

Lawrence Berkeley National Laboratory

Lawrence Berkeley National Laboratory

Title

What China Can Learn from International Experiences in Developing a Demand Response Program

Permalink

<https://escholarship.org/uc/item/6bc7j9kz>

Author

Shen, Bo

Publication Date

2012-06-30



**ERNEST ORLANDO LAWRENCE
BERKELEY NATIONAL LABORATORY**

What China Can Learn from International Experiences in Developing a Demand Response Program

Bo Shen, Chun Chun Ni, Girish Ghatikar, Lynn Price
Environmental Energy Technologies Division
Lawrence Berkeley National Laboratory

*Preprint version of paper for conference proceedings,
ECEEE Summer Study on Energy Efficiency in Industry,
Arnhem, the Netherlands, September 11-14, 2012.*

June 2012

This work was supported by the China Sustainable Energy Program (CSEP) of the Energy Foundation, Azure International, and Dow Chemical Company (through a charitable contribution) through the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.

Disclaimer

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor The Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or The Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof, or The Regents of the University of California.

Ernest Orlando Lawrence Berkeley National Laboratory is an equal opportunity employer.

What China Can Learn from International Experiences in Developing a Demand Response Program

Bo Shen, Chun Chun Ni, Girish Ghatikar, Lynn Price

Environmental Energy Technologies Division

Lawrence Berkeley National Laboratory

Abstract

China has achieved remarkable economic growth over the last decade. To fuel the growth, China added a total of 455 gigawatts of new generation capacity between 2006 and 2011, which is an increase of 76% in five years. Even so, this capacity does not meet the growing demand for electricity, and most of China's industrial sector is facing the worst power shortages since 2004. The Chinese government has been managing the capacity shortfall through direct load control programs. While such mandatory programs have spared China from electricity outages, it does so at a high cost to the industrial sector. The load control program has significantly affected business operations and economic outputs, while failing to trigger greater energy efficiency improvement. Instead, it has led to a proliferation of diesel generators used by industrial facilities when electricity is not delivered, increasing diesel use and associated air pollution.

Internationally, there is a growing trend in employing market-based approaches through demand response (DR) to effectively manage electricity supply and demand particularly during the peak power use. China can significantly benefit by localizing international experiences in DR. Such international experiences, when integrated in the ongoing pilot demand-side management (DSM) programs in China, can provide greater flexibility to electricity customers and help China identify a potential solution in addressing the peak load issues. After the discussion of why China needs a new approach to meet its peak demand, this paper highlights international experience in adopting enabling policies to promote DR and in employing practical DR strategies geared toward the industrial sector. Through these experiences, we provide recommendations for how to integrate DR in China's DSM programs.

Introduction

China has achieved remarkable economic growth over the last decade. Yet with increasing prosperity and a rapidly growing economy have also come sharp increases in electricity consumption. To meet the surging demand, China has been adding new generation capacity in an unprecedented pace over the last decade. China took 38 years to reach the milestone of 100 gigawatts (GW) of installed generation capacity. In 2007, however, China increased its generation capacity by over 100 GW in just one year,

82% of which came from coal-fired facilities (CEC, 2008). By 2011, China's total generation capacity reached to 1,056 GW, of which over 70 percent was thermal (CEC, 2012). Table 1 shows the historical trend of China's electricity capacity over the last three decades.

Table 1. Electricity Generation Capacity in China (1980-2010)

Year	Hydro		Fossil		Nuclear		Wind		Total
	GW	% of Total	GW	% of Total	GW	% of Total	GW	% of Total	GW
1980	20.32	30.8%	45.55	69.2%					65.87
1985	26.41	30.3%	60.64	69.7%					87.05
1990	36.05	26.1%	101.84	73.9%					137.89
1995	52.18	24.0%	162.94	75.0%	2.10	1.0%	0.04	0.0%	217.22
2000	79.35	24.9%	237.54	74.4%	2.10	0.7%	0.34	0.1%	319.32
2001	82.70	24.5%	252.80	74.8%	2.10	0.6%	0.40	0.1%	338.00
2002	86.07	24.1%	265.55	74.5%	4.47	1.3%	0.47	0.1%	356.57
2003	94.90	24.2%	289.77	74.0%	6.19	1.6%	0.57	0.1%	391.41
2004	105.24	23.8%	329.48	74.5%	6.84	1.5%	0.76	0.2%	442.39
2005	117.39	22.7%	391.38	75.7%	6.85	1.3%	1.27	0.2%	517.18
2006	130.29	20.9%	483.82	77.6%	6.85	1.1%	2.60	0.3%	623.70
2007	145.26	20.4%	554.42	77.7%	8.85	1.2%	5.90	0.8%	713.29
2008	171.52	21.6%	601.32	75.9%	8.85	1.1%	8.94	1.1%	792.53
2009	196.79	22.5%	652.05	74.6%	9.08	1.0%	16.13	1.8%	874.07
2010	213.40	22.2%	706.63	73.4%	10.82	1.1%	31.07	3.2%	962.19

Source: CEPP, 2011

Although China has been increasing its generation capacity at a pace equivalent to adding two large-scale coal-fired power plants a week in recent years, the country's electric supply is hardly keeping up with the demand. In recent years, China has been experiencing the worst power shortage since 2004 and it is particularly evident in the industrial sector as it is the largest electricity consumer in China, consuming over 70 percent of the country's total electricity. The Chinese government is managing the shortfall through direct curtailment of customers' loads under the mandatory "Orderly Use of Electricity" program. While the mandatory program has spared the country from blackouts, it does so at a high cost to the industrial facilities. The rationing program has significantly affected business operations and economic outputs, while failing to trigger greater energy efficiency improvement.

Instead, it has led to a proliferation of diesel generators used by industrial facilities when electricity is not delivered, with increased diesel use and associated air pollution. Internationally, there is a growing trend in employing a market-based approach through demand response (DR) to effectively manage electricity supply and demand particularly during the peak power use. DR refers to changes in electricity usage by end-users from their business-as-usual consumption patterns in response to changes in electricity prices, financial incentives, or a reliability signal. With greater flexibility for customers, DR presents a natural progression from direct curtailment and greatly improves the effectiveness of addressing the supply and demand gap.

