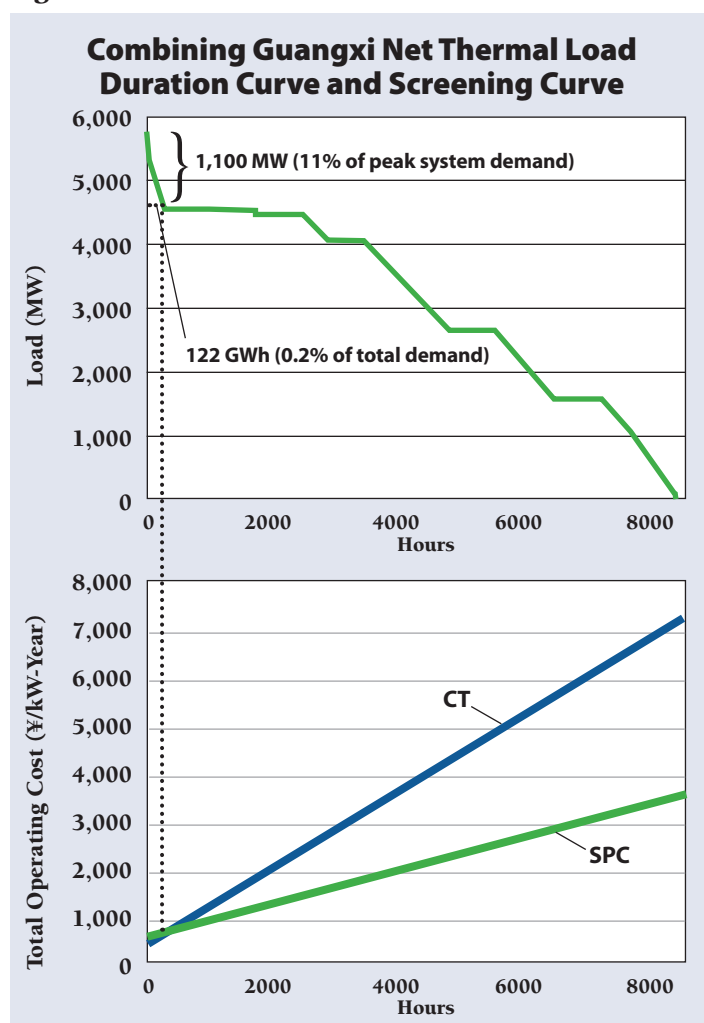
hours, technologies that have low fixed costs, such as CTs or combined cycle gas turbines, will be most cost-effective because they are inexpensive to build but are not used very often.

In combination, the net LDC and screening curve can be a useful tool for generation investment planning by providing a “screen” for which technologies are most cost-effective in which hours. By combining the net LDC and screening curve for Guangxi, we see that it would be cost-effective to build CTs to serve around 10 percent of Guangxi's total peak demand, even though these units are run in only a very limited number of hours. In fact, as long as the fixed costs of natural gas power plants are lower than the fixed costs of coal power plants, some amount of natural gas generation will always be economical.

Using natural gas units to provide peak capacity reduces the cost of providing electricity services. Total fixed costs fall, total variable costs increase, but overall total system costs fall. In Guangxi, at current capacity costs, using CTs instead of supercritical coal units to provide peaking capacity would reduce the power system's incremental fixed costs by around 5 percent, increase its incremental variable costs by around 1 percent, and reduce its total incremental costs by around 1 percent.

16 The E3 Generation Cost Model for China is available online at http://ethree.com/public_projects/generation_cost_model_for_china.php.

Figure 7



Cost reductions are relatively small because the difference between CT capital costs and SPC capital costs in China is much smaller than in most other countries, in part because gas turbines are imported, whereas steam turbines are manufactured domestically. In the United States, for instance, the ratio between natural gas and coal capital costs is around 1:2 to 1:3, whereas in China that ratio is around 1.0:1.1 to 1.0:1.3.

Meeting peak demand with natural gas rather than coal would also significantly increase capacity factors for coal-fired generators, as coal-fired generators no longer need to be built to cover the small number of hours in the summer where load is very high. In Guangxi, annual operating hours (full load equivalent) for coal-fired generators would increase from around 4,600 to more than 5,700, or by around 20 percent, if peak thermal demand were provided by natural gas rather than coal.

Increasing capacity factors for coal-fired generators could also reduce the number of hours during which they run at low load, increasing their efficiency. This improvement in efficiency will reduce fuel costs. The reduction in fuel costs will be in addition to the 1-percent reduction in total costs mentioned previously.

Because they are not operating a significant number of hours, gas requirements for gas peaking generation are relatively low. In Guangxi, using gas to meet around 1 percent of total generation would require around 35 million m³ of gas, which would have been around 20 percent of Guangxi's total natural gas consumption in 2010 (Guangxi's annual consumption of natural gas is very small).

If, at a national level, natural gas power plants accounted for 10 percent of total capacity, the scale of required capacity would be on the order of 80 GW, requiring an investment of around 200 to 250 billion yuan (US \$30-40 billion) in gas-fired capacity. Natural gas requirements for meeting 1 percent of total electricity generation with natural gas would be on the order of 10 billion m³, which is small relative to total gas consumption in China (around 110 billion m³ in 2010).

1.9.2 Conclusion

This analysis indicates that improved planning will demonstrate significant benefits to using natural gas to meet peak demand in China, including reduced system costs, higher capacity factors, and lower heat rates for coal generators. Using more gas generation when coal prices are high should be particularly cost effective.

Deciding how much natural gas capacity to build will be a challenge. The planning process should be done by balancing area, matching local load and local generation resources. To ensure that the planning process results in the least cost to electricity customers, the plan should also consider energy efficiency, demand response, and new transmission as options for meeting peak demand in the short and long run. Planning studies show optimal use of gas-fired generators requires making sure that generator dispatch is designed to use gas generators when load is high or when the system needs flexibility. Using some amount of gas-fired generation to provide capacity in China does not require subsidies, but it does require innovations in generation planning, dispatch, and pricing. These are the subjects of other chapters.

Chapter 2: Resource Acquisition

2.1 Introduction and Overview

Our recommendations for power sector planning (see Chapter 1) outline a comprehensive process to identify what power sector resources (supply side, demand side, and transmission) constitute the optimal mix. This Chapter discusses mechanisms to achieve the desired resources and also increase competition in the power sector.

Many analysts and policymakers in China are calling for rapid movement to a more competitive power sector. However, there are many models of power sector competition. Given China's legal system and institutional conditions, some models will be more difficult and raise more risk than others. The aim of this Chapter is to present some relatively low risk and effective means of addressing the sector's major challenges and China's goals. The fully liberalized models seen in portions of the United States and the European Union are not the best approach for China at this time, although these models are worth watching closely as the major market reforms in these countries proceed and as China gains more experience with incremental steps toward increased power sector competition.

We recommend different approaches for the acquisition of different types of resources in China. Acquisition of new coal- and gas-fired generation plants is a major focus of this chapter. For new coal and gas plants, we recommend auctioning of long-term contracts, in order to:

- Mobilize investment to achieve the generation resources identified in the planning process, thereby ensuring the realization of a more optimal and integrated generation and transmission planning process;
- Attract new entrants by fostering a well-established, transparent, and predictable competitive environment;
- Reduce investment and operation costs by injecting competitive forces;
- Replace an administrative approach with a market-based mechanism to establish fixed and variable

generation prices;

- Limit the power and discretion of grid companies by making the purchase decision subject to clear and transparent government oversight; and
- Build the foundation for other forms of competitive markets in the future, including bid-based spot markets.

China had some limited experience with competitive contracting for conventional generation resources during the 1990s and with renewables more recently. However, there were major defects in the design of these programs. We describe the international experience with better designs and make recommendations for China.

The final sections of this chapter address acquisition of other important power sector resources—specifically, renewable energy and demand-side resources (i.e., end-use energy efficiency). Acquisition of renewable energy is currently very effectively supported through feed-in-tariff (FIT) mechanisms, and we see no reason to abandon that practice at this time.

2.2 Auctioning Contracts for New Conventional Generation – International Experience

The type of contract auction mechanism that we suggest has been used in many countries. The basic idea is to require generators to compete for long-term contracts to build and operate new generation, as identified in a planning process that involves utilities (grid companies) and government. The contract terms define prices and performance conditions. There are many possible variations, but this kind of mechanism typically has the following characteristics:

- **Government management and oversight.** The auctions are organized—or at least closely overseen—by government authorities. Before the bidding begins, the government publishes information that defines, in

detail:

- the bidding process and rules;
- the required technical and financial qualifications needed to become a bidder;
- characteristics of the resources being sought (e.g., flexibility);
- key contract terms (e.g., termination and buy-out terms and payment mechanisms); and
- bid evaluation procedures (see Text Box 2).
- **Designation of contracting entities.** The government assigns responsibility for making the payments specified in the contracts to the contracting entities, which might be distribution companies, grid companies, or perhaps a new entity created by the government specifically to finance resource acquisition. In other words, the contracting entity may or may not be a government organization. However, particularly if the contracting entity is a company, the company is not allowed to have undue influence over the rules governing the bidding process, as those rules should, at a minimum, require careful government oversight and approval.
- **Prescreening of bidders.** Potential bidders are prescreened based on technical and financial criteria in order to ensure that winning bidders have adequate resources and ability to complete the project. In particular, bidders are required to post a financial deposit that is forfeited if predefined milestones (e.g., construction start date) are not met. Bids from bidders that fail to meet technical and financial criteria are not considered in the auction.
- **Operational obligations.** Contracts specify operational requirements (and associated penalties for failure to comply) that the winning bidder must follow, including:
 - The obligation to follow the direction of the system operator,
 - The obligation to follow dispatch to the full extent of the power plant's capability, and
 - The obligation to comply with environmental performance requirements.¹⁷
- **Efficient price structure.** A two-part (capacity and energy) pricing structure can help to support efficient dispatch and an efficient resource mix. (For further discussion of two-part pricing and dispatch reform, see Chapter 4.) Other price-related contract terms may:

- Link capacity payments to power plant availability (during times of system need), and
- Link energy prices to fuel costs.

Text Box 2

Bid Evaluation

The process by which bids are evaluated is essential to an effective auctioning mechanism. The challenge is establishing a transparent and fair system for selecting winners, given that power plant characteristics are complex and bids are not always easy to compare. If all bidders were selling identical products, the process would be easy. However, determining which power plant bid should win is more difficult than simply picking the lowest price.

Consider a simple example: two bidders compete to win a contract to build different 600-MW coal-fired power plants. According to the bidding rules, bidders must bid a two-part price. Plant A bids 950 yuan/kw and 20 fen/kwh and Plant B bids 1000 yuan/kw and 21 fen/kwh.

If the bids were evaluated on this information alone, Plant A, having both lower capital and operating price bids, would clearly be the winner.

However, other power plant characteristics should also be considered. Suppose Plant B has a lower forced outage rate, lower minimum load, faster start-up time, and faster ramping capability than Plant A. These are valuable characteristics, but are the benefits high enough to conclude Plant B should win the bid?

Ideally, the answer is derived from the same planning and operations tools used to develop the plan initially. The power system could be modeled with Plant A and then modeled with Plant B. The analysis would show which plant yields the lowest total cost.

A more practical solution for China in the near term might be to use the models to derive estimated price premiums for important power plant characteristics. This would allow a comparison to see whether the value of Plant B's favorable attributes is enough to overcome Plant A's lower price bid.

¹⁷ Contracts typically also specify that the generator will be paid "make-up" and/or "opportunity costs" if the dispatch operator asks the generator to provide regulation or spinning reserves.

In 2011, the World Bank published a review of international experience in this area, focusing largely on developing countries with high load growth (but also developed country experience).¹⁸ The developing countries discussed in the report include Brazil, Peru, Chile, Colombia, Mexico, Vietnam, Thailand, and the Philippines.

Overall, the World Bank report concludes that contract auction mechanisms have been successful at achieving new investment. Auctioning has also promoted competition and lowered costs.

Looking across countries that have used this type of mechanism, there are a number of different types of auctions (not necessarily mutually exclusive):

- Separate auctions for different types of resources, distinguished by plant capabilities, for example, baseload plants, peaking plants with operational flexibility, and renewable energy plants;
- Different types of resources (conventional, renewable, and sometimes even energy efficiency resources) compete against one another for the same contracts;
- Separate auctions for different types of technology (e.g., renewable-specific auctions);
- Separate auctions for new resources and existing resources;
- Project-specific auctions (e.g., for a particular site);
- Centralized auctions (e.g., the government organizes centralized auctions for contracts, which are then allocated to various regional distribution companies based on each distribution company's expected load growth); and
- Decentralized auctions (e.g., each regional distribution company conducts its own auction to meet expected load growth).

The World Bank report draws a number of general lessons, including:

- Auctions should have comprehensive, well-defined, and publicly announced rules that are strictly enforced in order to promote fair competition. There should be predefined penalties for violations of the rules;
- Regulatory stability is crucial. Although rules governing the auction process almost always have to be adjusted over time, maintaining continuity is important in order to bolster the transparency of the mechanism; and
- The government does not necessarily (and typically

does not) sign or guarantee the contract. In many examples, regional distribution companies take financial responsibility for the contracts that emerge from the government-overseen auction process.

In the following sections, we summarize a few international examples. The appendix provides more details.

2.2.1 India

India's experience with competitive procurement should be familiar in China: Chinese power plant builders have been involved in many of the winning bids.

In the 1990s, India adopted reforms allowing private and foreign investment in power generation through Independent Power Producers (IPPs).¹⁹ Each IPP negotiated a non-standardized contract (known as a "memorandum of understanding") with the relevant state government. Unfortunately, typically this IPP process was poorly organized and not transparent. As a result, there was insufficient competition and weak cost containment. The process was highly controversial, and many projects fell far behind schedule or were never completed.

Based on the lessons from the 1990s, the Indian government set up independent state electricity regulatory commissions and passed a new law, The Electricity Act of 2003, which changed power sector policy in favor of transparent contract auctioning under standardized rules established by the central government. This new approach has been more successful, with more than 42 GW of generation capacity contracted through the competitive bidding process by 2010.

The bidding process is based on the national Ministry of Power's "Standard Bidding Documents," which are designed for use in all auctions. These include a "Request for Qualification" (RfQ), "Request for Proposal," and model "Power Purchase Agreement" (PPA). The Ministry of Power's rules also define the details of the bidding process, as well as the bid formats and the evaluation criteria. Regional distribution companies conduct the auctions, subject to approval by the relevant state regulatory commission (or the central regulatory commission if the project crosses state borders).

18 Maurer & Barroso, 2011.

19 Our discussion of India is based on Gadag et al., 2011.

2.2.2 Brazil

Brazil's current system of auctioning contracts is more complex than India's.²⁰ The electricity sector has seen several rounds of reform over the past 15 years. Brazil started with government-run, state-owned entities that tended to be quite inefficient. Next came a partially competitive environment with both private and government-owned companies, and a relatively independent regulatory agency. The current power sector model, in place since 2005, relies on a combination of planning and competition—in the form of an auction mechanism—to guarantee supply adequacy and provide a relatively predictable environment for attracting new investors.

In the first five years of operation of the auctioning mechanism, Brazil held 31 auctions. Approximately 57 GW of new capacity was contracted during this period, including fossil generation, hydropower, and other renewable resources.

Sector reform has included creation of a number of institutions, including those responsible for identification of resource needs, and those responsible for conducting and overseeing the bidding process.

- ANEEL is the independent federal electricity regulator;
- ONS is the national independent transmission and system operator, which dispatches the system according to a least-cost centralized tight pool;²¹
- CCEE is a wholesale energy market operator responsible for spot price setting, contract settlement, and more recently, conducting energy auctions; and
- EPE is the planning entity.

Long-term contracts form the backbone of Brazil's power sector model. Competition for those long-term contracts is centralized, standardized, and transparent. This is an important mechanism for promoting low-cost expansion of a system that grows at about five percent per year. Prices set at auction are passed on to end-users.

