Supercritical and ultrasupercritical coal-fired power generation

Xiaomei Tan et al

Technology overview

Pulverized coal combustion (PC) is the most widely used technology in coal-fired power plants globally. The technology's developments in the past decades have primarily involved increasing plant thermal efficiencies by raising the steam pressure and temperature. Based on the differences in temperature and pressure, the technology is categorized into three tiers: subcritical, supercritical (SC) and ultrasupercritical (USC) (Table 1).

Table 1. Approximate pressure and temperature ranges

	Main steam pressure, MPa	Main steam temperature, ˚C	Reheat steam temperature, ˚C
Subcritical	<22.1	Up to 565	Up to 565
Supercritical	22.1–25	540–580	540–580
Ultrasupercritical	>25	>580	>580

Source: Nalbandian, 2008: p. 8

SC and USC technologies achieve high efficiency and consequently use less coal and result in reduced CO_2 emissions. According to the IEA Clean Coal Center, CO_2 emissions may be reduced by 23% per unit of electricity generated by replacing existing subcritical plants with SC/USC technology (Nalbandian 2008). Specifically, a 1% increase in efficiency reduces emissions by 2.4 million tons (Mt) CO_2, 2000 tons (t) NOx, 2000 t SO_2 and 500 t particulate matter over the life of the facility (Balling & Rosenbauer 2007).[1]

SC technology was invented in the late 1950s, initially in the United States and Germany. American Electric Power operated the Philo SC unit in 1957; the Philo SC was soon followed by

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This article first appeared in a WRI publication entitled Scaling up Low-Carbon Technology Deployment: Lessons from China. Permission has been granted by WRI to reprint this article here.

[1] These reductions are based on a 700 MW, 30-year operation, 7,000 full-load hours operation and control technology to reduce emissions of particulate matter to 50 mg/m^3, NO_x to 2 mg/m^3, and SO_2 to 200 mg/m^3.

Eddystone 1, a unit still in active service. USC facilities have been constructed and operated successfully since 1993 when Japan operated its 1000 megawatt (MW) Hirono 4. USC is routinely used for new pulverized coal power plants in Japan today. The efficiency gain also reduces fuel costs by 2.4%.[2] More advanced USC technology promises efficiencies of up to 55% for PC power plants. Its economic benefits are comparable to integrated gasification combined cycle (IGCC) and natural gas combined cycle (NGCC) technologies (Table 2).

Table 2. Estimated costs and thermal efficiencies

	Average efficiency	CO_2 emissions, g/kWh	Power generation cost, US¢/kW	Total plant capital cost, US$/kW
Subcritical	36	766–789	4.0–4.5	1095–1150
Supercritical	45	722	3.5–3.7	950–1350
Ultrasupercritical	>45	<722	4.2–4.7	1160–1190
IGCC	42–44	710–750	3.9–5.0	1100–1600
NGCC	50	344–430	3.4–6.8	400–700

Source: Nalbandian, 2008: p.10

Although SC/USC is a mature technology, the majority of existing coal-fired power plants worldwide are still using subcritical technology. The barriers to the diffusion of SC/USC technologies are not technical but largely economic and regulatory. First, the long lifetime of coal-fired power plants slows fleet turnover. Through much of the 1980s and 1990s low fuel costs eliminated the economic impetus for the higher capital costs of higher efficiency cycles such as SC/USC. The United States, for example, has not built any new SC plants since 1991 (EPRI 2008), because the coal cost was low and stable over most of the past 30 years. In addition, uncertain regulatory environments and prolonged permitting processes have made capital expensive, skewing the economics even further toward increased fuel use and decreased capital costs. Of the more than 500 SC/USC units in the world, nearly half operate in Europe and Russia, 24% in the U.S., and 10% in Japan. The remaining 19% are in China (EPRI 2008).