In 2011, the National Development and Reform Commission (NDRC) of the Chinese central government launched a comprehensive demand-side management (DSM) pilot program, under which four cities — Beijing, Tangshan, Suzhou, and Foshan — were selected as the pilot locations to design and implement a comprehensive program aimed at both reducing the peak demand and improving the efficiency of electricity consumption in industrial facilities and commercial buildings. Recently, an international team of researchers at Lawrence Berkeley National Laboratory and Azure International initiated collaboration with one of the pilot cities, introducing the new concept of DR into China. This paper presents information on the initial effort in this collaboration through which the international research team conducted a study in understanding China's current approach in load control, introduced to NDRC and the pilot city international experiences in employing DR to effectively manage supply and demand particularly in industrial sector, and provided recommendations to the pilot city on the integration of DR in the pilot design. The paper first discusses the power shortage in China including its causes, intensity, and consequences. It then discusses China's current approaches to addressing its electricity shortage and explains why a new approach is needed. An introduction of international DR experiences, particularly those in the U.S., on enabling policies and industrial sector strategies follows. The paper concludes with recommendations by drawing upon international experiences for how to integrate DR in China's DSM programs.

Energy Shortfall Challenging China's Economic Growth

Status of shortfall

China's power shortage does not just occur during the summer months but increasingly occurs in winter and spring months. According to the China Electricity Council, the country could face a combined peak power shortage of up to 40 GW in the winter and spring months in 2012 as rising demand outpaces expansion in generation capacity (Shanghai Daily, 2011). This is almost 4 percent of China's current total capacity and more than twice the shortfall that Japan faced after its earthquake in March 2011. The power shortage is more severe in the main manufacturing hubs in the delta regions of the Yangtze and Pearl rivers where power demand is much higher. Jiangsu Province, one of the country's economic powerhouses, had a deficit of more than 11 million KW or 10 percent of its power demand in 2011 (China Daily, 2011a). Figure 1 depicts the level of China's power shortage from 2004 through 2010. Despite the fact that the economic slow-down due to the global financial crisis which started in 2008 had lowered electricity consumption in China, a massive winter storm that hit a big part of China in early 2008 still made the electricity shortfall in 2008 the largest between 2004 and 2011 (Ni, 2009; Bar Stockstar, 2009; EEO, 2010; 360doc, 2011).

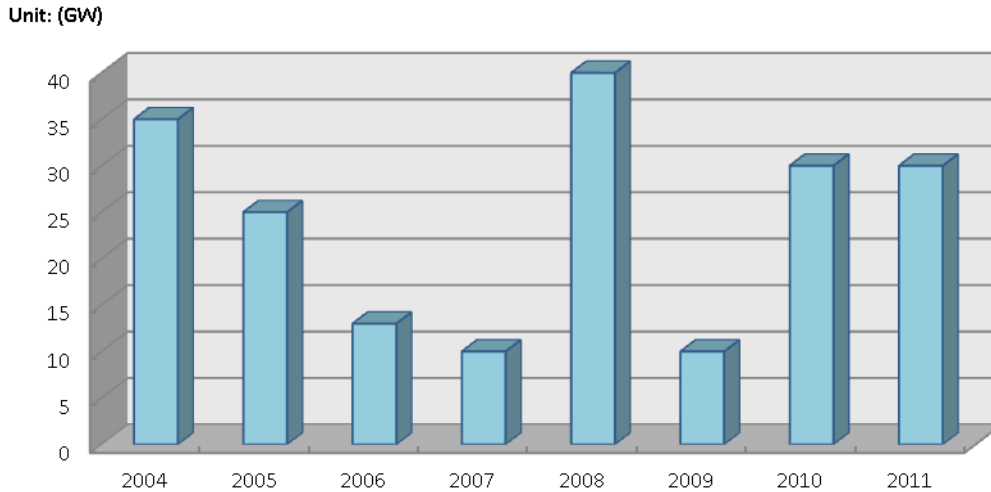


Figure 1. China's power shortage from 2004 through 2010

Why shortfall occurs

Over the last decade, China significantly increased its power supply to sustain the booming economy. The increase of power production is seen as one of the success factors for China's economic growth. Yet, the electric supply is hardly keeping up with demand. Power shortages have been a chronic issue since the middle of the 1980s. Under-investment in China's power sector for the most part of 1980s and 90s and under-estimating the demand for power during the Asian financial crisis that started in 1997 caused serious power shortages from the mid-1980s well into the early-2000s. The control of power prices coupled with coal supply shortages have further accelerated power shortages from the mid-2000s to date. Therefore, alleviating electricity supply shortages has been a long-term priority for China's power sector (Ni, 2009).

There are several reasons that China is now facing the worst power shortage since 2004, but the most significant may be surging demand. Electricity consumption in China grew by 14.76 percent — 15.88 percent in the industrial sector — in 2010 with the capacity to generate power only growing by 10.56 percent (CEC, 2011). Abnormal weather with hot summers and cold winters has been driving up the electricity demand while widespread droughts have negatively affected hydropower output, worsening the supply constraint. Coal is the main fuel for generating electricity in China. For the country's power producers, however, the price of electricity in China is capped by the government. Tight coal supplies and rising coal prices combined with relatively lower electricity price have eroded the power producers' profit margins, reducing the motivation to increase capacity utilization (China Daily 2011a). Utilization hours of thermal power equipment was 5,031 hours in 2010, 16 percent lower than 5,991 hours in 2004, indicating that the utilization of thermal generators has not reached the historical maximum point (Adkins, 2011).

Transmission constraints in China have further sparked power shortages during the peak demand season. A Barclays report estimated China's northern and north-western regions have generation surpluses of up to 14GW each, but the capacity could not be effectively channelled to power-hungry areas (Shanghai Daily, 2011). In addition, many manufacturers, who worried that power rationing will cut into their profits, stepped up production during the hours when power was available and that spike led to further shortages across the country (China Daily, 2011b).