2.2.3 United States

Competitive bidding for new generation under long-term contracts has been used in many parts of the United States. In a number of states, utilities—companies that are roughly analogous to grid companies in China—are required to use competitive auctions to acquire new generation resources. These states include Arizona, California, Colorado, Florida,

Louisiana, Montana, Oklahoma, Oregon, Utah, and Washington. There are variations, but typically these states:

- Identify needed resources through a resource planning process;
- Require government oversight of the request for proposals, the model contract, evaluation procedures, and other documents prepared by the utility ahead of bidding;
- Allow for public scrutiny and comments on these documents;
- Screen bidders on financial and technical criteria before main bidding begins;
- Require evaluation of bids in line with pre-set bidding criteria; and
- Subject winning contracts to final government approval.

Tierney & Schatzki, 2008 describe the experience in these states and discuss how state governments have spent considerable effort designing safeguards to make sure that auctions, which are typically carried out by the gridcos, proceed in a fair and competitive fashion. Typical safeguards include independent monitors, oversight by government officials, and emphasis on transparency so that non-government organizations and members of the public can monitor auctions. These states have been largely successful in safeguarding effective competition. The authors point out that safeguards are particularly important when non-price factors are a major consideration in deciding the winner of a bid. States have typically used independent monitors when contracts with complex or multiple non-price factors are auctioned.

2.3 China's Experience with Contracting for Generation

China had some limited experience with contracting for conventional generation resources during the 1990s. A contracting program was established during a time of power shortages. The program was successful in its goal of

20 This section is based on Maurer & Barroso, 2011 and Moreno et al., 2010.

21 The spot market is cost-based, not bid-based. Dispatch of every thermal plant is based on each plant's declared and audited marginal operating cost. The long-term contracts are financial contracts and do not determine dispatch.

quickly attracting foreign investment. However, there were major defects in the program design. The contracts were negotiated on a case-by-case basis, and the process was neither transparent nor competitive. Prices were often high, with generators earning high rates of return over short payback periods. In addition, when the power shortage turned to surplus, there were many disputes about contract terms, including whether dispatch hours were guaranteed.

Our recommendations address these problems by emphasizing:

- Transparency and competition; and
- Two-part pricing and efficient dispatch, so that contracts clearly do not guarantee dispatch hours.

China also has recent experience with auctioning contracts for renewables, with mixed results. The most serious problems were the lack of safeguards to ensure that bidders had the technical and financial ability to fulfill promised price and delivery terms, as well as insufficient performance guarantees.²² Often, bidders would “bid low” and then fail to deliver the project after winning the bid. In other cases, the bidding and incentive design rewarded installed capacity with less-than-optimal regard for energy production. Four bids were submitted in 2010 for two offshore and two intertidal wind projects, for example. None of these projects have been developed, due in large part to disputes among government agencies. A second scheduled bidding solicitation for offshore wind has not yet occurred.²³

2.3.1 A New Contract Auctioning Mechanism in China for Acquisition of New Conventional Power Plants – A Recommendation for China

We recommend that China adopt an auctioning mechanism for new conventional generation power plants, designed in light of the international examples discussed previously, and adapted to China’s conditions. This type of mechanism is very different from China’s previous experience with contracting for generation, and we believe it has the potential to be much more successful. We recommend that design of the new mechanism should emphasize:

1. Transparency, central government management, and competition (which may be adapted from the best international examples, as discussed earlier); and
2. Two-part pricing and efficient dispatch, so that contracts do not guarantee dispatch hours.

Two-part pricing is essential to support more economically efficient and less environmentally harmful dispatch of power plants. China’s current approach to dispatch, based on ensuring a target number of hours to each power plant, is highly inefficient. Multiple analyses have shown that improving dispatch efficiency in China can lead to cost and emissions reductions.²⁴

The biggest obstacle to dispatch reform is wholesale pricing practices. In the absence of pricing reform, both merit order and energy efficient dispatch, although beneficial to Chinese society as a whole, will have significant impacts on the financial performance of individual generators.

Simply described, two-part pricing for generation consists of a capacity price, denominated in RMB/kW per period (e.g., month, year), and an energy price, denominated in RMB/kWh. The capacity price is paid only for capacity that is available to operate in a period. The price is set so as to cover the non-operating costs of the generator, so long as it is available during times of system need. The energy price is set to cover the generator’s costs of operation—primarily fuel and variable operations and maintenance. Designed this way, the generator has a very strong incentive to keep its facilities in operating condition and to operate when called upon, but it derives no incremental profits from actual operations. The system can then be operated in the most efficient way—that is, dispatch is based on the generators’ energy prices—and without financially harming generators or creating perverse incentives for unneeded and wasteful output. (See Chapter 3 for a more detailed discussion of dispatch and wholesale pricing.)

22 These types of problems are not unique to China. Wiser et al., 2006 says that a contract failure rate of 20 to 30 percent should be expected, at minimum, for large generation bidding solicitations.

23 See Liu, 2012.

24 See Mercados Energy Markets International, 2009 and Kahrl et al., 2013.

2.4 Recommendations Regarding Acquisition of Renewable Resources in China

Rather than correcting the previous renewable bidding practices described earlier, China instead largely switched to a FIT approach. This decision made sense given the desire to simplify the process, reduce transaction costs, and accelerate investment in new renewable generation. For this reason, we recommend that China continue working to refine the FIT model for renewables (see Chapter 5 for more discussion), rather than moving toward a competitive mechanism in the near term.

Currently China's FIT for wind is location based, dividing the country into four regions, with the highest wind resource areas receiving lower FIT rates. We recommend transforming the FIT for both wind and solar to provide even greater encouragement for geographic diversity in wind and solar installations. Approximately 90 percent of installed wind capacity is deployed in the "Three Norths" of China (Northwest, North, and Northeast China). The Three Norths have relatively low load and heavy winter heat demand. Those two factors are already leading to 20 percent of wind generation being curtailed on average, which will likely worsen absent policy changes.²⁵ The best solar resources are in the northwest, which raises the concern that solar plants will be similarly concentrated.

Spreading wind and solar development geographically will aid in better grid integration and management and lower transmission costs. At least for wind, this is already occurring to a certain degree, as wind development is proceeding in lower wind resource areas in southwestern and central China.²⁶ Revamping the FIT to provide greater encouragement to locate new plants in higher-load areas and in locations with lower need for new transmission will boost this encouraging development even further. For solar, developing strong distributed solar policies can also facilitate the location of new plants close to load centers.

We also recommend regularly revisiting FIT compensation levels to account for declines in technology costs. China's FIT for wind has remained fixed since 2009, even though wind costs have declined. Not accounting for those cost reductions potentially provides a windfall to generation companies at the expense of ratepayers. On the other side of the coin, there may be reasons to adjust the FIT upward in the future. We suggest revisiting FIT rates at

least biennially and making any rate changes prospective, not retroactive. As some countries have seen, changing FIT rates retroactively can introduce market instability.

2.5 Recommendations Regarding Acquisition of Energy Efficiency in China

One of the important aspects of our recommended improvements in planning is to include both demand- and supply-side options in the same planning analysis. The purpose is to determine the optimal mix of resources, including the optimal level of end-use energy efficiency investment, through consideration of a wide range of costs and benefits, including emission reduction. In this type of analysis, energy efficiency is typically found to be a relatively inexpensive resource when compared to supply-side resources (e.g., new conventional power plants). Once an optimal mix of resources is determined, then end-user energy efficiency may be acquired in a way analogous to the acquisition of conventional power plants. Indeed, China already has experience with the concept of the efficiency power plant, which is a bundle of end-use energy efficiency investments that provide predictable load-carrying capacity, in much the same way that a conventional generating unit does.

We believe that mandating an end-use energy efficiency target (as determined in the integrated planning process) is a very good approach. China already has such a mandate under the late 2010 DSM regulations, which sets energy efficiency targets for achievement by the gridcos. Chapter 6 goes into further detail on this subject.

2.6 Conclusion

There has been significant experience and success in various countries with auctioning of long-term contracts to build generation resources. We recommend using this type of approach for acquiring new conventional generation resources in China. Care needs to be taken in designing this type of mechanism so that it is adequately competitive and avoids unnecessarily high costs. There is much international experience for China to draw from, and it is clear that several design aspects will be particularly important,

²⁵ See Xie, 2013.

²⁶ See Global Wind Energy Council, 2013.

including government management and oversight of the bidding process and rules regarding prescreening of bidders. In addition, price and non-price conditions will need to be defined and evaluated in a consistent manner.

For emerging energy technologies such as renewables, competitive bidding may not be the best approach, partly because there is a higher likelihood of relatively inexperienced developers bidding “too low” to win the bid and then failing to develop the project. China utilized competitive bidding for renewable energy generation for both onshore and offshore wind power, with mixed success. China has experienced much more success with renewable energy deployment after adopting a FIT. We recommend some modifications to China’s FIT to encourage more geographic diversity among wind and solar plants and to track changes in technology costs.

Acquisition of end-use energy efficiency, as identified in a rationalized planning process, is also extremely important. We recommend continued development of the targets for grid company DSM.

2.7 Appendix

This appendix provides more details on the Indian and Brazilian cases discussed previously.

2.7.1 India

India uses two types of auctions:

1. Location, technology, and fuel are not specified; and
2. Location, fuel, and technology are all specified. For example, contracts for large hydro power plants are typically auctioned in this manner.²⁷

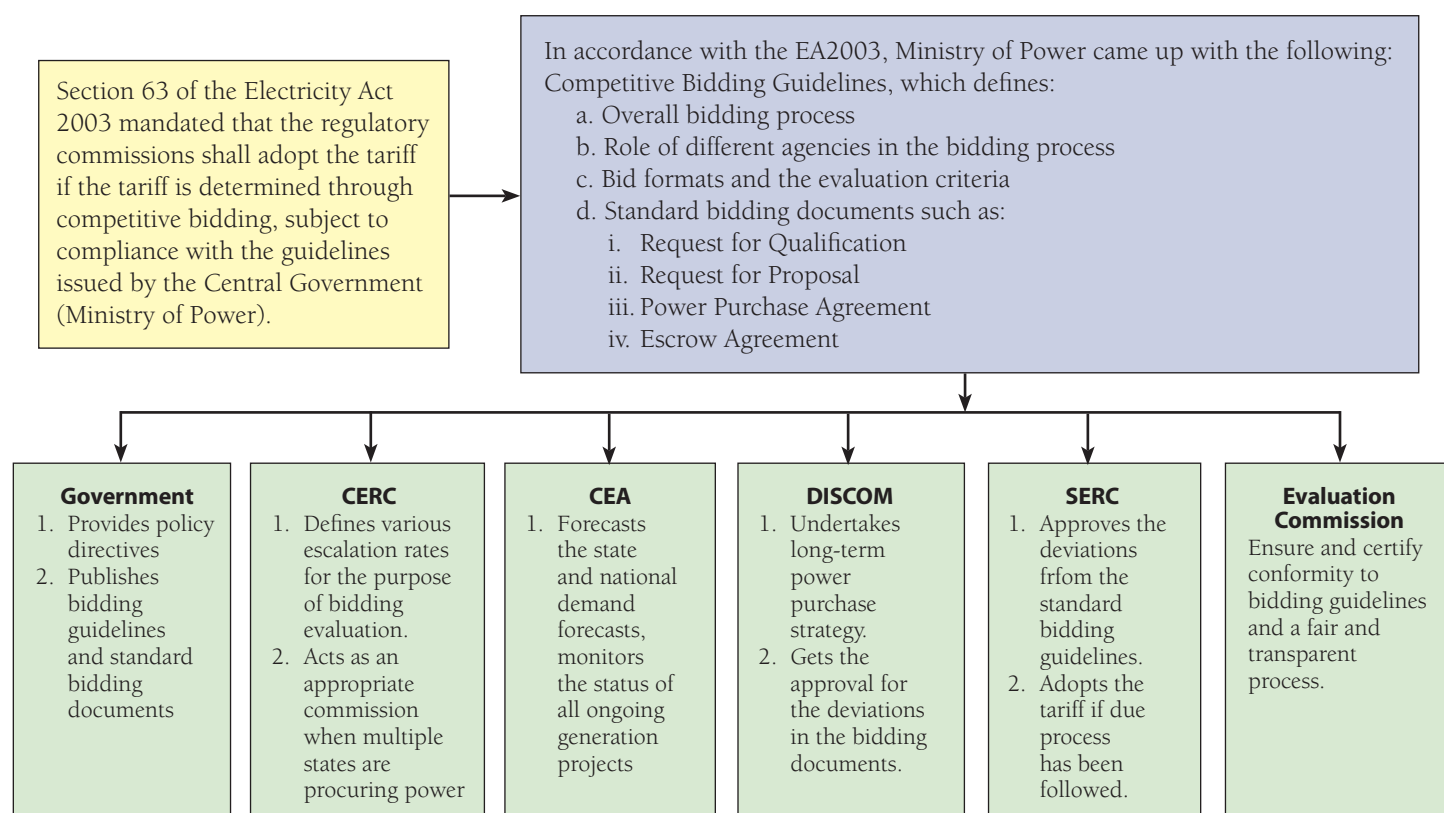
Contracts also have different lengths: medium-term (one to seven years) and long-term (greater than seven years). Figure 8 provides more details on the role of various organizations in the bidding process.

27 Our discussion of India is based on Gadag et al., 2011.

28 Gadag et al., 2011.

Figure 8

The Role of Organizations in the Bidding Process²⁸



CERC, Central Electricity Regulatory Commission; CEA, Central Electricity Authority; DISCOM, Distribution Company; SERC, State Electricity Regulatory Commission.

The Ministry of Power's guidelines define the details of the bidding process as well as the bid formats and the evaluation criteria. Distribution companies (distcos) conduct the auctions, subject to approval by the relevant state regulatory commission (or the central regulatory commission if the project crosses state borders). Distcos rely either on their own demand forecasts, which are approved by respective state regulatory commissions, or on demand forecast from the Central Electricity Authority. (If the proposed acquisition is in line with forecast, no additional approval is needed.)

The oversight committee within each distco plays an important role in ensuring transparency and compliance with bidding guidelines. Ultimately, however, the state regulator makes sure guidelines are followed. The state regulator must scrutinize the bid and approve the results if there are less than two bidders.

Two-part pricing is required for long-term contracts (but not medium term); all pricing is in Indian rupees.

In brief, a typical bidding process is as follows:

- Distco announces intentions for acquisition to SERC. SERC then reviews and consents.
- Distco completes environmental (and other) clearances (particularly if the bidding is to be site-specific).
- Distco publishes RFQ, which specifies bidder expected qualifications: net worth, experience, and so on. The RFQ also specifies details about the project and offers a model PPA.
- Bidders that meet the qualifications are announced.
- A request for proposal published by the distco specifies tariff structure and date for supply of power.
- The technical qualifications of the bid are evaluated by the evaluation committee formed by the distco.
- Winning price bids are determined by the distco evaluation committee based on comparison of levelized tariffs derived from each bid.
- Winners submit performance guarantee.
- PPA is initialed.
- The entire process is reviewed and approved by the regulatory commission, which issues tariff adoption order.
- PPA is signed.

- Bids (the winner and some anonymous comparators) are then published online, along with the finalized PPA.

2.7.2 Brazil

Maurer et al., 2011 offers the following description of the “three main rules” of the Brazilian contract auction mechanism:

1. First, all loads (the “captive” consumers associated with distribution companies as well as “free” large users) must prove to be 100 percent covered by energy contracts. Energy load coverage is verified monthly by CCEE, which certifies that the accumulated MWh consumed over the past 12 months do not exceed the accumulated MWh contracted in the same period. Any shortfall is penalized at a price that mirrors the cost of new energy.
2. All contracts are financial instruments and should be covered by firm energy certificates (FEC). FEC are defined in GWh/year and are issued by the Ministry of Energy. The methodology for their calculation is fairly complex. It basically reflects the sustained energy production of each generator when interconnected to the grid. The FEC of a plant is the maximum volume of energy that can be sold through contracts and establishes the reliability assured by the generator backing up the contract. It is therefore a critical parameter for the feasibility of a power plant. This rule is verified by comparing the volume of energy sold in a contract with the amount of FEC held by the seller. Any shortfall is penalized at a price that mirrors the cost of new energy.
3. In order to promote the most efficient procurement mechanism for regulated (captive) consumers, the contract obligation scheme for distribution companies operates in tandem with the use of energy auctions of long-term contracts as the main mechanism for energy procurement. On the other hand, free consumers can procure their energy needs as they please (as long as they remain 100-percent contracted).