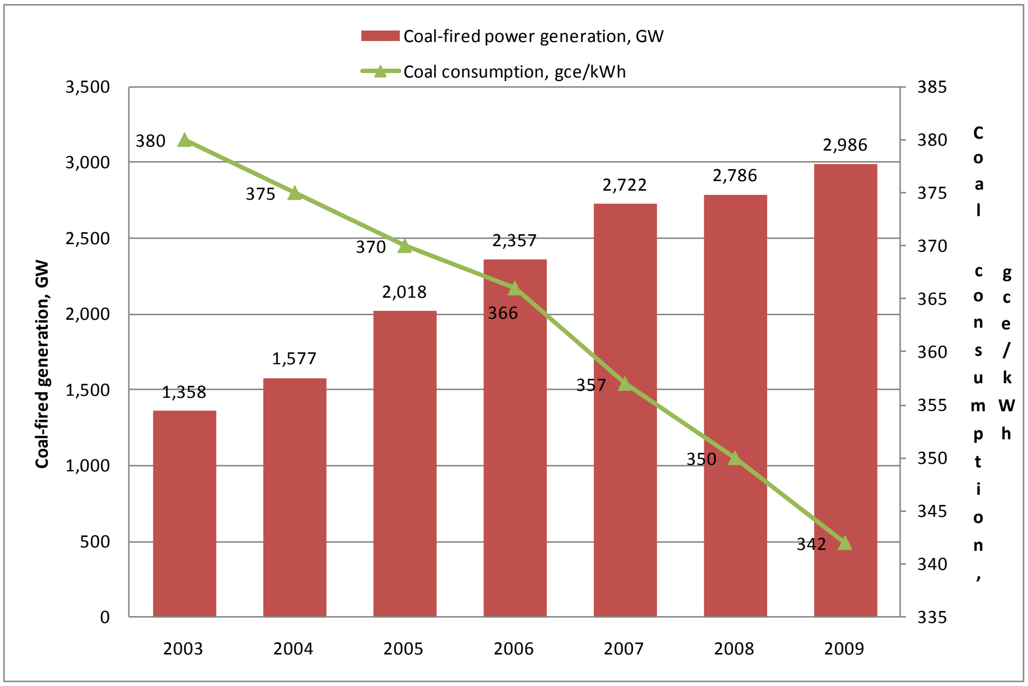
Where does China stand?

Coal consistently contributes to over 75% of electricity in China (China Bureau of Statistics 2009). To meet its ever growing demands for electricity, China has seen rapid growth of coal-fired power generation. From 2003 to 2009 the country more than doubled its coal-fired generation capacity, making its fleet the largest in the world. However, the fuel consumption per unit of electricity generated during this period has steadily decreased (Figure 3). The use of SC/USC technology has significantly contributed to the improvement of energy efficiency. In 2004 China surpassed the U.S. in average fleet efficiency (EIA 2009). As SC/USC continues to

[2] Same assumptions as above.

be the plant type of choice for coal burning in China, average fleet efficiency will continue to increase over time.

Figure 3. Coal-fired electricity generation versus coal consumption per kWh in China, 2003– 2009



Source: China Statistics Bureau, 2007; China Statistics Yearbook 2008, 2009

In the foreseeable future coal will remain the baseload fuel of choice in China. By 2030 China will add another 1344 gigawatts (GW) of coal-fired power generation (IEA 2009). Therefore, deploying and diffusing SC/USC technology, hopefully coupled with carbon capture and storage, is essential to China's effort to cut CO_2 emissions and improve the efficiency of fuel use. The national government has long considered SC/USC as a key low-carbon technology. A number of policies, measures, instruments, and cooperative arrangements have been made and implemented to facilitate the localization and accelerate the diffusion of the technology.

China now is the largest thermal power equipment manufacturer in the world (World Bank 2008). Shanghai Electric Group (SEG), Harbin Electric Corporation (HEC), and Dongfang Electric Corporation (DEC) have emerged as three key manufacturers in China. Their annual outputs all exceeded 35 GW in 2007, higher than any other major manufacturer around the world. All three manufacturers boast the capacity to design and manufacture SC/USC equipment. The successful operation of QinBei Power Plant's two 600 MW SC units in 2004 and Yuhuan Power Plant's four 1000 MW USC units in 2006 reflect this capacity. By the end of 2009, a total of twelve 1000 MW USC units were in operation (Table 3), complementing a fleet of more than 80 SC units across China. All of the USC units and the majority of the SC units were manufactured in China. In addition to supplying the domestic market, China has increased SC/USC equipment exports to other developing countries, including India and Turkey.