Consequence of shortfall to the economy and the environment

China's chronic power shortages since 2004 have disrupted manufacturers' productivity and have added inflationary pressures to the country's economy. To ease power shortages, utility companies have operated power rolling measures mainly to the industrial users. Manufacturers have been asked to shut down their assembly lines during the high peak. The restriction has imposed the biggest impacts on the main manufacturing hubs in China's coastal regions. Small and medium enterprises are hardest hit by the power interruption as many of their large peers are equipped with self-generation facilities thus avoiding service interruption. In Zhejiang Province, for example, small enterprises that have an annual output value of less than 5 million Yuan (€600,000) are required to stop using electricity between 7 am and 5:30 pm, while medium-sized enterprises that have an annual output value of more than 5 million Yuan are being asked to cut their use of power two days each week (China Daily, 2011c). As the world's largest manufacturing base, consequently, any unforeseeable and irregular suspension of production activity causes enormous business losses.

Many manufacturers in China have switched to back-up diesel generators as an immediate response to the power rationing. The increase of using diesel generator units has significantly driven up the consumption of diesel fuels, creating yet another shortfall with domestic supplies of refined oil products running low. A Chinese trade group, China Petroleum and Chemical Industry Federation, estimated in early 2011 that the country's diesel consumption would likely to rise by 15 percent from a year earlier. Consequently, in May 2011, the top economic planner, the National Development and Reform Commission (NDRC) imposed a ban on diesel exports to ensure domestic supply and also called for increasing production of petroleum by-products (China Daily, 2011d). Although modern diesel generators are more efficient and thus less polluting compared with old coal-fired plants, widespread use of diesel generators on a large scale to provide electricity will not only drive up the prices for fossil fuels but also create environmental problems as widespread diesel use not only emits large amount of NOx and other pollutants to the local environment but also releases more carbon dioxide into the atmosphere.

China's Approach to Dealing with the Power Shortage

DSM regulation

To address the growing demand for electricity, China's central government issued a directive on demand-side management (DSM) in late 2010. The directive *Administrative Measures in DSM*

Implementation, for the first time requires China's utility companies to achieve specific energy savings and peak load reduction targets, similar to Energy Efficiency Resource Standard (EERS) adopted in Europe, the U.S., and a number of other countries. The new DSM regulation urges utility companies to play a leading role in promoting DSM in China while making it an obligation for China's utility companies to achieve annual dual targets of energy savings and load reduction of 0.3 percent, respectively, in total electricity sales and maximum load from previous year level (NDRC, 2010). Although the targets sound modest, both energy and demand reductions could be tremendous based on China's current level of electricity use. China's total electricity consumption in 2011 was 4.6928 trillion kWh, a 0.3% energy savings would translate to 14 billion kWh – enough electricity to power 12.8 million average Chinese homes for a year (based on 1,100 kWh average household annual electricity use). A seemingly insignificant 0.3 percent of load reduction would reduce the country's peak load by over 1,900 MW in 2011, equivalent to the capacity of four large-scale power plants (Great Wall Net, 2011; Zhong Xin Net, 2011).

Under the new regulation, utility companies can meet the obligation in two ways: either creating its own DSM programs or procuring DSM resources from others. Furthermore, the regulation allows utility companies to incorporate the legitimate expenses incurred from implementing DSM programs into the cost recovery of providing electricity services.

In recent years, DSM has been promoted in China as a way to improve end-use energy efficiency. China has already adopted a number of policies and measures to promote the use of high efficiency equipment in the industrial sector, such as adjustable-speed motors, water pumps, high-efficiency transformers, compact fluorescent lamps (CFLs), etc. However, for a long time, China's approach to DSM has been focused on individual retrofit projects, and as such, there has not been a concerted effort to develop the capacity needed to identify and implement DSM – specifically, energy efficiency – projects on the sort of scale that can be used as a programmatic resource.

There is a growing trend in China that large-scale, cost-effective DSM programs are developed through the implementation of the concept of an Efficiency Power Plant (EPP) – a virtual power plant comprised of a portfolio of energy efficiency activities. An example of such an approach is the large-scale industrial EPP pilot in China's Jiangsu Province. The initial success of the program caught the attention of the Chinese top leadership, which led to Jiangsu being designed as a model for industrial DSM programs in China (Shen et al., 2009). EPP programs are now being implemented in Beijing, Jiangsu, and Hebei.

Regulation on load management

To tackle China's growing power shortage and enhance electricity service reliability, the National Development and Reform Commission (NDRC) issued a new regulation in April 2011, particularly governing load management. The regulation, *Administrative Measures for Orderly Use of Electricity*, requires local governments to take necessary administrative, financial, and technical measures to manage the use of electricity (NDRC, 2011). It further requires that load management take the following order depending on the level of emergency: load shifting through making operation arrangement and

adjusting maintenance schedules, then avoiding peak via interruptible load, then placing limits on electricity use, and finally service shut-off.

To make the load management more effective, the regulation provides guidance for local governments to take more economic and technical and less administrative measures. For example, the regulation encourages government administrators to use incentives to attract customers' interests in voluntarily shifting or curtailing their load, adopt enabling price mechanisms, and incite efficiency improvement by easing the limits on power use for customers who have performed well in energy efficiency.

Although energy efficiency and load management are both included in China's DSM programs, the two programs have been carried out separately. Aimed at enhancing activities on both fronts, NDRC launched a comprehensive demand-side management (DSM) pilot program in 2011, under which four cities — Beijing, Tangshan, Suzhou, and Foshan — were selected as the pilot locations to design and implement a comprehensive program aimed at both reducing the peak demand and improving the efficiency of electricity consumption in industrial facilities and commercial buildings. The pilot cities are encouraged to experiment with innovative policy mechanisms and market-based solutions and create experiences that could be transferable to other locations and on which new national policies and regulations on DSM could be developed.

Current practices in load management in China

Despite some variation among regions, load management programs in China are somewhat similar across the country. Approaches deployed include administrative, technical, and economic measures.