There are two public auctions annually (for energy delivery three and five years ahead). Distcos project demand requirements. The government conducts planning studies and provides a “menu” of options for capacity additions. Potential investors may suggest additional

projects to the menu. The environmental licensing process may knock some items off the menu.

The government designs and runs the centralized auction, but does not sign contracts or provide guarantees; instead, the contracts are allocated (according to the demand forecasts) to the discos, which thus stand on the “contractor/procurer” side of the contract. As in the Indian case, before the auction starts, potential investors must meet eligibility requirements, including financial assurances.

Generation investors that win at auction sign bilateral contracts with each of the distribution companies, based on the relative size of each distribution company’s forecasted loads.

Project-specific and technology-specific (renewable) auctions are also intermittently conducted.

Existing plants must compete in auctions, but these are separate from the auctions held for new plants. The contracts for existing plants are shorter (less than one year to eight years) than the contracts for new plants (15 years for thermal plants and 30 years for hydro plants).

The most common form of contract features two-part pricing for capacity and energy. The contractor pays a monthly fixed capacity fee per MW, regardless of whether the plant runs (as long as it is available); when it does run, the contractor pays an additional amount per MWh to cover variable costs.

Chapter 3: Generator Dispatch

3.1 Introduction and Overview

How generators are dispatched has important implications for electricity costs, reliability, the integration of renewable energy, and emissions. Throughout most of the developed world, generators are dispatched to minimize variable operating costs, including monetized environmental costs, while respecting system reliability constraints. In China, however, generator dispatch was designed to support capital cost recovery for coal generators rather than to optimize operations. Optimizing dispatch according to variable costs and environmental criteria will help China reduce generator investment, fuel, and maintenance costs; improve the integration of renewable energy; reduce emissions; and improve system reliability.

Generator dispatch has not been a focus of electricity reform discussions in China. It should be. Not only is dispatch the critical determinant of the sector's costs and environmental performance, it also influences a broad range of investment decisions—it tells generating companies which generation technologies and fuels will be most economical; it helps utilities determine when new transmission lines are cost-effective; and it helps to guide investment decisions in energy efficiency and demand response. Moreover, economic dispatch is essential for competitive wholesale markets, and thus dispatch reforms are a necessary step for a longer-term transition to a more competitive electricity sector in China.

A critical step for reforming generator dispatch in China is changing the way in which generators are currently compensated, to break the current link between investment cost recovery and dispatch. This chapter focuses on reforms in both generator dispatch and compensation. We offer two general recommendations:

- **Restructure methods of generator pricing and compensation:** Create a two-part capacity and energy price for compensating generators, with the capacity

price (paid in RMB per kW per year) tied to generator availability and the energy price (paid in RMB per kWh) tied to generator output; begin these changes in compensation methods with new units.

- **Optimize dispatch:** Dispatch generation to minimize the variable costs of meeting load, subject to security and environmental constraints.

The chapter begins with a brief description of current dispatch practices in China, followed by an overview of international practices and their relevance for China. It closes with a more detailed description of our two recommendations.

3.2 Current Practice in China

The approach to power generation operations in China historically did not, and still does not, follow the standard least-cost model used throughout most of the world. Instead, in China operators dispatch coal-fired generators to maintain approximately equal capacity factors for all of them and to allow them an equal chance to recover their investment (i.e., capital) costs and earn a reasonable return on that investment. Under this approach, dispatch is conducted to support capital cost recovery rather than to minimize costs.

This “equal capacity factor” approach to dispatch has its roots in methods for compensating generators. Beginning in the mid-1980s, as China began to experience severe power shortages, the central government relaxed investment rules so that local governments, the domestic private sector, and foreign investors could invest in new generation capacity. Each generator was given its own tariff to cover its variable costs, investment and other fixed costs (“fixed” because they are unrelated to output), and provide a reasonable return on investment. These tariffs were set on a per-kWh basis, which meant that generators were paid the tariff for each kWh of electricity they generated.

To convert generator fixed costs into a per-kWh rate, these tariffs needed to assume the capacity factor at which

generators would operate.²⁹ Capacity factors were set uniformly across coal generators. If actual capacity factors were too low, coal generators would under-recover their fixed costs; if capacity factors were too high, they would over-recover their fixed costs. Dispatchers attempted to keep all generators' actual annual capacity factors as close as possible to the value used in setting their tariffs. This meant that small, inefficient generators were operated just as frequently as large, efficient generators. Because of the need to fix capacity factors in generation tariffs, investment in generation with low and uncertain capacity factors (for example, seldom used plants fired by natural gas to serve peaking needs) was lower than economically justified.

Although there have been minor adjustments to generator pricing in China since the 1980s, this approach to dispatch and pricing has remained largely unchanged. In 2007, government agencies began piloting a new approach called “energy efficient dispatch,” which sets a dispatch order based on energy resource considerations. Under this policy, the dispatch order prioritizes renewable, hydropower, nuclear, CHP, clean coal, and natural gas generators (in that order). For coal generators, dispatch is determined by generators' heat rates (thermal efficiency), with more efficient generators dispatched first.

Energy efficient dispatch was piloted in five provinces. The policy has proved difficult to implement and has thus far not been extended to other provinces. One of the policy's main shortcomings is that it was not accompanied by reforms in generator tariffs and, thus, did not directly address the changes in generator or grid company revenues that result from changes in dispatch. Given the difficulties in scaling up the energy efficiency dispatch policy, most of China still uses the equal capacity factor approach to dispatch.

3.3 International Practices

In most countries, generator dispatch is optimized to minimize the short-run marginal cost (primarily the fuel cost) of generation. This is known as “economic” or “merit order” dispatch: lower variable-cost units operate before and for more hours than higher variable-cost units, and, as a matter of economic efficiency, they “merit” (deserve) more hours because they are less costly to operate. Once generating units have already been built, their investment costs have no bearing on dispatch decisions because those costs are “sunk.” They must be paid whether the generator operates or does not.

Internationally, economic dispatch is used across a range of industry structures and approaches to compensating generators: from vertically-integrated utilities that are subject to cost-of-service regulation, to hybrid markets with administratively determined capacity payments and market-determined energy prices, to energy-only markets where generators recover all of their costs through a single market clearing price. Across this spectrum of approaches for compensating generators, fixed cost recovery has no bearing on the order in which generators are dispatched. Because dispatch reforms in China require changes in generator compensation, we briefly explore the range of different compensation approaches used internationally and their relevance to China.

The industry structure most relevant to China—unbundled generation and transmission and distribution services—can be characterized by two factors (refer to Table 1): one, how generators recover their fixed costs (i.e., through a single payment or through separate energy and capacity payments) and, two, how energy and capacity prices are determined (i.e., set administratively, negotiated bilaterally, or cleared in a centralized market). The

Table 1

Fixed Cost Recovery and Pricing Mechanisms		
Pricing Mechanism	Fixed Cost Recovery Mechanism	
	Energy-Only	Capacity Payment
Administratively set	China	Argentina, Chile, Colombia, Peru, South Korea, Spain
Bilateral market		California ISO (CAISO), Southwest Power Pool (SPP)
Centralized market	Alberta, Australia, Electric Reliability Council of Texas (ERCOT), New Zealand, Norway, Ontario Independent Electricity System Operator (IESO), UK	Brazil, India, PJM, ISO-New England (ISO-NE), New York ISO (NYISO), Midwest ISO (MISO)

29 For instance, a coal generator with a variable cost of 0.3 yuan/kWh and an annual fixed cost of 500 yuan/kW per year would have a tariff of 0.4 yuan/kWh (= 0.3 yuan/kWh + 500 yuan/kW-yr ÷ [60% x 8,760 hours] = ~0.4 yuan/kWh) using a capacity factor of 60%.

approach currently used in China—energy-only, fixed-cost recovery based on administratively determined prices—is unique to China.

Energy-only markets require periods of sustained high prices for generators to recover their fixed costs, which makes prices in these markets extremely volatile. In addition, the difficulties in discerning normal market behavior and market power make regulation of these markets difficult and require administratively imposed protections, such as price caps. Because of their price caps, energy-only markets may have difficulties in attracting needed investment in new generation. As a result, the energy-only market model is not likely to be suitable for China, at least in the near term.

Many regions that have unbundled (separated) generation from transmission and distribution have moved to a two-part system for pricing generation—that is, separate energy and capacity prices. There are a number of design options for two-part pricing, which have to do with how the energy and capacity prices are determined and the schedule in which new solicitations for energy and capacity take place and in which prices are determined. Administratively determined prices are the simplest approach but are the least flexible. Centralized markets are the most flexible but tend to be the most complex to operate. The approach recommended in Chapter 2, of periodic solicitations through a centralized auction, is one kind of centralized market mechanism.

In most of these regions, the net capacity payments that generators receive are tied to their availability, that is, to their ability to operate when called upon by the system operator during times of system need (dispatcher). For instance, in the region served by the CAISO, generators are penalized if their monthly forced outage rate is more than 2.5 percent below the fleet-wide average for the previous three years; the penalty is based on the price that CAISO must pay for replacement capacity (“backstop procurement”). The Independent System Operator of New England (ISO-NE) is in the process of amending its Forward Capacity Market (FCM) rules by adding a Pay for Performance requirement whereby a resource’s FCM revenue will be contingent upon its performance during scarcity events.³⁰ There are two parts to the proposed capacity payment in New England: a base capacity payment and an additional performance payment. Parties that perform when called upon are paid the additional

performance payment; those parties that do not perform are penalized. The regional transmission organization PJM operates a market to secure capacity, known as the reliability pricing model. Entities with a capacity resource commitment (i.e., an obligation to provide a certain amount of capacity at a certain time) are assessed penalties if they fail to provide the agreed upon level of capacity.³¹

By tying the capacity payment to generator availability during times of system need rather than generator output, dispatch decisions can be made independently of fixed cost recovery considerations. The capacity price gives generators a strong incentive to be available when needed; and, so long as they are available when needed, they will recover their fixed costs. Economic dispatch is then determined by a generator’s energy prices, which are set to cover their marginal (variable) cost of production. This means that, in practice, economic dispatch usually follows the order of generator heat rates (lower, more efficient heat rate generators before higher heat rate generators), because fuel costs are typically the lion’s share of variable costs for thermal generators.

An important co-benefit of economic dispatch is that it makes dispatch decisions more predictable, which enables more accurate cost-effectiveness analysis to determine the economic viability of different investment options. For instance, a new natural gas-fired unit or storage facility can determine approximately what its revenue stream might look like based on how it expects to be dispatched. Energy efficiency program administrators can calculate detailed hourly avoided costs of electricity to help direct energy efficiency funding to the most cost-effective investment options.

30 Scarcity event is defined as any time the ISO is unable to meet the combined energy and operating reserve requirements needed to ensure system reliability.

31 Entities that are deficient are assessed a “daily deficiency rate” (denominated in \$/MW-day), which is equal to the entity’s weighted average resource clearing price for each resource plus the higher of 20 percent of the party’s weighted average resource clearing price for such resource or \$20/MW-day.

3.4 Recommendations

3.4.1 Recommendation 1: Restructure the Methods of Generator Pricing and Compensation

Generator pricing reform in China has been contentious, and an overhaul of the wholesale pricing system may not be possible any time soon. However, there are ways to make incremental changes to generator pricing and compensation in the near term that would facilitate a more optimized approach to dispatch.

Changes should start with new technologies that are likely to be operated at low capacity factors, including natural gas generation and electricity storage. These kinds of technologies, in limited quantities, will reduce the total cost of electricity supply in China, facilitate the integration of renewable energy, and increase the average utilization of China's coal units. These types of plants could be given two-part capacity and energy prices, structured to create strong incentives for availability during times of system need. The capacity price will encourage economical investment in these technologies even if they will seldom be used. The energy price, which is likely to be relatively high, will provide a signal to dispatch these technologies only when they are needed for capacity (peak) or balancing. Generators, grid companies, and government agencies will need to determine what kinds of technologies to invest in and how much investment is economically justified (refer to Appendix A in Chapter 1 for an example of the economic analysis that should underpin such decisions). Two-part pricing might also be extended to new coal and hydropower units using the auction approach described in Chapter 2.

Initially, changes in compensation will not necessarily need to be extended to existing generators in order to implement deeper reforms in dispatch. But without changes in compensation of the sort we recommend, other means of addressing the financial consequences of economic dispatch for existing generators will be required. In particular, the new dispatch will result in increased revenues for some units and decreased revenues for others. And it may force some units—the least efficient ones—into retirement. Determining how to deal with the windfalls and shortfalls—and especially whether and how much to pay the retiring generators for their remaining (i.e., “stranded”) capital costs—is complex and political. In the near term, however, either a generation rights trading system or an

administrative reallocation of revenues will allow for a more optimized dispatch of existing generators to proceed while protecting the recovery of investment costs. At some point, however, price reforms for coal and hydropower generators will be needed; the economic and political costs of not addressing stranded cost issues are growing as the power system expands.

3.4.2 Recommendation 2: Optimize Dispatch

The changes in compensating and pricing described here will facilitate a transition to generator dispatch optimized around short-run marginal cost and security and environmental constraints. The resulting dispatch order will likely be similar to dispatch under a well-functioning energy efficient dispatch policy, with a few important exceptions.

First, wind, solar, and CHP generation will still receive priority dispatch, because they have low marginal costs. Coal units will be dispatched according to their heat rates, with larger, more efficient units dispatched before smaller, less efficient ones. However, contrary to energy efficient dispatch policy, at current natural gas prices in China, natural gas units will be dispatched after coal units, for use in load following and peaking generation. Hydropower will likely be used more for load following and peaking than it currently is. Higher variable cost renewables, such as biomass generation, may need government support to be regularly dispatched under this kind of system.

Environmental considerations can be factored into dispatch either through pricing emissions or through adding emissions as a constraint (an operational decision rule). Because pollution control equipment reduces the net efficiency of thermal plants and thereby increases their variable costs, they would, under the strict rules of economic dispatch, operate less than lower variable cost—but more polluting—plants without emissions controls. A rule that adjusts economic dispatch in recognition of the environmental benefits of the less polluting units will address their variable cost disadvantage and will prioritize the lowest cost, lowest emissions generators.

An important benefit of economic dispatch in China will be a more rational, predictable economic framework for the electricity system, which will allow for new technology options to compete with coal generation. The current approach to dispatch was set up to support coal generators and, as a result, China has too much coal capacity relative to what is either economically or environmentally optimal.

Chapter 4: Retail Pricing

4.1 Introduction and Overview

China has a number of very good retail pricing practices that help align economic and environmental objectives for the sector. These include inclining block rates (known in China as tiered prices) for residential customers, time-of-use rates, and differential pricing that applies to energy intensive industrial customers. However, there are remaining challenges related to pricing that require further reforms. In particular, we recommend improving:

- Transparency of information about power sector costs and prices,
- Retail price adjustment mechanisms, and
- Incentive mechanisms for promoting demand response.

In addition, we recommend caution in allowing large industrial customers to negotiate power prices directly with generators, which, in our view, can have negative unintended consequences.

4.2 Current Situation in China

China has a number of pricing policies that support environmental and energy policy goals. We recommend that these be preserved, strengthened, and (in the cases that are still regional pilots) applied nationwide.

4.2.1 Inclining Block Rates

Residential retail rates in China are set in blocks, with higher rates for customers who are heavier consumers of electricity. These “tiered prices” encourage energy efficiency and peak load reduction while protecting smaller users.