Table 3. Large-scale USC units operated in China by the end of 2009

	Unit capacity	Number of units	Manufacturer	Remarks
Huaneng Yuhuan	1000 MW	4	Shanghai Electric Group	First unit operated on Nov. 28, 2006
Huadian Zouxian	1000 MW	2	Shanghai Electric Group	First unit operated on Dec. 28, 2006
Guodian Taizhou	1000 MW	4	Harbin Electric Corporation	First unit operated on Dec. 4, 2007
Guohua Zheneng Ninghai	1000 MW	2	Shanghai Electric Group	First unit in operation in 2009

Source: Tsinghua Study 2009; China NDRC website

To manufacture state of the art products, China acquires the designs for turbines, boilers, and generators from industry leaders in other countries through joint ventures or by purchasing licenses. By working with overseas thermal technology leaders, the three key manufacturers are able to produce SC/USC equipment (Table 4). HEC, for example, pays Mitsui Babcock over ten million Yuan (US$1.5 million) in licensing fees for every 600 MW boiler it produces (Tsinghua Study 2009). In addition to sourcing some core technology designs internationally, China still largely depends on imports to obtain alloys that can sustain high pressure and high temperature for the USC boiler. Globally only a few firms, including Japan's Sumitomo and Nippon Steel, Germany's VDM, and the U.S.'s Haynes and Special Metals can develop these special materials (Viswanathan et al. 2008). China is by no means the only importer.

Table 4: Sources of SC/USC technologies and transfer methods

		Production capacity (MW)	Technology source	Transfer approach
Shanghai Electric Group	Boiler	4500	Alstom	Licensing
	Turbine	36000	Siemens	Joint venture
	Generator		Siemens	Joint venture
Harbin Electric Corporation	Boiler	53000	SC: Mitsui-Babcock; USC: Mitsubishi	Licensing
	Turbine	12000	600 MW: Mitsubishi; 1000MW: Toshiba	Licensing
	Generator		Toshiba	Licensing
Dongfang Electric Corporation	Boiler	25000	BHK	Joint venture
	Turbine	20560	Hitachi	Licensing
	Generator		Hitachi	Licensing

Source: World Bank, 2008; Websites of SEG, HEC and DEC

The life cycle of SC/USC technology adoption and localization in China

In the 1980s Chinese factories were often idled for days each week because of power shortages. The Chinese government also faced severe foreign exchange constraints that its nascent export sector could not balance. Thus, China needed a source of cheap, domestic power in order to fuel export-oriented development and resolve its foreign exchange constraints.

China had a small thermal power manufacturing capacity before the 1980s. In the late 1950s, the government started to import 6 MW, 12 MW, and 50 MW pulverized coal manufacturing technologies from the former Soviet Union and Czechoslovakia. Building on imported technologies, China began to manufacture 125 MW, 200 MW, and 300 MW PC generators in the 1970s. However, these domestically made PC sets were extremely unreliable; accidents happened frequently. Consequently, many Chinese power plants turned to the international market to purchase 300 MW PC sets.

The large-scale imports of 300 MW PC sets and their drain on already stressed foreign exchange prompted the Chinese government to prioritize the localization, and particularly the domestic manufacturing, of advanced thermal power technologies. All of the existing PC manufacturers were state-owned enterprises (SOE), products of the state planning system. Their statist orientation and the fact that Chinese efforts began before SOE reform meant this was a planned process from the beginning. These companies collaborated in ways that one would not typically expect of competitors, and the work was undertaken more on the level of a national effort such as a space program than a private enterprise–driven system.

In 1980 China signed an array of technology transfer agreements with several American companies to obtain subcritical design and manufacture technologies. The agreements included purchasing 300MW and 600 MW gas turbine technologies from Westinghouse and boiler technologies from Combustion Engineering Company (CE). In the 7th and 8th Five-Year Plans (1986 – 1995) developing subcritical technologies, was listed as a key national project.

While China was focusing on the localization of subcritical technologies, SC technologies had already become mature and were widely deployed in many developed countries. In order to close the technology gap, in 1992 the then State Economic and Trade Commission (SETC), a central government agency, purchased two 600 MW SC units from the ABB Group and CE Power Solutions. Both units were installed in Huaneng's Shanghai Shidongkou II plant. Through operating these two units, the Chinese experts started to accumulate knowledge about SC technologies.