Administrative measures

Administrative measures are taken at different government levels. At the provincial level, the government electricity department develops an annual load allotment based on the forecasted regional power supply and demand for the year. The shortage allotment is then allocated to the city level. City officials in charge of load management further allocate the ration to particular lines/substations where congestion often occurs and/or to selected industrial and commercial customers who have specific characteristics including having an interruptible load, being a large consumer, or having inefficient or less environmental friendly operations. City officials then work with local utility companies in making a load management implementation plan based on the pre-determined target prior to the seasonal peak electricity use. The plan consists of separate sets of action based on the emergency level of the power shortfall. Typical actions include requiring manufacturing facilities to adjust production shift, stagger businesses' work hours, rotating industrial operations among factories during the week, and requiring industrial facilities to perform equipment maintenance or conduct employee trainings during peak seasons or peak hours.

Technical measures

To facilitate the load management programs in China, utility companies in many regions have installed millions of load control devices at customer's sites to tackle the shortfall. When a power shortage

reaches a certain level (e.g., forecasted power supply shortfall is 10 percent over the peak demand), the local utility company will send load reduction requests to targeted customers within a very short time frame (for example, 30 minutes in Suzhou, Jiangsu Province). These control devices are not only placed on a facility's main meter but also on key power equipment. For example, Suzhou, China's largest industrial city, has installed more than 40,000 load control devices for customers whose transformer capacity reaches a certain size. Generally, customers pay for the load control devices. The devices are equipped with on-off switches, which are set and controlled remotely by the local utility companies and can only be used to switch the load off or back on. The switch is operated by the utility company in accordance with its reliability requirement. If the required amount of load reduction was not shed by a customer, the switch at the customer site will turn off the service in minutes.

Economic measures

Many places in China have adopted time-of-use (TOU) tariffs to encourage industrial and commercial customers to shift loads from peak to off-peak. Table 2 displays TOU tariffs for regular industrial and commercial customers in Beijing, which shows an average ratio of 4:1 between peak and off-peak prices. Beijing has also adopted a high peak price scheme under which customers are charged 10% above the TOU peak price for 4 hours between July and August every year. In addition, a number of places in China have created incentive programs to motivate customers to voluntarily shift or shed their load during the peak. For example, several provinces/cities compensate customers who participate in the interruptible load programs. The compensation is 1.00 Yuan/kWh (€0.12/kWh) for standby and 1.50 Yuan/kWh (€0.19/kWh) for service interruption.

Table 2. TOU Rate for Typical Industrial and Commercial Customers in Beijing

Voltage classification within class	Usage Rate (Yuan/kWh) (€/kWh)			
	High Peak 4 hours only in July and August (11:00-13:00 and 20:00-22:00)	Peak 8 hours (10:00-15:00 and 18:00-21:00)	Flat 8 hours (7:00-10:00 and 15:00-18:00, 21:00-23:00)	Valley 8 hours (23:00-7:00)
Less than 1KV	1.4239 (€ 0.1770)	1.3042 (€0.1621)	0.8145 (€0.1012)	0.3508 (€0.0436)
1-10 KV	1.4009 (€ 0.1741)	1.2822 (€0.1594)	0.7995 (€0.0994)	0.3418 (€0.0425)
20KV	1.3939 (€0.1733)	1.2752 (€0.1585)	0.7925 (€0.0985)	0.3348 (€0.0416)
35KV	1.3859 (€0.1723)	1.2672 (€0.1575)	0.7845 (€0.0975)	0.3268 (€0.0406)
110KV	1.3709 (€0.1704)	1.2522 (€0.1556)	0.7695 (€0.0956)	0.3118 (€0.0388)
220KV and above	1.3559 (€0.1685)	1.2372 (€0.1538)	0.7545 (€0.0938)	0.2968 (€0.0369)

Note: 1 Yuan = €0.1243

Source: Beijing Development and Reform Commission

http://www.bjpc.gov.cn/ywpd/wjgl/jgcx/syig/syig_ggspxxig/200605/t119695.htm

Among all of the options adopted in China, administrative measures are used most often for load management. Experience to date shows that mandatory measures can effectively and quickly reduce demand during peak times. However, there are significant economic costs resulting from mandatory

closure of industrial operations. For this reason local governments in China need to find other innovative measures to address the load problem.

International experiences in addressing electricity demand

This section is a discussion of some international experiences in employing demand response (DR) strategies to address electricity demand. The international experiences described here are valuable for China as it is searching for more effective way to move away from the administrative approach towards a market-based approach in addressing its peak load issue caused mostly by its industrial operations. These experiences can potentially be considered in China in the DSM pilots underway at the city level and for future scale-up at the national level.

Internationally, DR is increasingly becoming a cost-effective alternative to traditional supply-side solutions for addressing peak demand. According to the California Energy Commission (CEC), DR is “a reduction in customers’ electricity consumption over a given time interval relative to what would otherwise occur in response to a price signal, other financial incentives, or a reliability signal” (CEC, 2011). The sections below present international experiences in developing enabling DR policy, employing relevant control technologies, and adopting DR strategies particularly in the industrial sector. Although the discussion includes activities in the United Kingdom (U.K.) and Australia, it focuses primarily on the U.S. experiences because the market for DR in the U.S. is more mature and relevant information is richer compared with other part of the world.

Demand Response Enabling Policies

DR, at least in a basic form, has been around for decades. In the U.S., for example, load management and interruptible/curtailable tariffs were first introduced in the early 1970s. The primary interest in load management was driven in part by the increasing penetration of air conditioning, which resulted in needle peaks and reduced load factor. These programs were effectively limited to the largest industrial customers in a given system, and in many cases never used. Deployed before the advent of the Internet or the load aggregator business model, these programs were very manual and typically featured slow response times. With such limited capabilities, interruptible programs served less as an alternative to generation investments, and more as a load management tool that could theoretically be used in emergencies.