4.2.2 Time-of-Use Pricing

Time-of-use (TOU) pricing is a demand-response policy that encourages shifting of loads from high-price periods to low-price periods. It applies to a majority of Chinese industrial customers and commercial consumers; in some provinces and municipalities, residential customers are also subject to TOU pricing.

4.2.3 Differential Pricing

Under this policy, eight industries are grouped into several categories based on the energy efficiency of their industrial processes: encouraged, permitted, restricted, and eliminated. The electricity price varies between different categories and is designed to phase out inefficient enterprises and encourage efficient ones.³²

4.2.4 Industrial End-Users Pay Higher Prices than Households

Industrial customers generally pay higher rates than residential customers. Although there is need to rationalize the structure and levels of the various price categories, this general characteristic of industrial prices that are higher than residential prices is worth preserving and strengthening, because it supports the Chinese government’s goals of improving energy efficiency, eliminating inefficient industrial production, and rebalancing the economy away from investment in energy-intensive industry.

4.2.5 Interruptible Loads/Demand Response

China has aggressive demand response programs focused on peak reduction. These programs include economic incentives that encourage customers to manage loads, as well as administrative approaches. We recommend the economic incentives be expanded so that they eventually replace the administrative approach.³³

32 Moskovitz et al., 2007.

33 In parts of China, interruptible pricing and reliability-based pricing pilots have existed for almost ten years. (Interruptible and reliability-based pricing refers to arrangements in which customers are compensated through lower prices for voluntarily shedding load in response to generation or transmission capacity shortfalls.) For example, Shanghai has years of experience with interruptible electricity pricing. Hebei province also provides economic incentives for load shifting.

4.3 Recommendations for China

Despite the positive aspects of retail pricing policy described previously, there remain some challenges.

4.3.1 Transparency and Cost-Reflective Prices

Lack of transparency is a problem in at least two major ways: first, there appear to be a few instances that represent inexplicable exceptions to pricing policy, with some customers receiving idiosyncratic preferential treatment. Second, power sector firms' costs are often opaque – including to the government – raising concerns about the possibility of excess profits.

By transparency we mean (1) establishing clear and consistent application of well-designed accounting rules for costs, revenues, and profits; (2) consistent application of those rules in a well-designed administrative process for review and application of the rules to set allowed revenues; and (3) establishing a mechanism for publicly sharing information. The government should be able to audit the accounting records of the company and exact penalties for failures to comply with requests for information or the determinations of government.

Increased transparency of power sector costs and pricing would:

- Ensure that electricity consumers, as a whole, are paying fair prices that cover the actual cost of providing electricity service;
- Ensure that the grid companies and generation companies are being fairly compensated; and
- Support adequate power sector investment.

4.3.2 Updating Retail Prices

Under current practice in China, retail prices are not updated frequently and do not fully reflect cost changes in the power sector. Allowing companies to automatically pass costs on to retail consumers is a complex issue. On one hand, the inability of gridcos and generators to automatically pass cost changes through to customers gives these firms a strong incentive to improve cost performance and hedge volatile costs like fuel. In other words, this is an incentive for improved operational efficiency, more productive use of labor and capital, investment in generation technology with lower fuel costs (such as renewable energy), and even for the gridcos to support improved end-use efficiency (particularly for unprofitable classes of customers). Pricing mechanisms that automatically pass through all power supply cost changes to

consumers insulate generators and grid companies from risks they are well positioned to manage. It also can potentially dramatically increase the grid company's incentive to increase sales and discourage end-use energy efficiency.³⁴

On the other hand, the lack of quick and predictable cost recovery can reduce grid company incentives to incur costs associated with meeting government regulations for emission reduction, increased use of renewable energy, distributed generation, investment related to renewable integration, and investment in end-use energy efficiency. For example, gridcos may lack proper incentives to provide certain services related to installation of PV by retail customers. The current pricing framework does not allow grid companies to recover the cost for providing grid interconnection and standby service to distributed PV generators.

Balancing these competing considerations is complex. A useful next step is to establish an explicit price adjustment mechanism allowing for timely cost recovery *relating to implementation of specific government policies*. Grid companies could be provided more timely recovery of qualifying expenses or investments that meet specific policy criteria.

4.3.3 Demand Response for Renewable Integration

Integrating variable energy renewables is a major challenge. Chapter 5 gives an overview of this subject and discusses many aspects of renewables integration. One of the possible tools for integration – demand response – is related to retail pricing, so we also raise it in this chapter.

There is now substantial experience with demand response in the United States, both in the regions of the United States still served by traditional vertically integrated utilities and in the regions that have moved to liberalized markets. This experience shows that, in addition to supporting peak load requirements, demand response can also be used to deliver energy services, balancing services, and operating reserve services – and can be useful in helping to cost-effectively integrate wind and solar.³⁵

34 Lazar et al., 2011.

35 Several studies have highlighted the role that demand response can play in helping to integrate renewables, for example, European Climate Foundation, 2010 and Western Governors' Association, 2010.

China has much experience with demand response, particularly load shifting to meet peak demand. However, China has relied heavily on rationing customer load reductions through administrative means, which can be inefficient. Incentives mechanisms, if well designed, can identify the lowest-cost opportunities for demand response. As noted earlier, China has experience with interruptible-load pricing mechanisms. These should be expanded to provide other energy services and help balance renewables.

Given the large share of end-user loads represented by industrial customers in China, it appears likely that the potential for demand response may be significant. We recommend developing a better understanding of the full potential of demand response through a formal technical assessment of the resource.

Electric vehicle pricing and charging strategies are closely related to the topic of demand response. The Ministry of Industry and Information Technology has objectives that should lead to five million electric vehicles by 2020. Effective strategies to manage the charging of electric vehicles will be needed reduce power sector costs and help manage a system with increasing reliance on variable renewables.³⁶

4.3.4 Retail Customer Bypass Directly to Generation

Several areas of China have pilot programs allowing large users to bypass the gridcos and negotiate prices directly with generators.³⁷ One possible outcome of these pilots could be a kind of generation market price. In other words, this kind of bypass policy could be used to create a wholesale market that brings together “many buyers and many sellers” (the phrase sometimes heard in China), in contrast to the current system of administratively set on-grid prices. We agree that increasing competition among generators is an important goal. However, our view is that

allowing large retail customers to contract directly with generators, especially existing generators, can potentially lead to problems:

- Industrial customers, which currently pay relatively high retail rates, will potentially be able to negotiate low rates directly with existing generators, meaning that residential and commercial customers may face higher rates in order to cover total system costs.
- Direct dealings between customers and generators will make it more difficult to achieve an optimal portfolio of resources, as identified in the planning process (see Chapter 1).
- Direct arrangements may neglect the need for reserves and ancillary services and could leave critical industries without essential electricity service if and when the contracted generators are unable to deliver the contracted product, even if only for a few seconds, minutes, or hours.

For these reasons, we recommend caution with allowing large users to bypass the gridcos. Instead, we recommend boosting competition by auctioning of long-term contracts for new coal and gas plants (see Chapter 2). We also see significant opportunities for improving generator efficiency through reforming dispatch and generator compensation (see Chapter 3). Finally, better gridco performance can be achieved through better gridco oversight and regulation

4.4 Experience in the United States

4.4.1 Demand Response

Demand response in the United States is typically economic (either encouraged through rate design or incentives). Demand response services began decades ago in the United States, first through interruptible rate designs that encouraged customers to curtail loads (“non-dispatchable demand response”) and as a means to provide

³⁶ In the future, some forms of retail dynamic pricing may become increasingly relevant and serve to either elicit forms of non-dispatchable demand response (i.e., customer initiative responses), especially for larger customers capable of making finer-grained utilization decisions, or for smaller user categories in which aggregators can be used to help assure customer benefit and manage the risk of price volatility. Dynamic pricing can help to encourage efficient time-of-use decisions by end-users. It is particularly useful in relation to managing

shorter-term energy costs (perhaps resulting from two-part pricing). Dynamic pricing may also be helpful for encouraging customer efforts to manage loads for improving system reliability at either the distribution level or the transmission system level.

³⁷ The State Council recently called for these pilots to move forward. See: http://www.gov.cn/zwgk/2013-05/24/content_2410444.htm.

Table 2

Types of Demand Response Services	
Incentive-Based Programs	Time-Based Programs
Demand Bidding and Buyback	Critical Peak Pricing with Control
Direct Load Control	Critical Peak Pricing
Emergency Demand Response	Peak Time Rebate
Interruptible Load	Real-Time Pricing
Load as Capacity Resource	Time-of-Use Pricing
Non-Spinning Reserves	
Spinning Reserves	

load reductions during system emergencies. They evolved to become more direct and routine forms of operator controlled loads (“dispatchable demand response”). In the last decade, demand response has continued to expand and evolve to provide new capabilities, including energy, capacity, and other categories of “ancillary” services that are used to balance the system and provide operating reserves.

In 2010, the potential resource contribution of demand response to system operators in the United States totaled nearly 32,000 MW. One measure of its emerging growth and contribution is its capacity value relative to system peaks. As a percentage of peak demand, these resources provided between two and ten percent of each region’s peak demand.³⁸ As of December 2012, the Federal Energy Regulatory Commission (FERC) estimates that total potential demand response capability in the United States was 9.2 percent of peak load.

The broad categories of demand response services that are available in the United States include both time-based and incentive-based capabilities that fall into the following categories.³⁹

4.4.2 Cost Recovery

Traditional forms of regulation involve some form of cost-of-service regulation in which prices are occasionally reset based on some assessment of underlying total cost considerations. Alternative forms of regulation may include forms of “performance-based regulation” (PBR) that make adjustments to price levels or allowed revenues based on performance of the grid company relative to performance targets. One special category of PBR, revenue-cap regulation, is often used to “decouple” sales growth from the financial performance of the grid company. Decoupling represents an approach to setting prices (or cost recovery)

that assures the grid company a level of revenues that is distinct from end-user sales volume. By separating patterns of sales growth from revenues, the financial performance of the company no longer is tied to sales growth. Some form of decoupling now exists in 25 states affecting 54 local gas distribution companies and 25 electricity companies in the United States.⁴⁰

PBR can also be used to spur investments in certain categories of investment based on regulatory objectives (like advance grid or demand response). Timely recovery of certain

cost categories can be implemented either through separate fees or performance incentives or through an explicit cost tracking mechanism for qualifying costs that are consistent with government policy objectives. Increased assurance of cost recovery can also come through accounting treatment that recognizes special categories of costs for later cost recovery in setting future prices.

There are now decades of experience in the United States with PBR. Other regions are also establishing plans. Examples of PBR or incentive regulation plans that spur timely cost recovery or provide incentives for investments include the following:

- **Pacific Gas and Electric (PG&E)** – In 2006, the California Public Utilities Commission established a three-part mechanism to encourage investment in energy efficiency. The first was a cost-recovery mechanism, funded through a system benefits charge to all electricity consumers. The second was a revenue regulation (decoupling) mechanism that recaptured net lost distribution revenues when sales declined. The third was a shared savings mechanism to give PG&E a portion of the net energy value that the energy efficiency savings produced for customers.
- **Central Vermont Public Service Corporation (CVPS)** – In 2007 (Docket 7336), CVPS embarked on a PBR plan that limited the amount of price increases that were permitted under the three-year plan, except for special provisions that allowed for adjustments to the energy efficiency component

38 Hurley et al., 2013; FERC, 2011.

39 FERC, 2012.

40 Morgan, 2013.

of charges and related energy efficiency program expenditures. The CVPS plan also made special provision through faster rate recovery mechanisms for large capital expenditures necessary to upgrade its network and install smart grid technology (largely metering technology).

- **United Kingdom Performance-Based RIIO (Revenue = Incentives + Innovation + Outputs)**

Plan – The United Kingdom’s chief economic regulator⁴¹ has embarked on a comprehensive plan for regulatory reform that aims to better align the revenues and incentives provided to the electric and gas utilities with the challenges of meeting longer-term objectives for cleaner energy and energy services. The RIIO plan is a performance-based revenue plan that will ultimately apply to 22 electricity and gas utilities. It is a framework that is output focused, is designed to allow market participants to help deliver, and is structured to encourage meeting targets through incentives. RIIO price plan is designed to establish more sustainable networks that deliver a low carbon energy sector with a long-term view of

consumer value. The RIIO model covers an eight-year period. The RIIO model is being applied in the transmission and gas distribution price control reviews beginning in 2013.⁴²

4.5 Conclusion

Many aspects of China’s retail pricing policies are worth preserving and strengthening. This chapter has discussed these positive aspects, as well as outlining recommendations for additional policy reforms. In designing an improved retail pricing system, it will be important to pay close consideration to the effects on incentives for various players, particularly the gridcos. A well-designed and transparent retail pricing system can give customers, gridcos, and generators the right incentives to work together to achieve the government’s goals for power system investment and related environmental outcomes.

41 Ofgem, 2010.

42 Id.

Chapter 5: Renewable Energy

5.1 Introduction and Overview

China's renewable energy development over the past decade has been remarkable. From a starting point of just over 1 GW in 2005 to 75 GW by the end of 2012, China now has the most installed onshore wind capacity of any country in the world.⁴³ Wind is now the third largest generating source in China, after coal and hydropower.⁴⁴ Much more renewable generation capacity is expected, as the Chinese government has set goals of 100 GW of installed wind capacity by 2015 and 200 GW by 2020, as well as 35 GW of solar capacity by 2015 and more than 50 GW by 2020.⁴⁵ By 2020, China aims to supply 15% of the country's total primary energy use with non-fossil energy (including hydro).⁴⁶

Despite success in expanding capacity, rapid growth of renewable energy in China has encountered substantial grid integration problems that risk stalling further progress toward these targets. Unconnected wind capacity amounted to 21% of China's total wind capacity in 2012, although that may decrease to 12% in 2013 because of slowing investments in new wind projects, increasing investment in new transmission, and improved generation and transmission planning.⁴⁷ Wind capacity is heavily concentrated, with about 90% of wind capacity concentrated in north, northwest, and northeast China, sometimes referred to as the "Three Norths."⁴⁸ An estimated 16% of wind generation in the Three Norths region was curtailed in 2011,⁴⁹ and substantial increases in wind curtailment are likely as more wind is added.

How China's electricity industry addresses these integration issues will determine whether higher penetrations of renewable energy will be technically and politically possible. Implementing the changes needed to integrate renewable energy on a larger scale will require improved government policies, reforms to electricity sector institutions and processes, and revamping compensatory arrangements to ensure that not only are grid companies

fully compensated for costs incurred but also to direct grid companies to work harder at integrating wind and solar generation. More fundamentally, abolishing "equal shares" dispatch is the most important and immediate step that China could take to integrate variable renewable energy generation and is discussed further in Chapter 3.

This chapter reviews some of the near-term challenges to managing and integrating renewable generation in China. Our recommendations fall into three main categories: (1) improving renewable energy policies to lower cost and improve efficiency; (2) addressing renewable integration by making the future power system more flexible by encouraging a flexible, least-cost mix of new conventional and renewable generation; and (3) improving power system operation and renewable integration by clarifying grid company responsibilities and accelerating power sector reform initiatives. All of these recommendations aim to maximize the amount of renewable generation on the grid while minimizing the cost impacts of renewable energy.

5.1.1 Recommendations

We encourage China to adopt policies aimed at improving existing renewable energy policies. If adopted, these recommendations will lower the cost of new renewables. Specifically, we recommend:

- Adopt stronger locational element to FITs to encourage greater geographic diversity for renewables. Although the FIT for wind has four different price

43 Global Wind Energy Council, 2012.

44 China Electricity Council, 2013.

45 State Council, 2012.

46 NDRC, 2007.

47 Feifei, 2013.

48 Xie, 2013.

49 State Electricity Regulatory Commission, 2012.

levels depending on the wind resource and the geographic conditions, the price differences are not high enough to strongly encourage development in regions with lower-quality wind resources. The recently announced solar FITs may similarly not be sufficiently differentiated and may lead to overly concentrated deployment that challenges grid operators.