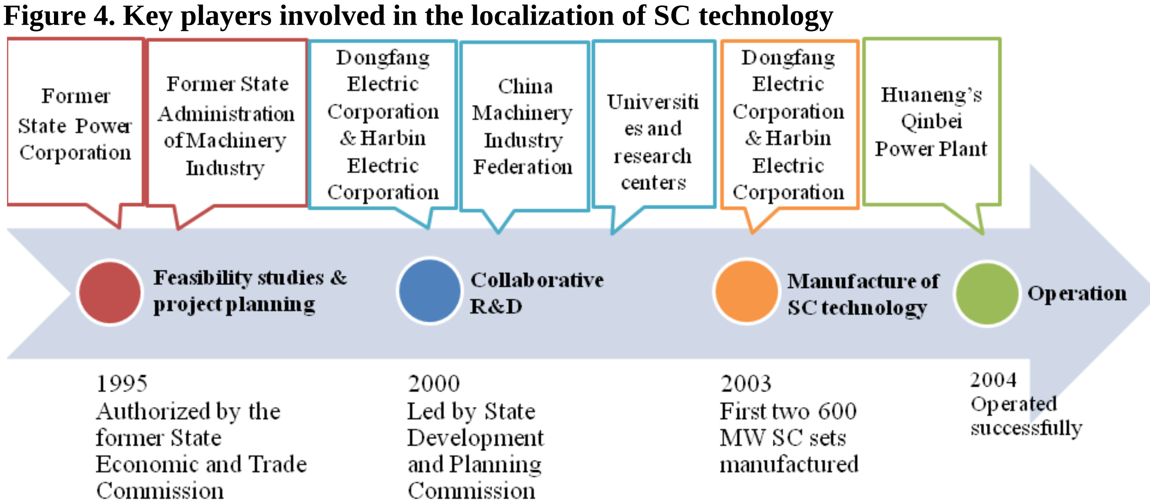
In 1995 the then State Power Corporation (SPC) and former State Administration of Machinery Industry (SAMI) conducted a feasibility study and began project planning for its own SC manufacturing capacity. The feasibility study included organizing a group of experts to assess whether China had the capacity to adapt the technology and which organizations should be included in the technology localization. After five years of study and planning, the 10th Five-Year Plan officially endorsed the localization of 600 MW SC as a Key National Program. The program covered the import, adaptation, and re-innovation of three key SC components: boiler, turbine, and generator.

The Chinese way of acquiring SC technologies raised two issues. The first issue is related to the ownership of imported technologies. The SETC first purchased SC technologies and shared the technologies with all the main Chinese companies. We have been unable to see the original contract, but there was a belief at least in some quarters that the technology was being sold to only one Chinese manufacturer. That may well have been because of misunderstandings of the nature and role of SETC. The second issue is the mixed feelings of the ABB and CE, which sold the technologies to China but lost the market because the Chinese decided to purchase licenses from Japanese companies. This issue in part relates to market conditions at the time, when these companies actually had few customers. However, because of the varied interpretations of these events, this history in part helped create a trust deficit between Chinese technology seekers and Western technology providers.

The second stage of the localization process as defined in the introduction mainly includes decoding the technology. Decoding is a broad process including learning-by-operating and learning-by-doing. It involves multiple actors such as component and system producers, R&D institutions, and upstream and downstream firms (Figure 4). Coordination among these actors is crucial to consolidate the learning and begin the local adaptation process. In the SC/USC case, the former State Development and Planning Commission (SDPC) directed a collaborative R&D team including participants from China Machinery Industry Federation (CMIF), DEC, HEC, state funded research centers, and major universities such as Tsinghua University, Shanghai Jiaotong University, and China University of Mining and Technology. As the team learned the complexities of SC technology they identified the technical specifications for China's SC needs and the necessary domestic capacity to manufacture the components. Based on these identifications, the team chose Hitachi as the IP provider for the boilers and generators and Mitsubishi for turbines. CE Power Solutions was left out of the arrangement, as the team did not find their design as strong a fit to China's needs and capacities (Tsinghua Study 2009).

In 2003 China manufactured its first two SC units. DEC manufactured the boilers, while turbines and generators were produced by HEC. Huaneng's Qinbei Power Plant was selected as the operation base for these first two SC sets and in 2004 they were brought successfully online.