Government policy in the establishment of these opportunities has been an essential driver to the growth of the DR industry in the U.S. The Energy Policy Act of 1992 (EPAct 1992) began the process of electric industry deregulation and opened up the opportunity for independent power generators to participate in wholesale markets. FERC Order 888 by the U.S. Federal Energy Regulatory Commission requires fair access and market treatment to transmission systems. While the aforementioned legislation and Order were primarily focused on increasing competition among generators, the concepts laid the groundwork for demand response to enter wholesale markets when such resources could meet the same technical requirements as their supply-side counterparts. The Energy Policy Act of 2005 (EPAct

2005) further codified that a key objective of U.S. national energy policy was to eliminate unnecessary barriers to wholesale market demand response participation in energy, capacity, and ancillary services markets by customers and load aggregators,¹ at either the retail or wholesale level. A major component of FERC Order 719 was eliminating barriers to the participation of demand response in wholesale markets operated by wholesale market operators. Order 719 permitted load aggregators to bid demand response directly into organized markets, unless the relevant laws of the local electric retail regulatory authority prohibit such activity (LBNL and ENERNOC, 2012).

The integration of DR into the U.S. wholesale power markets was further bolstered with the issuance of FERC Order 745, which requires that DR resources be paid the Locational Marginal Price (LMP), or the wholesale market price for energy. By codifying the ability for DR to be compensated in the same fashion as generation resources for services provided to the energy markets, Order 745 advanced the cause of equal treatment between generation and demand side resources. In the U.S., DR is primarily seen in the wholesale capacity markets. DR in these markets is procured in a competitive process that places demand side resources on equal footing with generation, creating an opportunity for cost-effective DR that can easily enter the market (should technical requirements be able to be met). In PJM, the largest regional wholesale market in the U.S., participation in DR is allowed in all markets types – capacity, energy, and ancillary services. In this market, participating resources include not only generating facilities, but also demand-side resources including demand response and energy efficiency measures by consumers. In this manner, demand-side resource is directly integrated into the wholesale market structure. Today, approximately 2,000 MW, or 8% of the resources in the ISO-NE (in New England) capacity market, are dispatchable demand response. This figure is estimated to grow to 3,400 MW, or 10% of the ISO-NE system, in 2014-15 (LBNL and ENERNOC, 2012).

Demand response resources also enjoy wholesale market access in the U.K., albeit in a much more limited context. Market-based opportunities for demand-side resources in the U.K. are currently restricted to ancillary service markets, whereas Australia's WEM is a capacity market similar in many ways to those in the U.S., and with a significant penetration of DR. In the most recent Reserve Capacity Cycle in WEM, more than 8% of the capacity procured came from demand-side resources.

In addition to allowing DR to participate in the capacity, energy, and ancillary services markets, several countries have adopted other policies to promote DR. These policies include:

- Cost recovery and DSM funds. Under a cost-recovery mechanism, a utility can recover prudently incurred costs of DR and EE investments on a dollar-for-dollar basis, typically through a rider or customer surcharge. In some jurisdictions, utilities are authorized to recover additional costs associated with the lost revenue due to the energy efficiency measures. There are also provisions for earning a fair rate of return on the DSM investment, typically at levels that are equivalent to allowable returns on power generation assets.

¹ Load aggregation is the process by which individual energy users band together in an alliance to secure more competitive prices than they might otherwise receive working independently. Oftentimes, load aggregator companies are formed to represent the interests of these groups of customers.

- Loading orders and similar regulations. Loading orders are governmental proclamations that define the priority order in which resources are to be developed. In California, for example, to underscore the importance of energy efficiency and demand response in the State's future energy picture, the state government developed the Energy Action Plan that established a "loading order" of preferred resources, placing energy efficiency and demand response as the state's highest-priority procurement resource, and set aggressive long-term goals for energy efficiency and demand response resources.
- Peak demand mandates and energy efficiency portfolio standards. Peak demand mandates and energy efficiency portfolio standards have recently emerged as another mechanism to encourage DR outside of market-based opportunities. Perhaps most well known is a mandate in the state of Pennsylvania, the so-called Act 129 legislation, signed into law in October 2008, which requires all electric distribution companies to achieve peak demand reduction targets of 4.5% and energy efficiency reductions of 4% both by 2015. Other states with peak demand mandates that are similar to Pennsylvania include New York, Colorado, Michigan, and Ohio (LBNL and ENERNOC, 2012).

The Role of Technology

Technology plays an important role in the reliable operation of demand response. Internationally, great progress has been made in automating the DR process in order to maximize load reduction savings without affecting day-to-day business operations. To enable DR applications, advanced control-device technologies, communication network and protocols, and smart metering are working seamlessly to form fully functioning systems. Increasingly, automated DR activities in the U.S., particularly in California, are carried out through open communication technologies, namely the Open ADR technology.

OpenADR is defined as "a communications data model designed to facilitate sending and receiving DR signals from a utility or independent system operator to electric customers. The intention of the data model is to interact with building and industrial control systems that are pre-programmed to take action based on a DR signal, enabling a demand response event to be fully automated, with no manual intervention. The OpenADR specification is a highly flexible infrastructure design to facilitate common information exchange between a utility or regional transmission organization (RTO)/Independent System Operator (ISO) and their end-use participants. The concept of an open specification is intended to allow anyone to implement the signalling systems, providing the automation server or the automation clients." (OpenADR Alliance, date) Widespread adoption of OpenADR will accelerate the successful implementation of DR programs, thereby providing the major benefits for all stakeholders including lower costs, assured interoperability, greater reliability, and enhanced flexibility.

DR Aggregation

There are bilateral DR programs that are used outside of capacity as a way to avoid or defer investments in generation and/or transmission and distribution (T&D) infrastructure, and tend to look similar in

structure to a power purchase agreement (PPA) that a utility might sign with an independent power producer. In the U.S., for example, Pacific Gas and Electric (PG&E), a large utility company in Northern California, implements the Aggregator Managed Portfolio (AMP) program, which is a non-tariff program that consists of bilateral contracts with aggregators to provide PG&E with price-responsive DR. The program can be called at PG&E's discretion. Each aggregator is responsible for designing and implementing their own demand response program, including customer acquisition, marketing, sales, retention, support, event notification and payments. To participate, customers must enroll through a load aggregator. The customer in turn authorizes the aggregator to act on their behalf with respect to all aspects of AMP, including receipt of notification of an event, receipt of incentive payments and/or penalties. As with the aforementioned DR programs in California, the load aggregator is responsible for all roles from customer acquisition through resource dispatch and settlement. Should the load aggregator fail to do either, financial penalties against the aggregator may be assessed.