- Include, to a greater degree, transmission and location considerations when considering approval of proposed wind projects.

We also encourage China to adopt practices and policies aimed at addressing renewable integration by making the future power system more flexible:

- Extract flexibility from existing generation to the extent possible, and restructure the generation price structure to compensate for that flexibility among existing and new plants.
- Establish further compensation schemes for ancillary services.
- Adopt grid codes, policies, and/or incentive mechanisms to encourage flexibility for new conventional and renewable generation.
- Cease the addition of inflexible plants in areas with high wind/solar potential.

Finally, we encourage China to adopt power sector reform initiatives with renewable energy integration in mind. This group of recommendations could be addressed through some industry restructuring and stronger regulation and oversight of power sector operations, but we believe they are best addressed in the near term by clarifying grid company obligations and by aligning future grid company practices with government renewable energy policies. A well-motivated grid company could quickly adopt practices that improve renewable integration, reduce renewable interconnection time, and decrease renewable energy curtailment.

- Share curtailment costs between grid companies and renewable generators, with a larger share of the burden born by grid companies. This recommendation will allow wind (and eventually solar) generators to be paid the FIT even if they are curtailed.
- Reduce the number of balancing areas, either virtually (through sharing reserves, for example) or through consolidation, and encourage more regional power transfers.

- Connect renewable generation more quickly and improve renewable generation siting through a clear interconnection procedure and coordinated transmission planning.
- Improve and make better use of wind forecasts
- Adopt faster generation scheduling and dispatch practices
- Implement priority dispatch for renewables.

5.2 Improving China's Renewable Energy Policies

Ultimately, the pace and extent of renewable energy development will depend on whether its costs and its impact on retail prices can be managed. In particular, renewable FITs should strike a balance between providing adequate incentives for development and limiting impacts on ratepayers.

5.2.1 Adopt Stronger Locational Element to FITs to Encourage Greater Geographic Diversity For Renewables.

China's 2006 National Renewable Energy Law instituted FITs which replaced competitive bidding for some types of renewable energy generation. For wind, the NDRC instituted four feed-in tariff levels in 2009, with lower tariffs in areas with better wind resources. The tariffs range from 0.51 RMB/kWh for better than average wind resource areas to 0.61 RMB/kWh for lower wind speed areas. For solar, the NDRC also set FITs that differ by region, based on the strength of the solar resource and costs of construction.⁵⁰ The solar FIT prices are 0.90, 0.95 and 1.00 RMB/kWh for three regions and will be in effect for all PV plants approved after September 1, 2013 and all PV plants approved before that date but not in service until after January 1, 2014.⁵¹

50 Distributed PV projects will be eligible for a price subsidy of 0.42 RMB/kWh for the self-consumption part of power generated, as long as they have not received any government investment subsidies.

51 The 0.90 RMB/kWh rate applies mostly to western China and parts of Inner Mongolia, Gansu, Qinghai and Xinjiang. The 0.95 RMB/kWh rate will apply primarily to the northern and southwestern provinces; parts of Gansu, Qinghai, Xinjiang and Inner Mongolia not covered by the lower FIT rate. The 1.00 RMB/kWh rate will apply to eastern and southern China. See Solar Server, 2013.

An unintended consequence of the current FIT system is that wind projects have clustered in areas with the best wind resources, primarily the “Three Norths.” Although this is economical from a developer’s perspective, it may not represent a least-cost build-out of wind generation after considering diversity and transmission needs. The output of more geographically diverse wind projects will be less variable, as these different wind projects will generate at different times and in different amounts. In contrast, wind generators that are located near each other will tend to have similar wind profiles. Without the ability to cost-effectively store wind energy, this means that each additional unit of wind capacity will reduce the value of wind generation from the site. This high spatial concentration of wind projects has also exacerbated integration challenges.

In other words, there is value in greater geographic diversity of wind and solar generation, but this value is not currently being incentivized sufficiently through the FIT. The difference in price between high-speed and low-speed wind resource areas does not appear to be high enough to strongly encourage wind development in low-speed wind resource areas and avoid the concentration of wind projects in high-speed wind resource areas. The solar FIT, as currently structured, may produce a similar outcome.

Increasing the FIT price differential is one of four recommendations we make in this chapter aimed at influencing the location of new generation. The others are 1) taking better account of transmission considerations and geographic diversity of renewable projects as part of the review process, as discussed further below; 2) adoption of an interconnection process that includes identification of areas with weak and strong transmission; and 3) adoption of a more integrated transmission planning process.

5.2.2 Consider, to a Greater Degree, Transmission When Approving New Generation

All new major renewable and conventional generation projects require government approval. We are not aware of the full range of factors considered by the government when reviewing generation proposals, but recent experience with renewable energy curtailment and integration issues shows that the location of new generation and the locations of existing and planned transmission should be priority considerations. For example, northern China has too much wind and CHP capacity relative to what can be supported with current demand and transmission capacity. We are

concerned about the possibility of significant further additions of CHP to northern China in the near term, particularly given the region’s expected new inflexible nuclear power and the continued expansion of wind.

5.3 Practices and Policies Aimed at Addressing Renewable Integration by Making the Future Power System More Flexible

China’s existing power system is dominated by coal-fired generation (around 80% of total generation in 2011),⁵² with multiple provincial balancing areas and limited electricity trade between provinces. While this system was not designed with variable loads and energy resources in mind and is not very flexible, there are a number of near-term steps that could be taken to improve its flexibility.

5.3.1 Extract as Much Flexibility from Existing Generation as Possible, and Restructure Generator Payments to Compensate for that Flexibility

Coal-fired power plants tend to be relatively inflexible. They typically require a significant amount of time to start up and shut down, must be kept on or off for a long time once started up or shut down (long minimum up/down times), have relatively high minimum output levels, and can only gradually adjust their level of output up and down (low ramp rates). Increasing penetration of wind and solar energy will place greater demands on the ramping capabilities of coal units. Coal generators in China do not, however, have much incentive to provide higher levels of flexibility. When thermal generators operate above or below their rated capacity, they decrease their efficiency and thus increase their fuel costs.⁵³

We divide this issue into two categories. First, all generation has some flexibility and some ability to provide ancillary services, including the ability to ramp up and

52 China Electricity Council, 2011.

53 In 2006, all regional grids introduced tariffs for compensating ancillary services. These tariffs were developed by region under Management and Implementation Details for Ancillary Services for On-Grid Generators (并网发电厂辅助服务管理实施细则). However, generators are not compensated for any increase in net load variability caused by wind.

ramp down. The willingness of generators to operate their plants in a flexible manner within the normal range of their plants' technical ability depends mostly on the structure of their on-grid prices. The current administratively set benchmark tariff for coal generators in China does not include an adjustment mechanism to account for potential increases in fuel costs that result from ramping. In addition, China's current generation pricing approach is entirely at odds with the need for increased flexibility of operations. As discussed in Chapters 2 and 3, single price contracts with minimum guaranteed hours provide inadequate incentives for flexible operation and the provision of most ancillary services. Adopting the recommended two-part contract structure we suggest in Chapter 2 provides a payment structure that allows grid operators to use existing generation more flexibly without financial harm to generators or their owners.⁵⁴

Second, power plants can generally provide even more flexibility with small increases in capital and operation costs. The willingness of generators to provide this increased level of flexibility also turns on compensation. Acquiring this added level of flexibility from generation that requires increased investment or operation costs may require a separate ancillary services payment. Currently, generation is required to provide ancillary services as part of their generation contracts without compensation except in limited circumstances such as providing deep peaking. Separate compensation should be provided to generators for this increased level of flexibility and for providing ancillary services, over and above contracted rates for generation. This could be achieved by tariff, through competitive bidding, or creating a market for a defined service.

For northern China, an additional challenge is that a significant portion of heating load is provided by coal-fired

CHP plants during the winter months. When providing heat, CHP plants are limited in their ability to adjust their electric output, thus requiring wind generation to be curtailed during winter nights when wind output exceeds the portion of demand not already met by CHP and other coal units operating at minimum load levels. In addition to ceasing the additional build-out of even more inflexible CHP plants, expanding electric heating and thermal storage could provide a partial solution to this problem, as could load management options. Five pilots encompassing 550 MW of wind capacity are underway in Inner Mongolia, Jilin, and other provinces in China.⁵⁵ To encourage electric heating and/or load management on the scale required, however, would likely mean sharing benefits with customers through rebates for equipment or appliances, or through reduced rates.

5.3.2 Making the Future Power System More Flexible by Requiring and Encouraging Increased Flexibility for New Wind and Thermal Generation

China first issued a grid code for wind in 2005 and updated it in 2011. The grid code stipulates that wind generators are required to control real power from directives issued by the grid operator. They must also provide reactive power equal to the reactive power loss of the wind generator and half of the transmission line for a single wind plant or all of the transmission line for clusters of wind power plants.

China's grid code for wind can be updated to reflect increased capabilities available in new wind generation.⁵⁶ For example, revising the wind grid code and equipping new wind turbines with automatic generation control to provide regulation will give grid operators in China greater confidence to dispatch wind and back down conventional

54 The two-part payment structure has a fixed capacity payment and an energy payment covering variable costs. The energy component can easily be designed to reflect a power plant's heat rate curve. Adding a third component tied to plant start-up is also common internationally.

55 Xie, 2013.

56 Internationally, some grid operators have already adopted frequency control requirements for wind. Hydro-Québec requires wind plants to contribute to reducing large (> 0.5 Hz), short-term (< 10 seconds) frequency deviations

comparable to the inertial response of a conventional synchronous generator. These frequency control capabilities must be available permanently and not just restricted to critical periods of time. In addition, wind generators must be able to increase generation to 5% above their current output during under-frequency events for a duration of 10 seconds. Ireland, the United Kingdom, Germany, Spain, and Denmark all have various frequency control requirements for wind in their grid codes. See Zavadil et al., 2009; Ela et al., 2011; Ecar Energy, 2011.

generation, instead of the other way around.

Minimum performance standards for new thermal generation would also help to enhance power system flexibility. We recommend four steps.

- First, any new generation plant should be required to meet minimum flexibility requirements, such as the amount of time for starting and stopping operations, capability to operate at low levels for extended periods of time, and the ability to ramp up and down, both in range and in speed.
- Second, our recommended competitive acquisition and planning processes described in Chapter 2 should specify how competitive bid evaluation will value flexibility over and above the minimum requirements.
- Third, inflexible generation plants should not be added in regions with expected or current high levels of wind and solar capacity.
- Fourth, China should adopt our recommendations in Chapter 1 for improvements in the planning methods to more realistically assess the value of flexible peaking capacity.

5.4 Power Reform Initiatives Aimed at Grid Company Actions to Improve Renewable Integration

According to the 2007 Regulatory Measures Requiring Grid Companies to Purchase all Renewable Generation (电网企业全额收购可再生能源电量监管办法), grid companies in China are required by law to purchase all renewable generation, subject to reliability constraints. In reality, grid companies have used reliability concerns to justify large amounts of uncompensated wind curtailment.

International renewable integration experience shows that many needed policies, reforms, and practices require institutional, regulatory, and market conditions that do not exist in China. In the long term, power sector reform in China may develop the needed reforms and organizations, but in the near term we believe China can benefit from taking advantage of existing conditions. In particular, several conditions in China make solutions easier than in other countries:

- China has very large grid companies whose geographic scope is well suited to address issues that other countries address through new organizations or regulation.

- Grid companies are technically skilled and currently serve many of the functions of grid operators, grid planners, and grid owners. This makes them familiar with grid issues. Their role also gives them access to needed data.
- Grid companies are government owned and are responsive to clear government directives. Taking steps to make the grid companies active and enthusiastic implementers of government policies can solve many problems.
- Grid companies have been largely separated from generation so it is possible to create conditions under which they have no direct interest in favoring one source of generation over another.

These conditions suggest that a practical way to address many renewable integration issues is for the Chinese government to adopt policies that make the grid companies an active and enthusiastic participant in China's expansion of renewable energy. This requires two steps:

- First, China's government should further reinforce the fact that efficient integration of renewables is a grid company obligation. For example, the government could make reducing wind curtailment a performance requirement for grid company managers.
- Second, China's government should adopt policies that reinforce the obligation with assured cost recovery and rewards and penalties for performance.

5.4.1 Share Curtailment Costs Between Grid Companies and Renewable Generators, With a Larger Share of the Burden Borne by Grid Companies

Efficient grid integration is difficult to assess, but the level and frequency of renewable energy curtailment is a good indicator. An efficient grid will always have some level of generation curtailment because it is less costly to bear the curtailment cost than it is to bear the cost of transmission or flexibility needed to address the congestion issue. The challenges are to rationalize the level of curtailment, decide which generation is curtailed, and decide who bears the cost of curtailment.

In some countries the cost of curtailment is borne by the generator curtailed. In others the cost is borne by the grid company. And in others the cost is shared by the grid company compensating wind and solar generators for curtailment beyond an agreed upon frequency (e.g., times

per day) and number of hours (e.g., consecutive hours, hours per year).

The approach that best fits conditions in China is to have the wind generators and grid companies share the costs for curtailment. Grid companies could curtail wind without cost for a certain frequency (e.g., number of hours or times per day). Beyond that level, the curtailment cost is borne by the grid companies, i.e., wind (and eventually solar) will be paid the FIT even if they are curtailed.

The rationale here is that having the generator bear some of the risk provides an incentive to locate in areas where transmission is adequate and curtailment is less likely. We suggest the generator's risk be kept low because we have also suggested other more powerful ways to influence the location of new generation (e.g., FIT reform, inclusion of transmission considerations in approval for new generation projects, and improved transmission planning).

Exposing the grid company at least partially to curtailment costs makes sense because they are well positioned to take action to address integration issues and reduce curtailments. In particular, the grid companies can internalize the trade-off between curtailment and transmission investments. The grid company is also in the best position to implement the reforms discussed below, each of which will improve renewable integration and reduce curtailments.

5.4.2 Enlarge Provincial Balancing Areas and Expand Linkages Between Them

One of the most effective ways to integrate large amounts of variable renewable energy is to increase the balancing area size. Larger regional balancing areas improve integration for three main reasons: (1) load, wind, and solar variability decreases over larger geographic scales; (2) because loads and resources are less variable, forecasting accuracy improves; and (3) more generation can be accessed to balance supply and demand.⁵⁷ This reduces wind and solar integration costs by reducing the amount of operating reserves that system operators need to hold, the cost of holding those reserves, and the amount of renewable energy curtailment.

Currently, balancing areas in China generally coincide with provincial boundaries. This creates a challenge to grid operators for integrating higher penetrations of wind and solar energy. For instance, operators in Inner Mongolia (East), Liaoning, Heilongjiang, and Jilin must

face higher variability and uncertainty in net load (load minus wind, in this case) and largely use their own coal and hydro generation resources to manage that variability and uncertainty. Alternatively, a grid operator for the entire Northeast Grid would see lower variability and uncertainty in net load and could use generation resources across the region to balance supply and demand.

There are two options for creating larger balancing areas in China. First, system operations could be physically consolidated within each of the six regional grids, perhaps managed by a grid company or an independent system operator. Second, operations could be coordinated across balancing areas without actually consolidating them into a single entity. The Southwest Power Pool in the south central United States initially adopted this approach by administering an open access transmission tariff for all participants and using a voluntary energy imbalance market.

Physical consolidation of balancing areas may be difficult in China without more extensive regulatory reforms. However, in the near term, incremental steps taken to better coordinate operations between balancing authorities could significantly improve and reduce the costs of renewable integration. At the simplest level, these might include agreements to share operating reserves between provincial balancing authorities. More extensive coordination might include the creation of voluntary regional energy imbalance markets, where multiple provinces use a centralized real-time dispatch to handle deviations between day-ahead schedules and real-time net load conditions.