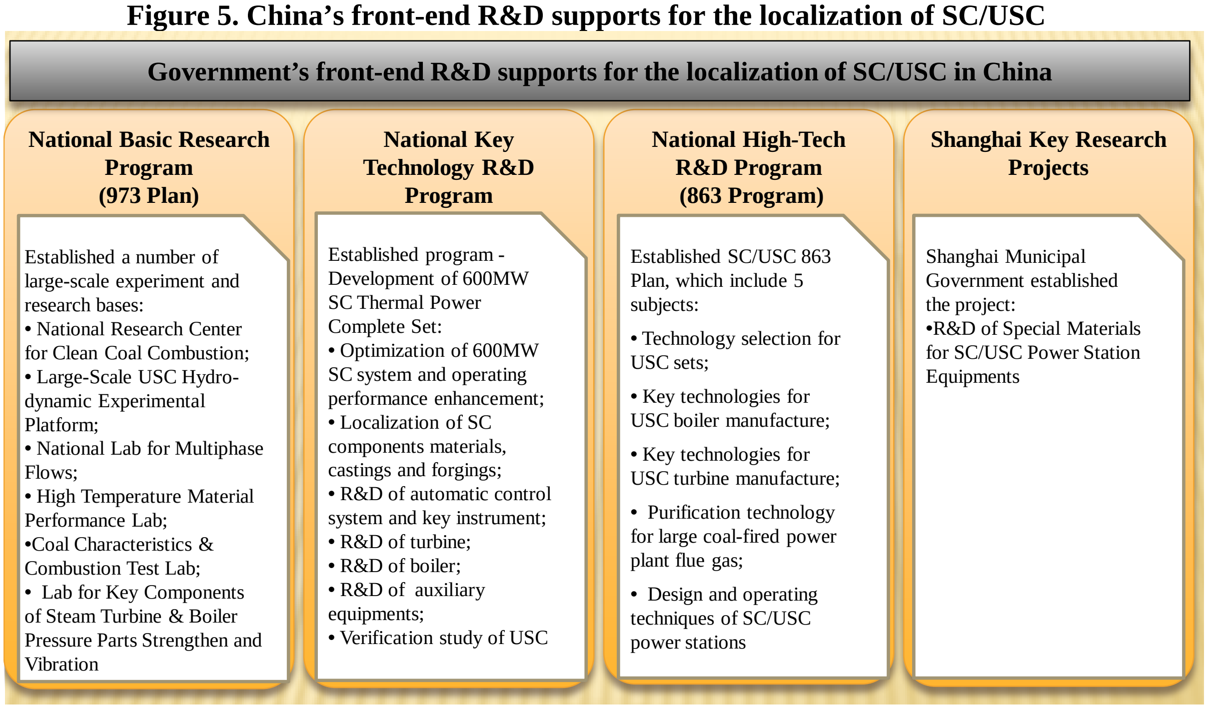
Figure 4. Key players involved in the localization of SC technology



While pushing for the localization of SC, SPC also started the feasibility study of USC technology in 2000. Two years later the Ministry of Science and Technology (MOST) officially approved the R&D and deployment plan for USC technologies. The plan was run under the National High-Tech Program (863 Program), National Basic Research Program (973 Program), and National Key Technology R&D Program during the 10th Five-Year Plan. SEG and HEC were tasked to manufacture the first 1000 MW USC units, and in 2004 the Huaneng Group's Yuhuan Power Plant was chosen as the localization base. Two years later, in December 2006, a total of four 1000 MW USC units started to operate at Yuhuan.

The success of the localization of SC/USC technologies in China can be attributed to a number of factors. However, since the process was centrally planned and funded, the Chinese government's front-end supports and back-end pulls play an especially important role. Figure 5 summarizes the specific R&D programs/projects involved in the development of SC/USC technologies in China.

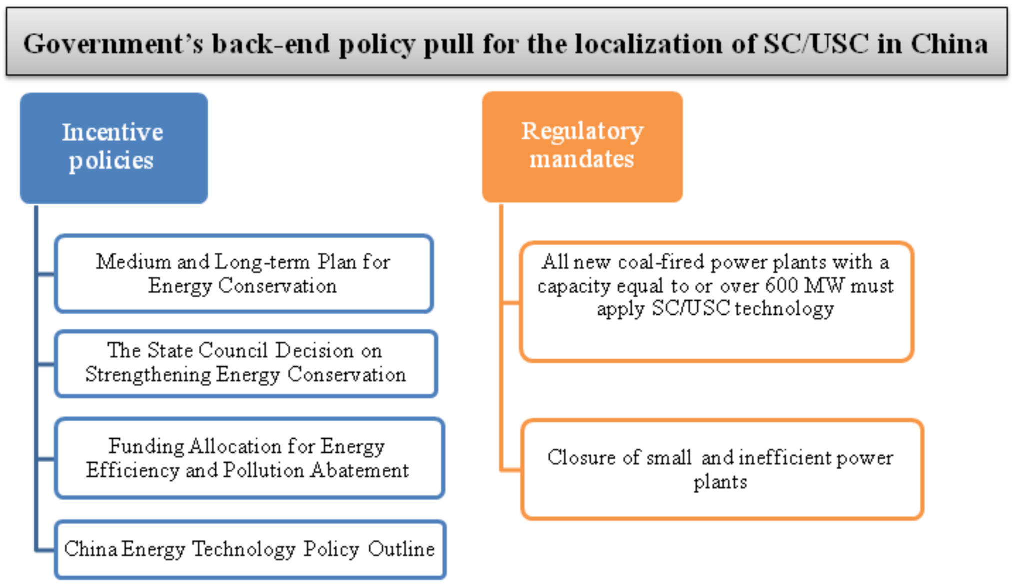
Figure 5. China's front-end R&D supports for the localization of SC/USC