Incentives and Pricing

Internationally, regulators and utilities have been designing effective price mechanisms and creating incentive programs to promote DR options and encourage greater participation of customers. In the U.S., for example, these programs are classified into two categories: . price-based DR and incentive-based DR.

Price-based DR refers to changes in usage by customers in response to changes in the prices they pay and include real-time pricing, critical-peak pricing, and time-of-use rates. If the price differentials between hours or time periods are significant, customers can respond to the price structure with significant changes in energy use, reducing their electricity bills if they adjust the timing of their electricity usage to take advantage of lower-priced periods and/or avoid consuming when prices are higher. Customers' load use modifications are entirely voluntary (see Table 3).

Incentive-based DR refers to programs which are established by utilities, load-serving entities, or a regional grid operator. These programs give customers load-reduction incentives that are separate from, or additional to, their retail electricity rate, which may be fixed (based on average costs) or time-varying. The load reductions are needed and requested either when the grid operator thinks reliability conditions are compromised or when prices are too high. Most demand response programs specify a method for establishing customers' baseline energy consumption level, so observers can measure and verify the magnitude of their load response. Some demand response programs penalize customers that enroll but fail to respond or fulfil their contractual commitments when events are declared (see Table 3).

Table 3. Demand response pricing mechanisms and Incentive programs

Price-Based (Voluntary)	Incentive-Based (Mandatory)
<ul style="list-style-type: none"> • <i>Time-of-use (TOU)</i>: a rate with different unit price for usage during different blocks of time, usually defined for a 24 hour day. TOU rates reflect the average cost of generating and delivering power during those time periods. • <i>Real-time pricing (RTP)</i>: a rate in which the price for electricity typically fluctuates hourly reflecting changes in the wholesale price of electricity. Customers are typically notified of RTP prices on a day-ahead or hour-ahead basis. • <i>Critical Peak Pricing (CPP)</i>: CPP rates are a hybrid of the TOU and RTP design. The basic rate structure is TOU. However, provision is made for replacing the normal peak price with a much higher CPP event price under specified trigger conditions (e.g., when system reliability is compromised or supply prices are very high). 	<ul style="list-style-type: none"> • <i>Direct load control</i>: a program by which the program operator remotely shuts down or cycles a customer’s electrical equipment (e.g., air conditioner, water heater) on short notice. Direct load control programs are primarily offered to residential or small commercial customers. • <i>Interruptible/curtailable (I/C) service</i>: curtailment options integrated into retail tariffs that provide a rate discount or bill credit for agreeing to reduce load during system contingencies. Penalties may be assessed for failure to curtail. Interruptible programs have traditionally been offered only to the largest industrial (or commercial) customers. • <i>Demand Bidding/Buyback Program</i>: customers offer bids to curtail based on wholesale electricity market prices or an equivalent. Mainly offered to large customers (e.g., one megawatt [MW] and over). • <i>Emergency Demand Response Programs</i>: programs that provide incentive payments to customers for load reductions during periods when reserve shortfall arise. (e.g. ERCOT EILS) • <i>Capacity Market Programs</i>: customers offer load curtailments as system capacity to replace conventional generation or delivery resources. Customers typically receive day-of notice of events. Incentives usually consist of up-front reservation payments, and face penalties for failure to curtail when called upon to do so. (e.g. PJM ELRP, IMO WA) • <i>Ancillary Services Market Program</i>: customers bid load curtailments in ISO/RTO markets as operating reserves. If their bids are accepted, they paid the market price for committing to be on standby. If their load curtailments are needed, they are called by the ISO/RTO, and may be paid the spot market energy price. (e.g. PJM SRM, UK STOR)

Source: DOE (2006), p.12.

International experiences in carrying out industrial DR programs

While DR focuses on managing the peak loads and reducing the operational costs of energy use, it is important to note that energy efficiency is the first order and an important tool to reduce overall demand. DR also becomes extremely important to address intermittency issues as China starts adding more renewables in the power generation mix. Effective DR strategies could become a strategic tool, flexible enough to address the intermittency issue. The following section provides experiences regarding

DR strategies in industrial facilities, through ongoing studies. Table 4 identifies the typical end-uses that are in industrial facilities. It is from these end-uses that DR strategies are identified and acted upon.

Table 4. Common examples of industrial end-use loads for DR

Air handlers	External/Internal lighting
Anti-sweat heaters	HVAC systems
Chiller control	IT equipment (servers, storage, networking devices)
Chilled water systems	Motors
Cogeneration / CHP	Production Equipment
Defrost Elements	Processing lines
Emergency generation	Refrigeration systems

Implementing DR in the industrial sector presents a number of challenges, both practical and perceived, to meet the generation needs. Some of challenges are: the wide variation in loads and processes across sectors and even within sectors; resource-dependent loading patterns that are driven by outside factors such as customer orders or time-critical processing (e.g. tomato canning); the perceived lack of control; and aversion to risk, especially unscheduled downtime. However, experiences in the industrial sector have proven that with careful planning and preparation, this sector holds significant promise and great opportunities for DR (Ghatikar et al., 2012). Some of these study findings and industry categories may be relevant to DR applications in China.

Various studies on different types of industrial facilities, such as data centers (Ghatikar et al., 2010), water and waste water facilities (Thompson et al., 2010), refrigerated warehouses and food processing facilities (Lekov et al., 2009; Lewis 2007) discuss DR strategies for peak load reduction in different industrial facilities. The followings are examples of how these strategies work.