Regardless of the approach taken, larger balancing areas will require the availability of sufficient transmission capacity. However, transmission capacity between provincial balancing areas in China has historically been limited and may not be sufficient to address regional renewable integration challenges. Many of the barriers to increased interprovincial trade and interprovincial transmission relate to the way provinces get revenue when electricity is generated within the province versus imported from a nearby province. Similar barriers have been overcome in other countries. The solutions vary, but they

57 Multiple studies have confirmed these findings. A summary can be found in the geographic diversity chapter of Schwartz et al., 2012.

all rest on the fact that increased trade results in lower total costs. Cost savings are by definition large enough to assure that both trading partners are better off.

Making the grid company a motivated partner with an obligation and incentive to address integration issues and reduce curtailment will encourage them to require provincial grid companies to participate in a regional transmission planning process and develop proposals for allocating the costs and cost savings in ways that address existing barriers. This approach has been used in the U.S., where the Federal Energy Regulatory Commission has required all transmission providers to participate in a regional transmission planning process that, among other things, requires the consideration of “public policy” projects (e.g., projects to meet a renewables portfolio standard). In China, this kind of regional transmission planning process would also help provinces and grid companies to meet their quotas for renewable generation laid out in the Renewable Electricity Quota Management Measures (可再生能源电力配额管理办法).

5.4.3 Develop a Generator Interconnection Process

Internationally, generator interconnection is typically managed through an interconnection process, which provides a standardized, transparent process for grid companies to evaluate the impacts of new generation on the transmission system, as well as any transmission upgrades needed to accommodate new generation projects. The generator interconnection process revolves around an “interconnection queue,” which is essentially a line to get interconnected to the grid.

In China, a basic interconnection process might include the following elements:

1. At the earliest possible time, and certainly no later than at the time the developer seeks project approval from the government, the grid company would be informed of the size and location of the proposed project.
2. The grid company would undertake system impact studies to determine how the project would impact the transmission system.
3. The grid company would, by its own rules, have a specified number of days to respond with an estimate of the time it would take to interconnect the project. The grid company may also suggest alternative

locations or project configuration that would shorten the interconnection time.

4. The grid company would prepare and routinely update maps identifying current and planned transmission to aid generators evaluating new sites.

5.4.4 Improve and Make Better Use of Wind Forecasts

Better wind and variable generation forecasting is almost universally cited as an essential tool in integrating more renewable generation in China. However, due to ongoing issues with forecasting techniques, data quality, and data sharing, the accuracy of wind forecasting is not progressing as fast as it should. In addition, wind forecasts are not widely used in generator unit commitment decisions in China. The result is dispatchers overcommit coal generation and curtails wind when more thermal units are online than are needed to reliably meet demand.

China’s electricity industry has experimented with wind power forecasting since at least 2009. In 2011, the NEA issued a wind forecasting rule that places responsibility for forecasting on individual wind plants. The NEA rule attempts to encourage increased forecast accuracy by the individual wind plants through a policy that first curtails wind plants with the least accurate forecast.

Our recommendation to have the grid company share curtailment cost with generators aims to address the need for better forecasting in two ways. First, it addresses the need to improve data quality and availability. With our cost sharing recommendation the grid company will have a reason to continually improve forecasting by integrating and evaluating multiple forecasts, by comparing forecasts with actual production data, and by calibrating forecasting methods with the growing amount of actual data.

Second, grid company dispatchers appear not to trust or rely upon the wind forecasts for operational decisions. The incentives created by our sharing recommendation give the grid company a strong reason to use the improved forecasts for actual generation scheduling purposes.

5.4.5 Develop a Coordinated Generation and Transmission Planning Process

Inadequate planning and planning coordination failures have exacerbated wind curtailment in China. Current generation planning practices have led to too much inflexible generation capacity in areas with high levels of

renewables. In particular, northern China has too much wind and CHP capacity relative to what can be supported with current demand and transmission capacity. Despite widespread recognition of this problem, we are concerned about the possibility of significant further additions of CHP to northern China in the near term. This would cause difficulties given expected new inflexible nuclear power and the continued expansion of wind. This would clearly aggravate existing integration challenges. Reallocating the cost of curtailment to generators and grid companies, instead of generators solely bearing the costs, will provide a strong incentive to improve this situation.

Lack of coordination in generation and transmission planning has also created problems. Generation projects tend to have short planning and construction times, whereas transmission planning and construction, particularly between balancing areas, tends to require more lead time. In several areas, renewable development has far exceeded what was planned and insufficient transmission is available to export surplus power. In 2012, for instance, the Chifeng area, part of the Eastern Inner Mongolia power grid, was expected to have 7.6 GW of total generation capacity, including 2.3 GW of wind capacity, but the area only has a 1.6 GW peak load and 2.7 GW of transmission capacity interconnecting Chifeng with other areas.⁵⁸

The improved planning and resource acquisition process we recommend in Chapters 1 and 2 will help address this problem. The reallocation of curtailment costs suggested here will encourage the grid companies to integrate resource planning into their transmission planning process. The interconnection recommendations above will also help. Finally, the transmission plans will be used by the government, whose approval is required for wind projects to receive the FIT. These steps would help to address coordination failures between generation and transmission planning.

5.4.6 Improved Dispatch

Chapter 3 describes China's method of dispatch, sometimes referred to as "equal shares" dispatch; it resembles a fixed quota system for power delivery.⁵⁹ Chapter 3 also describes our recommended reforms for new and existing conventional generation. In addition to improving the efficiency of dispatch, the recommended pricing reforms will support faster scheduling and dispatch that can access flexibility from existing generation

needed to integrate wind and solar. Abolishing equal shares dispatch is the most fundamental and immediate policy action to take to help integrate variable renewable energy generation and will make implementation of our recommendations in this chapter much easier and more effective.

5.4.7 Priority Dispatch

China's renewable energy law requires that renewable energy generation has priority over other generation sources, otherwise known as priority dispatch. In part this requirement recognizes that regardless of how renewable generators are paid, their operating cost is so low that they should always be the first to be dispatched.⁶⁰ Grid operators in China, though, have largely not implemented priority dispatch, citing concerns about grid security and reliability.

Many of the suggestions outlined in this chapter would make priority dispatching easier, such as enlarging balancing areas, faster scheduling, improving and making more use of wind forecasting, and updating the grid code for wind. The reallocation of curtailment costs will provide a strong incentive to implement priority dispatch.

5.5 Conclusion

China has added impressive amounts of wind capacity in recent years and looks poised to do the same with solar energy in the near future. However, lack of transmission, annual plans specifying minimum hours of generation for non-renewable units, inflexible generation, and incompatible operating, scheduling, and dispatching protocols have resulted in severe grid integration challenges for China to address. Resolving these challenges will require new policies and practices in how the power grid is administered and managed. The government can make some of the necessary changes. Others will be more easily addressed by creating clear obligations for the grid

58 State Electricity Regulatory Commission, 2012.

59 Baron et al., 2012.

60 The European Commission's (EC's) Renewable Energy Directive requires that renewables have priority in interconnection and in dispatch, in order to ensure compliance with the EC's 20% renewables requirement by 2020.

company and reinforcing the obligation with performance-based rewards and penalties.

Fortunately, there are several countries and regions world-wide that have addressed integration of variable generation, and although every situation has unique circumstances, a rough consensus is forming on successful grid integration strategies. These include defining and compensating for the provision of ancillary services; adding transmission; extracting flexibility out of existing generation; adding flexible generation; consolidating balancing areas, either physically or virtually; revisiting and revising grid codes as necessary; and adopting faster schedules and dispatch. As with any other country or region, China will have to adjust some or all of these strategies to its own circumstances.

Inflexible generation is a major factor in China's renewable integration challenge. Current generation pricing practices make matters worse. Moving to two-part generation pricing will deliver increased flexibility from existing conventional generation. For more flexibility it will be necessary to devise a compensation scheme to cover added capital and operating costs. For new wind and conventional generation the best option is to first establish updated grid codes specifying minimum technical requirements aimed at flexibility. Requiring these capabilities of future generation projects will give the grid company greater capabilities in managing the grid and will likely result in less wind curtailment. We recommend new conventional generation be acquired in a competitive bid process. For this generation, flexibility should be a priority factor in the bid evaluation process.

China's current renewable energy policies, notably the FIT, have proven quite successful for increasing renewable energy capacity. However, the vast majority of China's installed wind capacity is located in northern China, in areas with large amounts of inflexible CHP plants and not enough load to consume the wind generation. Although China's FIT for wind divides the country into four wind resource areas, the difference in FIT prices is not high enough to strongly encourage wind companies to develop

wind plants outside of northern China. Sharper locational differences in FIT prices are required for wind and may also be needed for the solar FIT. Greater geographic diversity with both wind and solar is needed to make grid integration easier, and therefore, greater variations in compensation favoring lower wind resource areas are needed.

Wind curtailment has increased substantially and will increase exponentially if action is not taken, particularly in northern China. Grid companies should bear part of the lost production revenues that wind companies would have otherwise received, but wind generators should as well. This will have two desirable effects: wind companies will seek to minimize their curtailment by locating in other areas besides northern China, and grid companies will receive an economic signal to take proactive measures to minimize wind curtailment.

Among the proactive steps we expect from grid companies are 1) consolidating balancing areas, either virtually or physically, and adding transmission capacity, especially to support greater power transfers between provinces;;2) improving the transmission planning process, not only to help identify where transmission is needed but also in siting generation capacity where transmission may be available; 3) instituting a generator interconnection process to aid in transmission planning, generation location and help expedite connecting generators to the grid; and 4) improve and make better use of wind forecasting, improve dispatch to access available flexibility and implement priority dispatch.

Some of these recommendations, if acted upon, will reinforce each other. Larger balancing areas will reduce wind variability, increasing wind forecasting accuracy. Proactive transmission planning and encouraging variable generators to not site in geographically concentrated areas will also reduce variability. Increased transmission will make regional power transactions more feasible, which will help manage the variability and uncertainty of variable generation.

Chapter 6: Grid Company DSM Regulation

6.1 Introduction and Overview

Successful power sector reform depends on two complementary regulatory reforms: (1) the presence of a fully empowered and competent regulatory agency to oversee grid company costs and performance and (2) the adoption of regulatory and accounting practices that harmonize the grid companies' interests with policy goals. In China, the second point is especially important because the grid companies (gridcos) are large and powerful, government regulatory agencies are new and relatively weak, and national energy and environmental goals are high priority.

In all countries, grid companies are subject to government regulation and oversight because of the natural monopoly characteristics of their “wires” businesses. How regulation is structured is a government decision. International experience shows that ordinary regulatory designs create serious conflicts between the financial interests of grid companies and national clean energy and energy efficiency policies. Experience also shows a well-designed regulatory framework can improve grid company cost management, reliability, and environmental performance by adopting practices that harmonize grid company incentives with policy goals. The choice is between two regulatory schemes, one that puts grid company interest at odds with government priorities and the other that makes the grid company an enthusiastic promoter of government policies.

In China, it is important to give gridcos the right incentives to support – and certainly not actively oppose – national energy and environmental policy. This chapter examines how changes in regulation could improve grid company incentives in China for one important national policy: grid company-administered demand-side management (DSM) and end-use energy efficiency programs.

To enable the grid companies to deliver DSM and end-use energy efficiency without suffering adverse financial

consequences, we recommend:

- redefining the role of grid companies to include investment in end-use energy efficiency;
- *either* determining that reduced net revenues and energy efficiency program costs are part of the grid companies' cost of doing business or developing and implementing regulatory mechanisms to mitigate the impact of reduced net revenues and program costs on grid companies' financial positions; and
- redefining the standards by which the State-Owned Assets Supervision and Administration Commission assesses overall grid company performance to include assessment of grid company efforts to increase end-use energy efficiency in their customers' facilities.

6.2 Role of Energy Utilities in DSM and Energy Efficiency

When energy utilities were established over 100 years ago, their standard business model was based on the concept of energy as a commodity. Utilities were remunerated on the basis of the quantities of energy (typically electricity and/or gas) that they generated, transported, and sold to end-users. In some jurisdictions, changes in energy industries have led to unbundling of vertically integrated utilities and the establishment of smaller energy businesses that are each responsible for only part of the energy supply chain. The existing business model has largely survived these changes, and today most energy utilities are still remunerated on the basis of the quantities of energy that pass through their systems. Energy utilities therefore have a strong incentive to maximize energy throughput.

This throughput incentive works directly against energy utilities assisting their end-users to use energy more efficiently.⁶¹ Such activities affect the financial positions

61 Lazar et al., 2011.

and profitability of energy utilities in two ways: (1) energy sales are reduced, resulting in lower revenues, and (2) the energy utilities incur increased costs in developing and administering end-use energy efficiency programs.

If these negative financial impacts can be overcome, energy utilities are in a uniquely strong position to promote energy efficiency among their end-users. They have:⁶²

- a strategic position in energy markets;
- long-standing commercial relationships with even the smallest end-use customers, allowing them to influence energy saving activities in diffuse markets;
- the technical capacity and infrastructure for delivering services;
- detailed information on the consumption habits of energy consumers, a useful resource when providing energy savings advice; and
- very large revenue streams from selling energy, which can be an alternative to public budgets as a source of energy efficiency funding.

6.3 Energy Efficiency as a Resource

In some jurisdictions, particularly in North America, power sector planning combines demand- and supply-side resources in a single integrated least-cost plan. End-use energy efficiency delivered by energy utilities is regarded as a resource that can be used to meet end-users' demand for energy in an analogous way to supply-side resources such as coal, gas, and electricity. Energy savings obtained through increased energy efficiency reduce the demand for energy so that smaller quantities of supply-side resources are needed, reducing the cost of energy supply. Energy efficiency also reduces other costs, such as the cost of augmenting energy distribution infrastructure (poles and wires for electricity and pipelines for gas). Energy efficiency can also reduce some environmental impacts that result from the use of supply-side resources, therefore reducing costs to society as a whole. The sum total of these cost reductions is called the "avoided costs" resulting from intentionally deploying energy efficiency as a resource that reduces energy demand.

In addition to costs that are avoided, acquiring energy savings involves other costs that have to be paid, such as the cost of developing and administering end-use energy efficiency programs. When a comprehensive analysis is carried out, taking into account both the costs that have

to be paid and the costs that are avoided, the total cost of energy utilities acquiring energy savings is often lower than the cost of purchasing an equivalent quantity of supply-side resources. When this is the case, energy efficiency is regarded as being more cost-effective than supply-side resources from the perspective of society as a whole; that is, the present worth of lifetime energy supply costs avoided by energy savings exceeds the present worth of the costs of acquiring the savings.

6.4 Energy Efficiency Obligations

Where energy utilities have the potential to acquire energy savings that are cost-effective, many jurisdictions have established regulations that require energy utilities to deliver set levels of energy savings. These regulatory mechanisms are known generically as "energy efficiency obligations."⁶³

An energy efficiency obligation (EEO) is a regulatory mechanism that requires obligated parties to meet quantitative energy-saving targets by delivering or procuring eligible energy savings produced by implementing approved end-use energy efficiency measures.⁶⁴ The requirement to meet quantitative energy-saving targets distinguishes EEOs from other similar mechanisms, such as a general requirement to acquire all cost-effective energy efficiency with no target specified.

Governments in various jurisdictions around the world have endeavored to improve end-use energy efficiency and, in some cases, also achieve other objectives by designing and implementing schemes that place EEOs on particular parties.

These EEO schemes share three key features:

- a quantitative target for energy efficiency improvement;
- obligated parties that must meet the target; and
- a system that defines the energy-saving activities that can be implemented to meet the target; measures,

62 Heffner et al., 2013.

63 There are several other terms used for this regulatory mechanism, including "energy efficiency portfolio standard," "energy efficiency resource standard," "energy efficiency commitment," and "energy supplier obligation."

64 Crossley et al., 2012.

verifies, and reports the energy savings achieved through these activities; and confirms that the activities actually took place.

Typically, obligations in EEO schemes are placed on utilities that supply networked energy (e.g., electricity and natural gas distributors or standalone retail suppliers). Obligations can also be placed on utilities that supply other energy forms (e.g., LPG, heating oil, transport fuels, district heating) and even on end-users of energy. In some jurisdictions, energy savings to meet the obligation are delivered by a third-party “energy efficiency utility.”