Having established domestic manufacturing capacity, the Chinese government designed and implemented an array of incentive policies as well as regulatory mandates to motivate power plants to adopt SC/USC technologies. In 2006 China mandated that all new coal-fired power plants with 600 MW capacity or above must apply SC/USC technology. Simultaneously, the government published a list of small and inefficient power plants planned for closure by 2010. In addition, China has announced a series of economy-wide policies to encourage energy efficiency efforts, including the Medium and Long-term Plan for Energy Conservation (2005), the 11th Five-Year Plan (2006), the State Council Decision on Strengthening Energy Conservation (2006), the Top-1000 Energy-Consuming Enterprise Program (2006), the Revision of Energy Conservation Law (2007), the Allocation of Funding on Energy Efficiency and Pollution

Abatement (2007, 2008), and the China Energy Technology Policy Outline (2007) (Figure 6). These policies and regulations provided incentives such as tax credits, low-cost financing, price guarantees, loan guarantees, government procurement, and new-product buy-down.

Figure 6. Policy incentive and regulatory mandates



The success of the localization of SC/USC technologies dramatically brought down their costs in China. Two factors worked together to achieve this. By focusing on technology adaptation, the Chinese were able to scale-up demonstrations quickly and coordinate their learning in order to push down the cost curve. Domestic production also took advantage of a difference between the cost structures in China and that in the OECD.

The total investment of four 1000 MW USC sets at the Yuhuan Power Plant, for example, cost 14.5 billion Yuan (US$2.2 billion), equivalent to 3625 Yuan/kW (US$541/kW). This is about 40% lower than the cost in OECD countries (Table 5). The comparatively low costs make SC/USC technologies more affordable and have consequently assisted with accelerated diffusion in China.

Table 5. Comparison of plant capital cost

	China, US$/kW	OECD, US$/kW
Subcritical (300 MW)	650–800	1095–1150
Supercritical (600 MW)	550–700	950–1350
Ultrasupercritical (1000 MW)	550–700	1160–1190

Source: Hogan et al., 2007

By the end of 2008, China had a total of 100 SC/USC units in operation (Nalbandian 2008). This is only second to the U.S., which has 120 SC units. The large-scale operation of SC/USC has significantly contributed to energy conservation and CO_2 reduction. In 2007 and 2008, China's coal consumption per kWh respectively reduced 9 grams of coal equivalent (gce) per kWh and 7 gce/kWh. The efficiency gain in 2008 was equivalent to a savings of 27 million metric tons of standard coal, or the avoidance of 55 million metric tons of CO_2 emissions (Tsinghua Study 2009). In terms of capacity, temperature, and pressure, China's technologies are comparable to those in the countries owning the most advanced SC/USC technologies (Table 6).

Table 6. Comparison of SC/USC technology features, 2008

	First SC/USC operated	Number of SC/USC units	Average unit capacity, MW	Average pressure	Average reheat, ˚C	First Reheat ˚C
China	1991	93	646	25.3	563	568
U.S.	1959	120	724	25.0	543	543
Japan	1968	53	661	25	562	575
Germany	1960	21	585	26.0	551	563
UK	1967	2	375	25.1	599	568
India	2008	1	660	24.7	540	565

Source: Nalbandian, 2008

Chinese companies have now started to export SC/USC equipment. In 2008 China's Dongfang Electric Corporation sold a 600 MW SC unit to Turkey. This was China's first export of SC technology. In September 2009 Dongfang signed a contract with the Indian East Coast Electric Power Corporation to build a coal-fired power plant equipped with two 660 MW supercritical units. The contract not only includes equipment and facilities but also expertise and services. In addition to Dongfang, Shanghai Electric Power Corporation's overseas sales have also seen a sharp increase, accounting for 45% of total revenue in 2008, up from 13% in 2006 (Autonet 2009).

Summary

The case of supercritical/ultrasupercritical (SC/USC) coal power generation highlights the importance of creating and nurturing supportive systems and infrastructure for technology deployment. To improve energy efficiency in the power sector, the Chinese government employed a dense array of instruments to induce the launch of an innovation life cycle for SC/USC technology. These primarily included initial government subsidized procurement of new technologies, front-end R&D supports, and back-end policy pulls. The front-end R&D supports were constructed and channeled through China's numerous publicly funded R&D programs. The back-end policy pulls were executed by the National Development and Reform Commission (NDRC) and Ministry of Finance (MOF) via various incentive policy and regulatory mandates. Front-end supports contribute to technology launches and start-up, while back-end pulls help to scale-up manufacturing production; stimulate market demands; and therefore drive down costs.