DR Strategies in Data Centers

Because data centers are both energy-intensive and highly automated, they are excellent candidates for Auto-DR. However, the sophisticated controls of environmental conditions, high level of technology implementation, and users' technical knowledge make participation of data centers in DR unique, especially in implementing Auto-DR strategies. "Non-mission-critical" data centers are the most likely candidates for early adoption of DR. The largest opportunity for DR or load reduction in data centers is in the use of software algorithms, server consolidation and virtualization to reduce information technology (IT) equipment energy use, which correspondingly reduces facility-cooling loads. In the case of data centers located in multiple regions, load migration may work well for DR events. DR strategies could also be deployed for data center lighting and HVAC systems.

End-use curtailment is just one form of DR for data centers. More common is the utilization of on-site generation. Data centers and other mission-critical facilities (e.g. financial institutions) are fully backed with standby generation to ensure business continuity in the event of a power interruption. These facilities often regularly test these generation units to ensure readiness should a power loss occur.

Instead of testing at random times, these facilities can shift site loads onto these generation assets during periods of grid need, and achieve the co-benefit of testing and providing a resource.

DR Strategies for Water or Wastewater Facilities

Wastewater treatment facilities are energy-intensive and have significant electricity demand during peak periods. Most of the facilities have storage ponds, which make a load-shifting strategy possible. Turning off the energy-intensive equipment such as effluent pumps and centrifuges during the peak can result in significant load reduction (Thompson et al., 2010).

DR Strategies for Refrigerated Warehouse Facilities

Pre-cooling strategies using the thermal mass in some refrigerated warehouses enable load shifting from peak to off-peak periods. Shifting of batch process, shifting operation of equipment such as conveyors, pump systems, space conditioning, motors, process cooling, and storage can be utilized here. One load shifting strategy is to defer forklift battery charging to off-peak hours (Lekov et al., 2009). Those load shifting strategies can be used in combination with load shedding strategies such as process shutdown; shutting down operation of equipment such as aerators, electrical, process air, shutting off air-handlers serving freezers, and increasing set point of HVAC systems.

Refrigerated warehouses and cold storage facilities have also proven to be successful loads for the emerging field of bi-directional DR. The ability to both increase and decrease demand is becoming increasingly important with the rising penetration of intermittent renewable resources such as wind.

DR Strategies for Food Processing Facilities

Significant DR opportunities exist to both reduce and shift essential demand (i.e. manufacturing-related demand) and non-essential demand (e.g. office buildings, warehousing, etc.) in food processing facilities (Glen Lewis Group, 2007). These strategies include adjusting operation schedules, adjusting raw material delivery, shutting off or adjusting set points of end-use applications, as well as adjusting lighting and HVAC systems. Various supply chain factors such as scheduling of raw material delivery, perishability, labor, logistics, shelf life, and product transport require the food processing sector in particular to carefully plan for curtailment or postponement.

DR Strategies in Heavy Industry

Heavy industry and manufacturing is another area for demand response application. While such facilities often have very specialized equipment, their energy-intensive operations can represent significant load reduction capability. For slow response (i.e. 4 or more hour notification), production lines can often be fully shut down, and perhaps rescheduled. On a more rapid basis, variable speed drives, balers, and even arc furnaces can be both curtailed and remotely controlled. Of course, many industrial facilities also have standby and cogeneration capacity, which can be leveraged as well.

Conclusion and Recommendations for the Next Steps

China is facing and will continue to face the challenge of growing its economy with an unbalanced energy supply and demand. To address the problem of electricity shortfalls, China has taken significant measures. Among all options, administrative measures through the implementation of the Orderly Use of Electricity power-rationing program are used most often in China to minimize the country's power shortage. Mandatory measures can effectively and quickly reduce demand during peak times. However, there are significant economic costs resulting from shutting down industrial operations. To address the challenge more effectively, China needs to find other innovative solutions.

Internationally, DR has provided a cost-effective alternative to traditional power capacity expansion to address the growing demand during times of peak electrical load. With a combination of support of advanced control, networking, and communication technologies, DR manages customer consumption of electricity in response to supply conditions, having electricity customers change their consumption patterns in response to market prices, incentive payments, and/or reliability signals. International experiences so far have shown great results of DR reducing demand at critical peaks.

China is seeking ways to moving away from an administrative approach towards a market-based approach in meeting its peak demand. Through launching comprehensive DSM city pilots, China aims to develop innovative approaches to both reducing the peak demand and improving the efficiency of electricity consumption in industrial facilities and commercial buildings. China could benefit from international experience in utilizing DR resources in its DSM pilots. As the second phase of the collaborative project described earlier, the international team is working with one of the pilot cities to incorporate the DR concept and strategies in the pilot. Clearly, the adoption of DR in China needs several steps. Some could be taken immediately while other steps may require a change of current market structure or broader power sector reform. China could consider taking the following measures:

Integrating DR into the country's DSM program: this is essential for DR to receive necessary policy and resource support.

Raise the awareness about the DR opportunities in the industrial sector and their benefits through training and customer education: this is critical to help the customer understand the value of DR, the strategies and technologies needed for DR, and the policies and procedures put into place to enable further development of DR.

Integrate DR deployment into China's smart grid development: develop automation capability and promote enabling technology to facilitate DR through the deployment of smart meters and DR-enabled control and communication technologies.

Develop open standards to allow interoperability: open standards like openADR can be of great value in reducing the cost of DR programs and eliminating stranded assets. Creating an open and competitive market for control vendors is an effective way to reduce the cost of DR equipment. Open standards also

allow interoperability among systems, facilitating the wide use of automated-DR, which enhances the performance of DR programs by allowing the response to be more reliable.

Feed in customers with energy use information: governments should make consumers aware of the time-varying value of electricity costs, allowing customers to take advantage of lower price periods. This is necessary for prompting customer response.

Facilitate accurate and transparent measurement and verification (M&V) procedures: One of the most important aspects of DR M&V is the determination of the baseline, reflecting the load that would have been in place had there not been a DR program. Determining the baseline is very important in that it creates the entire foundation for assessing both the capacity delivered and financial payments needed.

Encourage aggregation to scale up DR and remove risks: aggregation allows pooling resources in a way that ensures that performance requirements for the entire portfolio can be met. This will not only scale up DR but also mitigate the risks on non-performance from individual customer.