6.5 Regulating to Enable Utility Delivery of Energy Efficiency

In North America, the primary focus of most regulators of energy utilities is to ensure that utilities’ investments in both demand-side and supply-side resources are economically efficient, that is, they are cost-effective to society as a whole. However, energy savings that are cost-effective to society as a whole may not be cost-effective to the utility because of the impacts of reduced revenues and energy efficiency program costs on the utility’s financial position. This conflict between maintaining (or increasing) energy sales while also achieving energy savings is also faced by energy utilities in other countries and jurisdictions where utilities are required to achieve energy-saving targets.

In some countries (particularly the United Kingdom and some other European countries) reduced revenues and energy efficiency program costs are regarded as being part of the utilities’ cost of doing business, and it is left up to the utilities to determine how they recover those costs. In other jurisdictions, (particularly Australia, Brazil, Canada, Thailand, South Africa, and the United States) a range of mechanisms have been developed to mitigate the impact of reduced revenues and energy efficiency program costs on utilities’ financial positions. These mechanisms include:

- revenue regulation in which a utility is guaranteed to receive a set amount of annual revenue irrespective of the volume of energy sales it achieves;
- surcharges on electricity bills that are designed to recover financial losses incurred by utilities resulting from their energy efficiency activities;
- lost revenue adjustment mechanisms that compensate utilities for the reduced “net revenues” resulting from their energy efficiency activities⁶⁵; and

- performance incentives that provide financial rewards to utilities that achieve specified energy efficiency targets.

6.6 International Experience with Utility Delivery of Energy Efficiency

Energy utilities already play important roles in delivering energy savings to end-use customers. The International Energy Agency has estimated that in 2011 energy utilities spent almost USD 12 billion on energy-saving activities.⁶⁶ Most of this spending is from state and provincial efforts in North America, where some energy utilities spend as much as three percent of their revenue on energy efficiency.

A recent study examined over 15 years of data from customer-funded energy efficiency programs implemented by electricity utilities and third parties in the United States.⁶⁷ The study found that these programs produced an estimated one-percent saving in electricity consumption over the period 1992 to 2006 and almost two-percent cumulative electricity savings when savings in future years were taken into account. The electricity savings came at an expected average cost to utilities of roughly five cents per kWh saved when future savings were discounted at a standard discount rate of five percent. This is substantially cheaper than the average national retail electricity price in 2006 of 9.1 cents per kWh across all sectors. Energy savings were also more cost-effective than the levelized costs of investment in new generation capacity in 2006 that ranged from 8 to 9 cents per kWh for new baseload fossil fuel-fired capacity to approximately 13 cents per kWh for a

65 Under current conditions in China, grid companies purchase electricity from generators that they then on-sell to end-users. When they deliver energy savings rather than electricity, their purchasing costs from generators are reduced. The grid company’s “net revenue” loss is the difference between the price for which it sells electricity and the purchase cost the grid company saves from delivering energy savings instead. China is now considering reforms that allow the generation cost to be passed directly on to consumers. If this occurs, it will mean the generation cost savings will no longer offset the grid companies’ revenue losses, creating an even stronger disincentive for grid companies to deliver energy savings.

66 International Energy Agency, 2010.

67 Arimura et al., 2011.

new gas turbine peaking plant.

These results demonstrate that energy efficiency delivered by energy utilities can make a major contribution to achieving cost-effective energy savings. The high levels of energy utility-delivered energy efficiency in North America are a result of the regulatory mechanisms established there that mitigate the impact of reduced revenues and program costs on energy utilities' financial positions, and in some cases, even enable energy utilities to make money from promoting energy efficiency.

6.7 Grid Company DSM Regulation in China

In November 2010, China's National Development and Reform Commission issued the document Demand Side Management Implementation Measures (发改运行 [2010] 2643号).⁶⁸ This regulation, for the first time, requires grid companies in China to carry out DSM activities, including both energy efficiency and load management, to achieve specified targets for reductions in electricity sales (GWh) and peak demand (MW). In addition, grid companies are required to install load monitoring equipment on 70 percent of the peak load, and load control equipment on ten percent of the peak load, in any locality. This regulation is the first example in China of an EEO.

The 2010 regulation was a big step forward for DSM and energy efficiency in particular, although China has had very good success since the 1980s with a suite of non-power sector policies to improve energy efficiency.⁶⁹ More importantly, the 2010 regulation may encourage grid companies to integrate energy efficiency as a resource into power sector planning, as recommended in Chapter 1. However, there is significant room to improve the implementation of the 2010 regulation, broaden its scope, and provide corresponding incentives for the gridcos, as we will discuss below.

Chinese grid companies are currently carrying out various DSM activities to meet their energy-saving targets. Where these activities involve assisting their customers to be more energy-efficient, the grid companies' financial positions and profitability are impacted in two ways: (1) electricity sales are reduced, resulting in lower revenues, and (2) the grid companies incur increased costs in developing and administering end-use energy efficiency programs.

Working to reduce electricity sales and peak demand does not fit easily with the grid companies' profitability targets. In China, the State-owned Assets Supervision and Administration Commission evaluates grid company performance based on profit levels, which under current regulatory and accounting practices are tied to electricity sales. Any activities that reduce sales could be seen as reducing profitability and therefore lowering grid company performance. The grid companies consequently face conflicting objectives in attempting to meet both their profitability targets and their energy-saving targets.

6.8 Funding of Grid Company DSM Activities

In China, grid companies have access to funding to cover some of their energy efficiency program costs. The DSM Implementation Measures regulation states that reasonable DSM expenses incurred by grid companies can be recovered as part of power supply costs. In addition, where a grid company implements its DSM activities through a subsidiary energy management company⁷⁰ registered with the National Development and Reform Commission, qualified energy efficiency projects receive from the central government CNY 240 (USD 38) per ton of standard coal equivalent (tce) energy saved plus at least CNY 60/tce (USD 9.60/tce) from provincial and municipal governments, with some of these governments opting to pledge more.

In addition, there are two other funding sources that grid companies may be able to access to defray the program costs of their DSM and energy efficiency activities:

- capital and O&M cost savings that the grid companies make from reducing energy consumption and energy demand; such cost savings can result from, for example, a reduced need for grid augmentation and grid expansion; and
- additional funding sources identified in the DSM Implementation Measures regulation, including: a city utility surcharge (城市公共事业附加费) collected

68 National Development and Reform Commission, 2010.

69 Crossley, 2013.

70 "Energy management company" is the term used in China for what in North America would be called an energy service company (ESCO).

through electricity tariffs; revenues from differential electricity prices (差别电价), mainly through implementing differential prices for energy-intensive industries; and other fiscal means, for example, an energy saving and emission reduction special fund (节能 减排专项资金) established through the budgets of central and provincial governments.

However, it is unclear whether this funding will be sufficient to cover all the program costs grid companies incur in carrying out their DSM and energy efficiency activities. Also, grid companies are currently unable to seek compensation for reduced net revenues resulting from these activities. Consequently, the financial positions of grid companies are likely to be made worse by their DSM and energy efficiency activities, and grid companies are certainly unable to make money from these activities.

6.9 Conclusion

Experience in China and in many other countries has shown that energy efficiency is more cost-effective than supply-side resources from the perspective of society as a whole. Chinese governments have recognized this

by implementing a range of energy efficiency programs, particularly in the industrial sector. These programs could now be supplemented by expanding the current scope of the DSM Implementation Measures regulation to require grid companies to acquire all cost-effective energy efficiency before purchasing electricity from generators. This would significantly reduce costs and increase economic efficiency in China.

To enable the grid companies to meet this expanded obligation, several actions would be required, including:

- redefining the role of grid companies to include investment in end-use energy efficiency;
- *either* determining that reduced net revenues and energy efficiency program costs are part of the grid companies' cost of doing business *or* developing and implementing regulatory mechanisms to mitigate the impact of reduced net revenues and program costs on grid companies' financial positions; and
- redefining the standards by which the State-Owned Assets Supervision and Administration Commission assesses overall grid company performance to include assessment of grid company efforts to increase end-use energy efficiency in their customers' facilities.

Chapter 7: International Best Practices Regarding Coal Quality

7.1 Introduction and Overview

China's use of low quality coal increases environmental damage, adds unnecessary expense, and decreases the operating life of power plants. The goals of the 9th Five Year Plan to increase the percentage of coal washed have yet to be realized. At least four major effects can be identified from the current system China uses to transport and burn coal in power plants:

- The high ash and sulfur content decreases the effective operating life of power plants, increases the costs to dispose of fly ash, increases emissions of fine particulate and sulfur oxides, and, where this practice occurs, increases the risks to the plant of exposure to future regulatory actions related to the hazardous materials collected and disposed of on-site.
- Higher ash content burdens China's transport network, adding to or creating rail network congestion, and causing more diesel fuel to be burned by trains to carry coal from mining areas to power plants.
- Uncovered rail cars leak coal and coal dust, creating public health and environmental impacts to areas along China's rail network.
- Because China's rail network is congested, diesel trucks are used to transport coal between mining areas and power plants. These trucks burn high sulfur fuel and are not subject to the same emissions standards as light duty trucks and cars. As a result, diesel truck transport of coal is increasing the PM_{2.5} concentration in certain urban areas.

The purpose of this chapter is to examine ways in which China can improve the quality of the coal it burns for electric generation, thereby gaining both environmental and economic benefits. We will look at the lifecycle of coal, the benefits and costs of using higher quality coal, and points where pressure may be applied to increase the use of high

quality coal. We conclude with several recommendations that can help Chinese regulators encourage the use of better quality coal.⁷¹

7.2 International Experience

Coal continues to be the dominant fuel choice for power generation around the world. While hydraulic fracturing and new drilling techniques have increased natural gas supplies, coal consumption continues to rise, especially in Asia. China and India alone are responsible for nearly all of the growth in global coal consumption since 2000. We know that the emissions characteristics of coal combustion are substantially influenced by the type and processing of coal used; it is also true that the quality of coal affects the profitability of a particular power plant and can facilitate or hinder the plant's ability to meet environmental requirements.

The main variables that influence coal quality are its ash⁷² and sulfur content. Ash and sulfur are inorganic and have no heating value. The higher the ash content, the lower the heating value of raw coal (i.e., coal straight from the mine mouth). Many lower heating-value coals, or "lower rank" coals, as they are referred to in the industry, have ash content of 40% or higher. Removing the ash through washing or additives increases coal's heating value. This processing has several other benefits, which directly affect the profitability of a coal plant, its ability to meet

71 This chapter was originally published by RAP as a standalone paper: James & Gerhard, 2013. James, 2013 contains additional information on coal quality.

72 Ash is found in all coals. In raw, unburned coal, ash is comprised of crustal materials (i.e., dirt and small rocks) as well as inorganic compounds, such as salts and metals. Ash has little to no heating value, so when coal is burned, the ash, now called fly ash, travels through the boiler and duct work, and is collected in emissions control devices, with finer particles being directly emitted to the atmosphere.

environmental requirements, and its ability to avoid future economic risks. The presence of ash and sulfur in the boiler combustion chamber is linked to increased scheduled and unscheduled maintenance and decreased capacity factors (meaning fewer hours of generating electricity). Further downstream, higher ash concentrations (products of incomplete combustion) coat ductwork and increase the quantity of solids that have to be collected by emissions control devices and then disposed of in landfills. Ash and sulfur deposits on plant duct work increase corrosion and shorten the plant's expected life. Improving coal quality by lowering its ash and sulfur content is, therefore, both environmentally and economically beneficial and is an advisable course of action to pursue.

7.3 Life Cycle of Coal⁷³

There are a number of steps in the lifecycle of coal: extraction, processing, transport, use/combustion, and disposal. The description below is a general description for illustrative purposes, not meant to be exhaustive.

7.3.1 Extraction

Coal is extracted (i.e., mined) in one of two different methods: surface or “opencast” mining and underground or “deep” mining. The choice of method is mainly driven by geology. Surface mining is used when the coal seam is near the surface; the coal seam is exposed by blasting away and removing the surface layer of rock and dirt, and then the coal seam is systematically drilled and removed. Underground mining is used when the coal seams are deeper underground; the coal seams are accessed by drilling tunnels hundreds of feet underground, and the coal is then mined and brought to the surface.

7.3.2 Processing

From the earliest days of mining, people have attempted to improve its quality by removing impurities, such as rock and slate, or by sizing and washing the coal. Generally, in contemporary practice, the first step is to wash the coal, which involves chemical processes that separate dirt, vegetation, and raw rock from coal. The process reduces the amount of ash and sulfur content of the coal and increases the heating value of the coal. It also produces a byproduct called slurry or sludge, which is comprised of the water and chemicals used to wash the coal. Slurry

is a highly toxic substance that is collected and stored at the mine site, giving rise to environmental concerns about groundwater contamination. Washing is frequently followed by an additional mechanical process wherein the coal chunks are crushed and ground and then separated into different grades of coal. Throughout the washing and crushing process, the coal may be sampled to measure ash, moisture levels, kCal (BTU), sulfur, iron, calcium, sodium, and various other elements. In China, coal washing was emphasized by the 9th Five Year Plan, and again in the new Air Law.⁷⁴

7.3.3 Transport

Once processed, coal must be shipped from the mine to the point of consumption; this happens by train, truck, barge, and conveyor belts, although some generation plants are built near the mine mouth to lower transport costs. Transportation of coal is a significant issue in China, where most of the coal mines are located in the northwest and the coal must be transported to the consumption centers in the southeast. Some estimates suggest that over 0.56 billion tons of coal are shipped each year over long distances (average greater than 500 km).⁷⁵

Coal transport is an expensive and environmentally harmful activity. The United States Energy Information Agency reports that, in 2010, transportation costs made up 38.6% of the total cost of a delivered short ton of coal in the U.S.⁷⁶ Furthermore, the diesel engines used by many of the trucks and trains that transport coal emit into the air significant amounts of oxides of nitrogen (NO_x) and particulate matter. In addition, there is the dust and particulate matter that comes off the coal as it is transported long distances.

73 See: Lockwood, 2012; Epstein et al., 2011; World Coal Association, 2012.

74 Article 44 of existing Air Law “the State shall promote coal washing and processing, lower the sulfur and ash contents of coal, and restrict the mining of coal with sulfur and high ash contents”. Article 89 permits fines to be imposed on new mines that fail to include coal washing.

75 Xiaolon, 2012.

76 U.S. Energy Information Administration, 2012.

7.3.4 Combustion

The majority of the coal that is mined globally is “thermal” coal, that is, coal burned to produce steam and used mainly in electricity production.⁷⁷ Coal combustion “releases over 70 harmful chemicals into the environment and contributes significantly to global warming.”⁷⁸ Prior to combustion, coal is pulverized into a coarse powder to improve the efficiency with which it burns. Roughly 90% of coal-fired generation capacity worldwide uses pulverization techniques.⁷⁹ Some of the more notable byproducts of burning coal are ozone precursors⁸⁰, sulfur dioxide, particulate matter, nitrogen oxides, mercury, and carbon dioxide. In addition to gases, there is also a solid byproduct from burning coal called coal ash, which is discussed below. Generators can install mitigation equipment, such as scrubbers, to reduce the emissions of harmful pollutants.

7.3.5 Disposal

As mentioned earlier, the combustion of coal produces a solid byproduct called coal ash. A number of different substances fall under the label “coal ash”: fly ash, bottom ash, boiler slag, and flue gas desulfurization gypsum, among others. Once the coal ash is collected, it is often impounded and stored in a storage pond or in a landfill or can be used for various industrial purposes.

7.4 Benefits and Costs Associated with Improved Coal Quality

There can be both benefits and costs associated with the use of higher quality coal in electricity generation. Our position is that the benefits far outweigh the costs.