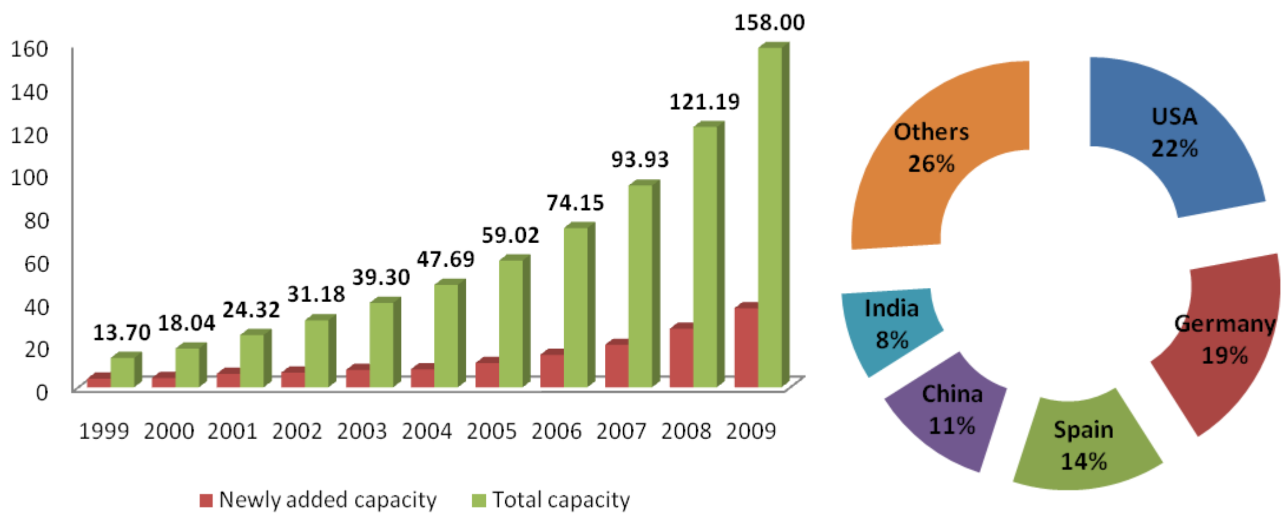
Onshore wind power

Technology overview

Wind energy technology is relatively mature compared to most other types of renewable energy. The technological development of wind energy in recent decades has been largely focused on increasing turbine size. From 10 meters with a capacity of 50 kW in the mid-1970s, wind turbines have grown to diameters of 126 meters with a 7 MW capacity. A U.S. company, American Superconductor, is currently developing full 10 MW turbine components and system design through a partnership with the U.S. Department of Energy. The turbine is set for testing in 2012. Large turbines can usually deliver electricity at a lower average cost, because the costs of foundations, road building, maintenance, grid connection, and other factors are the same regardless of the size of the turbine. A large-scale turbine's typical electricity cost is US$0.04–0.06 per kWh, while for a small turbine it is about US$0.10 per kWh, as the fixed costs are supported by less electricity production.

Other technological developments in wind include variable-pitch rotors, direct drives, variable-speed conversion systems, power electronics, better materials, and improved ratios between the weight of materials and generating capacity (IEA 2006). All these developments have helped to improve wind energy's affordability and reliability. Consequently, compared to other renewable energy sources, the price of wind power is the closest to that of fossil fuel energy. Potential breakthroughs in wind power development include better power electronics to improve the interface with the grid, improved composite materials for lighter-weight and stronger blades, simplified power trains to end the need for gearboxes, which account for 30% of costs, and online diagnostics for better monitoring.

Figure 7. Global installed wind energy capacity (GW) by nation, 2009



Source: GWEC 2010; WWEA 2009

Due to constant technological improvement as well as enabling policies, worldwide installed wind power capacity has risen rapidly, from about 14 GW in 1999 to 158 GW in 2009, of which the United States and Germany accounted for approximately 41% (Figure 7). The 158 GW installed capacity was estimated to generate 340 terawatt-hours (TWh) electricity and save 204 million tons of CO_2 in 2009 (Sawyer 2010). An ambitious scenario by the Global Wind Energy Council (GWEC) shows that if the current annual growth rate of over 30% continues, global wind energy capacity could increase to over 1000 GW by 2020 and 2,400 GW by 2030. This would lead to annual CO_2 savings of more than 1.5 billion tons in 2020 and 3.2 billion tons in 2030 (GWEC 2010).