Create clear pricing signal to induce DR: electricity prices should be better designed to show the time-varying value of electricity costs. Prices between peak and off-peak periods should be different enough to prompt customer active response.

Provide incentives to compensate DR: Participants should be properly compensated for being ready and able to reduce loads when called upon to do so. Such payments create a visible revenue stream allowing customers to better assess the costs and benefits of participation, and for DR providers and aggregators to invest in the requisite technology to ensure reliable performance.

Acknowledgements

Our work was supported by the China Sustainable Energy Program (CSEP) of the Energy Foundation, Azure International, and Dow Chemical Company (through a charitable contribution) through the U.S. Department of Energy under Contract No. DE-AC02-05CH11231. We greatly appreciate the guidance that has been provided by Wang Wanxing of CSEP. We would also like to thank the review comments on this paper by anonymous reviewers.

References

- Adkin, Paul, 2011. <http://cij.inspiring.com/?p=1557>
- Bar Stockstar, August 11, 2009, National Power Grid Expects 10 GW Power Shortage This Summer. <http://bar.stockstar.com/p6917452-1.html>
- California Energy Commission (CEC), 2011. *California Clean Energy Future Metrics*. http://www.energy.ca.gov/2011_energypolicy/documents/2011-07-06_workshop/background/Metrics_July_IEPR_DR_v1.pdf
- China Daily, 2011a, Energy Crunch Looming. http://www.chinadaily.com.cn/business/2011-05/17/content_12522522.htm
- China Daily, 2011b, Factory-rich provinces thirst for electricity. http://europe.chinadaily.com.cn/china/2011-04/26/content_12395892.htm
- China Daily, 2011c, Power cuts worst for smaller businesses. http://www.chinadaily.com.cn/imqq/bizchina/2011-04/28/content_12416095.htm
- China Daily, 2011d, Power Crisis Forces Halt to Diesel Exports. http://www.chinadaily.com.cn/business/2011-05/14/content_12510611.htm
- China Electricity Council (CEC), 2008. *Quick report on China's Electricity Sector Statistics (2007)*. <http://tj.cec.org.cn/tongji/niandushuju/2010-11-29/36284.html>
- China Electricity Council (CEC), 2011. *Overview on China's Electricity Sector Development in 2010*. <http://tj.cec.org.cn/niandufazhanbaogao/2011-06-27/58873.html>
- China Electricity Council (CEC), 2012. *Quick report on China's Electricity Sector Statistics (2011)*. <http://tj.cec.org.cn/tongji/niandushuju/2012-01-13/78769.html>
- China Electric Power Press (CEPP), China Electric Power Yearbook, 1985-2011.
- Department of Energy, U.S. (DOE), 2006, *Benefits of Demand Response in Electricity Markets and Recommendations for Achieving Them*.
- EEO, February 7, 2012, *China Electricity Council Forecasts 40 GW Power Shortage Nationwide for This Year*. <http://www.eeo.com.cn/2012/0207/220340.shtml>
- Ghatikar, G; McKane, A; Goli, S; Therkelsen, P; Olsen, D, 2012. *Assessing the Control Systems Capacity for Demand Response in California Industries*. 2012. LBNL-5319E.
- Ghatikar, Girish, M.A. Piette, S. Fujita, A. T. McKane, J.Q Han, A. Radspieler, K.C. Mares, D. Shroyer., 2010. *Demand Response and Open Automated Demand Response Opportunities for Data Centers*. California Energy Commission, PIER Program and Pacific Gas and Electric Company (PG&E), January 2010.
- Glen Lewis Group, 2007. *Strategies to Increase California Food Processing Industry Demand Response Participation: A Scoping Study*, LBNL-63668, November 2007.

Great Wall Net, 2011. <http://news.hebei.com.cn/system/2011/07/28/011309444.shtml>

LBNL and ENERNOC, 2012. *Addressing Electricity Demand through Demand Response: International Experiences and Practice*. LBNL report, forthcoming.

Lekov, A., Thompson, L., McKane, A., Rockoff, A., Piette, M.A., 2009. *Opportunities for Energy Efficiency and Automated Demand Response in Industrial Refrigerated Warehouses in California*, LBNL-1991E, May 2009.

National Development and Reform Commission (NDRC), 2010. *Measures in DSM Implementation*.

National Development and Reform Commission (NDRC), 2011. *Measures for Orderly Use of Electricity*. http://www.ndrc.gov.cn/zcfb/zcfbtz/2011tz/t20110428_408768.htm

National Development and Reform Commission (NDRC), 2012. *Notice Concerning Rational Use of Electricity*.

Ni, Chunchun, 2009, *China Energy Primer*, Lawrence Berkeley National Laboratory, LBNL-2860E. <http://china.lbl.gov/sites/china.lbl.gov/files/China%20Energy%20Primer%20w%20LBNL%20cover.Sept2010.pdf>

OpenADR Alliance, *The OpenADR Primer*, <http://www.openadr.org/>

Shanghai Daily, 2011. *China Power Shortfall may Hits up to 40GW*. October 28, 2011. http://www.china.org.cn/business/2011-10/28/content_23748327.htm

Shen, B., Finamore, B., and Yew, M., 2009. *Promoting Energy Efficiency as a Cost-Effective Resource in China: A Review of Jiangsu's Efficiency Power Plant Pilot*, ACEEE Proceedings of the 2009 Summer Study

State Electricity Regulatory Commission (SERC), 2007, *2007 Electricity Regulatory Annual Report*.

360doc, March 22, 2012, *Power Demand and Supply for 2011 and Projection for 2012*. http://www.360doc.com/content/12/0322/15/584_196640545.shtml

Thompson, Lisa; Lekov, Alex; McKane, Aimee; Piette, Mary Ann, 2010. *Opportunities for Open Automated Demand Response in Wastewater Treatment Facilities in California – Phase II Report: San Luis Rey Wastewater Treatment Plant Case Study*, LBNL-3889E, August 2010.

Zhong Xin Net, 2011, <http://www.chinanews.com/ny/2011/09-16/3334042.shtml>