7.4.1 Benefits

All coals contain inorganic materials, such as sodium, chlorine, and sulfur. During the combustion process, the inorganic materials form ash that is deposited in a dry (called fouling) or wet (called slagging) state in the boiler’s combustion chamber. The quantity and types of compounds present in the ash dictate the necessary frequency of cleaning the boiler’s tubes (to maintain their design heat transfer rate), as well as how often the boiler must be shut down for more extensive maintenance. These inorganic compounds can be removed by the application of mineral additives to the coal prior to its combustion or by washing the coal at either the mine mouth or at the coal plant itself.

The industry term for improving coal quality is called “beneficiation.” Beneficiation improves the coal’s quality and produces both environmental and economic benefits.

7.4.1.1 IMPROVE HEAT RATES

The higher the ash content of coal, the lower the heating value of that coal. By removing the ash through washing, the coal’s heating value can be improved dramatically. This means that less coal must be burned to produce a comparable amount of electricity. Thus, power plants that use higher quality coal will have an economic and performance advantage over those that use lesser quality coal.

7.4.1.2 IMPROVE PLANT OPERATIONS

Beneficiation results in a variety of improvements to power plant operations, which directly affect the profitability of a coal plant, its ability to meet environmental requirements, and its ability to avoid future economic risks.

Applying mineral additives containing aluminum can reduce ash fouling and slagging in pulverized coal boilers by up to 78%.⁸¹ Wet pretreatment can reduce the amount of ash that adheres to boiler tubes, thus reducing fouling. Dry additives, such as alumina, can make the ash less sticky and thus reduce the amount of ash that forms on boiler surfaces. Reducing the ash content of coal also makes the coal less abrasive.

Reducing the presence of ash and sulfur in the boiler combustion chamber is good. By reducing the amount of ash accumulation, operators can reduce the amount of scheduled and unscheduled maintenance required to remove the ash accumulation. Reducing the abrasiveness of the ash and sulfur deposits on plant duct work can reduce corrosion that shortens the plant’s expected life.

Higher ash content in the fuel affects every piece of

77 The other type of coal is called metallurgical coal and is used to create coke, a product required in the making of iron and steel. See World Coal Association, 2012.

78 Lockwood, 2012.

79 World Coal Institute, 2005.

80 Ozone is not directly emitted by coal plants, but compounds such as NO_x and hydrocarbons, which are directly emitted, contribute to the formation of ozone downwind from coal plants.

81 Vutharulu, 1999.

plant equipment that handles and processes coal, such as conveyors, pulverizers, crushers, storage, etc. The increased load on this equipment also increases the quantity of plant-site energy needed simply to operate the plant, which takes away from the quantity of electricity that can be transmitted for sale, thus increasing the plant's operating costs and decreasing its profit potential.

Beneficiation also has benefits for the operation of emissions control devices. About 80% of the ash in coal eventually travels through the combustion process and, along with the flue gas, is captured by the emissions control equipment. Coal washing reduces the amount of ash produced and collected by particulate control devices, thereby extending the life of the particulate control devices. Washing coal also helps to extend the life of ash disposal landfills. Beneficiation also extends the life of emissions control equipment by reducing the amount of pollutants the devices need to capture. Washing or processing coal before it is combusted can also permit the power plant to design and purchase smaller emissions control devices, thus reducing capital costs.

Thus, power plant owners benefit directly from burning better quality coal. Coal-fired boilers represent significant economic assets for their owners and operators. Construction materials used are high value, such as stainless steel for certain ductwork and equipment, and boilers are designed to last for 20-30 years or more. Improving coal quality preserves the value of this long-term investment.⁸²

7.4.1.3 IMPROVE AIR QUALITY

Reducing sulfur in the fuel combusted also will reduce sulfate formation and fine particulate emissions and help to improve visibility by reducing regional haze. The actual quantity of sulfate formed is dependent on the amount

of SO₃ that is emitted and on various meteorological and chemical reactions caused by the emissions. Data from U.S. coal plants show that about 1-2% of sulfur oxides are emitted as SO₃. Sulfur trioxide also easily converts to hydro sulfuric acid (H₂SO₄), a potent contributor to acid rain.⁸³

Studies of U.S. coals show that washing reduces sulfur content by 10-20% (on a pounds-per-MMBtu basis). Ash reductions of 30-50% were reported for Mexican coals, with a 20-30% reduction in sulfur content. A National Academy of Sciences study reports sulfur reductions for China's coals of up to 20%.⁸⁴ A minimum 10% reduction in SO₂ is considered to be a conservative assumption of the emissions-savings potential from coal washing. This minimum 10% reduction in SO₂ for a 600 MW plant, operating at an 80% capacity factor (or 7000 hours per year), would result in a minimum SO₂ reduction of 1,682 metric tons.

7.4.1.4 IMPROVE TRANSPORTATION SYSTEMS

Coal washing reduces the weight of the raw coal by up to 25%, with the effective heat content, in Btus per gram, increasing. A net reduction in transportation energy demand of about 20% is possible, requiring less fuel to transport the coal from a mine to a power plant, yielding reductions in fine particulate, NO_x, and greenhouse gas emissions.⁸⁵ The same study reports that 45% of China's railway capacity goes to transporting coal, and 70 million tons of dirt and rock are moved along with coal each year.

7.4.1.5 LESS EXPENSIVE

One joint U.S.-India study showed that washed coal was, on average, about 10% less expensive than that of raw coal, even with a calculated washing fee of RS 130 per ton (about 15 RMB or U.S. \$2.40 at exchange rates as of December 2012).⁸⁶ This report graphed the heating value of coal after

82 It must be acknowledged, however, that even with higher quality coal, boiler design is still critical to the efficient operation of a power plant. Boiler design life is predicated on adherence to good fluid dynamics and heat transfer principles. Layout of the plant's ductwork and piping aims to minimize turns and bends and have large diameter ducts to minimize pressure drops, to maximize the thermal efficiency of the plant, and to avoid extra energy demand just to move flue gases from one point to another. Critical to this are well-mixed flue gases, which depend upon adequate retention time in the combustion chamber to complete chemical reactions, achieve maximum heat transfer, and minimize the formation of air

pollutants. Well-mixed flue gases also ensure that duct velocities are uniform from top to bottom and side to side. Doing so helps to assure that flue gas temperatures are as uniform as possible. Flue gas hot spots can cause duct deformation and flue gas cold spots can cause corrosion if the temperatures drop below the acid dew point.

83 Allen et al., 2004.

84 National Research Council, 2004.

85 Glomrod, 2003.

86 Sharpe, 2011.

different levels of washing and showed that, for distances greater than 900 kilometers, the delivered price (on a cost per k-cal basis) was lower for washed coal than for raw. The study also concluded that washing produced additional plant benefits (higher heat content per kg of coal, lower ash disposal costs, lower operations and maintenance costs, etc.). Finally, the report compared imported coal with both raw and washed coal (including the benefits to the power plant). This analysis found that washed coal was 10-20% less expensive than that of imported coal.

A recent study of the U.S. “Acid Rain” SO₂ reduction program, which was launched in 1990, supports the notion that improving the quality of coal has significant and quantifiable benefits. The program led to a significant decline in SO₂ emissions, largely achieved through a shift to better quality coal (although installation of emissions control equipment also played a supporting role). Overall, the program achieved annual benefits of \$122 billion (chiefly from reduced PM_{2.5} mortality), compared to annual costs of only \$3 billion.⁸⁷ The next section will discuss these costs in more detail.

A technical paper completed for the U.S. Electric Power Research Institute (EPRI) confirms the benefits of using higher quality coal. The paper states that “it is safe to say that higher ash content for a particular coal is undesirable at any plant for any reason.”⁸⁸ This paper analyzed coals with different quantities of ash and then determined the effect of ash content on several boiler performance and operation parameters, including thermal efficiency, quantity of ash landfilled, annual tube failures, unit availability, and the quantity of carbon dioxide emitted. Increasing ash content negatively affected all boiler parameters. Thermal efficiency decreased, annual tube failures increased, the quantity of ash sent to landfills and carbon dioxide emissions increased, and unit availability decreased. Even a one percent improvement in boiler efficiency will have a significant impact on the quantity of coal combustion by a power plant over the course of a year. Improving the generation or “heat” rate of a unit, i.e., reducing the grams of coal to produce one kilowatt-hour of electricity, reduces fuel costs and improves profitability. Later studies on the benefits of improving coal quality have supported the conclusions of the study completed for EPRI.⁸⁹

7.4.2 Costs

Precise data on the costs associated with washing and processing coal are scarce. A review of publicly available

information emphasizes the benefits to coal producers from washed coal, i.e., they can fetch a higher price for their product.⁹⁰

The environmental and private benefits associated with improving coal quality must be compared with the costs, including the environmental costs of washing and processing coal. In certain geographic areas, water resources are constrained, in some cases severely so. Using scarce water resources to improve coal quality may not be advisable in such areas, and it may be better to improve coal quality at the power plant or at some intermediate site between the mine mouth and the plant, where water resources are more plentiful and can be reused.

Also, washing coal creates a need to impound the residual slurry from the washing process itself. Slurry storage ponds give rise to the risk of contamination of local waterways and ground water if the containment ponds leak. This is a serious environmental consideration and requires careful oversight by regulators.

7.5 Points of Regulation

Because not all costs associated with poor quality coal are borne by the plant owners, and because many plant owners have already invested in plants that can effectively use low quality coal,⁹¹ it is advisable for the Chinese government to take certain actions to encourage the increased use of higher quality coals.

There are several ways in which quality control requirements can be specified. Contractual arrangements between the seller of the coal and the purchaser are the primary means by which commercial quality control is established. One example of contractual standards for coal quality comes from the New York Mercantile Exchange (“NYMEX”). Under standard NYMEX rules, there are a

87 U.S. EPA, 2013.

88 Anderson & Nowling, 2002.

89 Canadian Clean Power Coalition Technical Committee, 2011.

90 See Mostrous, 2012, for example, about how Mongolia’s coal producers are enjoying a higher price per ton for selling washed coal to China.

91 Steinfeld et al., 2008.

number of coal quality specifications:

- (A) Coal delivered under this contract shall meet the following quality specifications on an as received basis, (as-received does not refer to subsections (6) and (7)):
- (1) **Btu:** Minimum 12,000 btu/lb., gross calorific value, with an analysis tolerance of 250 btu/lb below (A.S.T.M. D1989)
- (2) **Ash:** Maximum 13.50%, with no analysis tolerance (A.S.T.M. D3174 or D5142)
- (3) **Sulfur:** Maximum 1.00%, with an analysis tolerance of 0.050% above (A.S.T.M. D4239)
- (4) **Moisture:** Maximum 10.00%, with no analysis tolerance (A.S.T.M. D3302 or D5142)
- (5) **Volatile Matter:** Minimum 30.00%, with no analysis tolerance (A.S.T.M. D5142 or D3175)
- (6) **Grindability:** Minimum 41 Hardgrove Index (HGI) with three-point analysis tolerance below. (A.S.T.M. D409)
- (7) **Sizing:** Three inches topsize, nominal, with maximum fifty five per cent passing one quarter inch square wire cloth sieve to be determined basis the primary cutter of the mechanical sampling system. (A.S.T.M. D4749)⁹²

Under these kinds of contractual arrangements, quality standards are enforced by the parties to the contract, with recourse to the appropriate judicial body in cases of disputes over performance.⁹³

A second type of quality control can take place through air pollution permitting. Permits impose different types of restrictions on the specific permitted sources, with site-specific parameters. Restrictions may be placed on the heating value range of coal (minimum and maximum), its sulfur and ash content, and its throughput (tons of coal combusted per hour) and on record keeping and reporting (including sampling and emissions testing requirements). Typical entities in need of permitting are power generators and large industrial facilities that use coal in their operations.

An example of a permitting program is the U.S. Environmental Protection Agency's ("EPA's") New Source Review ("NSR") program.⁹⁴ NSR applies when a company, such as the future operator of a coal-fired generator, intends to build a new plant or modify an existing plant to such a degree that certain emissions will increase by a large amount. NSR permits are construction permits, and they require that a company minimize specified emissions either by changing the proposed industrial process or by installing air pollution control equipment.

Another type of permitting program that the EPA operates falls under Title V of the Clean Air Act as it was amended in 1990.⁹⁵ Title V permits are operating permits that govern the activity of sources once they are in operation. They cap a facility's allowable emissions of certain pollutants, such as CO₂, SO_x, mercury, and NO_x.

EPA is the body responsible for enforcing the NSR program, and regulated entities are required to comply with a strict regime of data collection and reporting to EPA.

Finally, there are general quality-control measures that can be applied across a region or across an industry (as opposed to permits, which are site-specific). Regulations can take a number of forms, such as "command and control," whereby a regulator sets emissions targets for pollutants and penalizes entities that exceed those levels; incentives, whereby a regulator sets targets and rewards entities that achieve those targets; and market mechanisms, such as cap-and-trade regimes.

Perhaps the most well-known global example of emissions control policies is the European Union's Emissions Trading Scheme ("ETS") for the regulation of CO₂ emissions.⁹⁶ The ETS began in 2005. The program places a limit (a cap) on the total amount of particular greenhouse gases that can be emitted from industrial operations and power generators. Companies each receive permission to emit up to a specified amount per compliance period (this permission takes the form of an allowance per unit of emissions).⁹⁷ Allowances can be

92 CME Group, 2012.

93 Contracts generally specify the method of resolving conflicts, as well as the adjudicatory body and jurisdiction.

94 A description of the New Source Review program can be found on the EPA's website at <http://www.epa.gov/nsr/>.

95 See EPA website for Title V information at <http://www.epa.gov/air/caa/title5.html>.

96 See the European Commission's website on its Emissions Trading System at http://ec.europa.eu/clima/policies/ets/index_en.htm.

97 A common criticism of the ETS is that emission allowances were given out freely to emitters. An alternative, preferred methodology is to sell the allowances and then reinvest those funds into energy efficiency and renewable energy programs, thereby further reducing emissions levels. See Cowart, 2008.

bought and sold, depending upon each emitter's strategy for achieving compliance with the pollution limits. At the end of a compliance period, each regulated entity must submit allowances to cover its emissions during that period. If an entity emits more than it has allowances to cover, then it is fined. Emissions levels can be gradually reduced by limiting the number of allowances issued.

The European Commission is the entity that enforces the ETS.

7.6 Recommendations for China

China can improve upon the quality of the coal burned. Doing so can help to improve the economics of the power plant and reduce the environmental damages that are currently occurring. Following are several recommendations that China can consider to improve the quality of coal combusted in power plants:

- Conduct research in conjunction with a cognizant university, China's coal institutes, and the China Electricity Council to:
 - Determine the potential in China to improve the quality of coal through a cost-benefit analysis and planning process (i.e., how much ash and sulfur can be removed, what would be its costs, to what levels could coal's heating value be increased, what quantities of water would be required?).
 - Develop the appropriate policy mechanisms to recover any costs associated with improving the quality of coal and where those costs are best allocated.
- Include coal quality specifications in EIAs and licenses for coal-fired power plants. This will permit the power plants to contract with the coal companies for the type and quality of the coal to be burned. The specifications should include: the types of coal to be burned; the acceptable ranges of heating value, sulfur and ash; and require the received coal to be tested.
- For coal washing, require facilities to recycle and reuse water used for processing.
- In areas with water constraints, or where drinking water or ground water supplies might be used to wash coal, instead improve the quality of coal in these areas through dry additives and processes that do not require water.
- Work with MEP to reduce the sulfur content of fuel burned in diesel trucks. The recent "Joint Prevention, Joint Control" for air quality plan, with commitments by MEP, NDRC and the Ministry of Finance, announced accelerated targets to improve China's fuel quality. Reducing the sulfur content will also allow these trucks to be fitted with modern devices to reduce fine particulate matter.

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北京市朝阳区建国门外大街19号国际大厦2504室 • 邮编:100004 • 电话: +86-10-8526-2241

CITIC Building, Room 2504 • No 19 Jianguomenwai Dajie • Beijing 100004 • *phone:* + 86-10-8526-2241

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