Where does China stand?

China's wind industry has followed a strikingly different model from the Chinese thermal power sector. The wind sector is marked by multiple, competitive companies with varying amounts of support from government. The ownership of these companies varies from state-owned enterprises such as DEC to joint-stock companies such as Goldwind and to privately owned companies such as New Unite. Their integration with international markets has also varied. In recent years the Chinese government has strongly stimulated demand, but it has not forced suppliers to supply world-class product. Chinese wind suppliers can sell in the domestic market without certification and other quality controls demanded by international purchasers. The result is a domestic market with extremely low barriers to entry but less opportunity to engage in exports.

China has abundant wind resources. Its technically exploitable onshore wind resources at a height of 10 meters are estimated to be 250–300 GW, and its offshore potential is about 750 GW (China Wind Power Center 2009). In recent years, China has made impressive progress in wind power development (Figure 8). In 2008, 6.2 GW of wind energy capacity was added, bringing total installed capacity to 12 GW and making China the fourth largest wind power generator in the world, behind the United States, Germany, and Spain (WWEA 2009). The rapid development of wind power has greatly outpaced the goal of 5 GW by 2010, which was set by the 11th Five-Year Plan. In May 2009 the NDRC announced plans to at least triple the 2020 goal for wind energy to 100 GW (Shanghai Daily 2009).

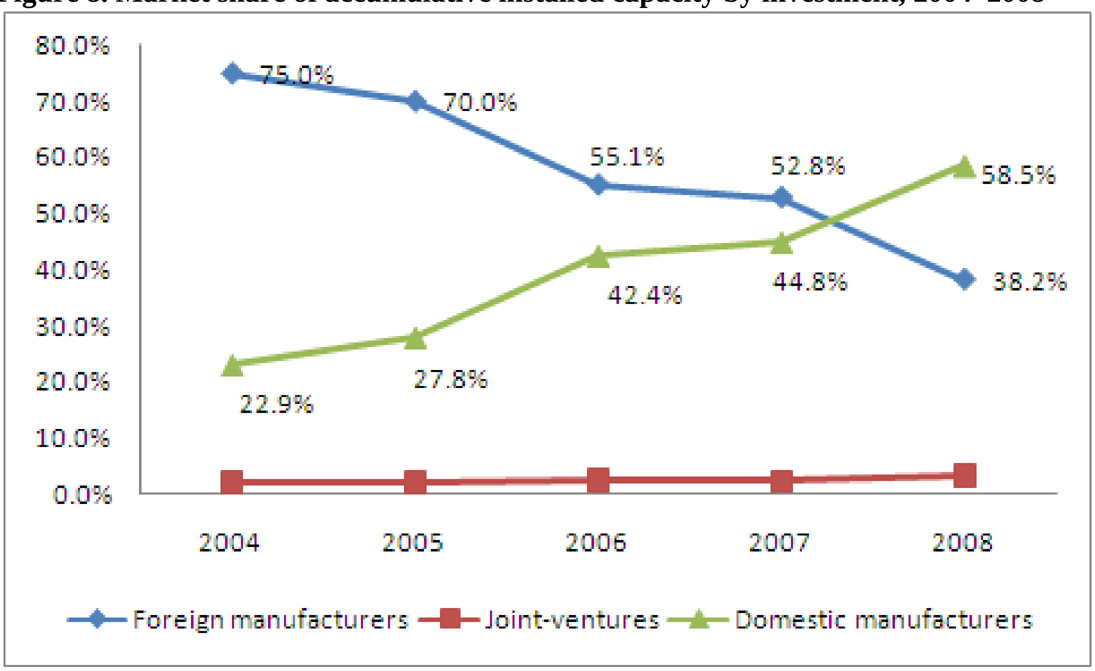
In spite of this remarkable progress, China's wind energy technology lags behind the European Union and the United States. Chinese turbine manufacturers struggle to compete with foreign counterparts in terms of reliability and quality. Foreign turbine manufacturers and joint ventures also still take a significant portion of China's domestic market share, representing 42% in December 2008 (Figure 8). Through joint venture, license purchasing, or joint design, China is able to manufacture turbines, blades, gearboxes, and generators. However, it still relies on imports to acquire control systems and bearings (Table 7), which is also the case with leading wind turbine producers around the world (Kirkegaard et al. 2009). These limited technological capabilities have affected the pattern of wind power development within China. This is reflected in three ways.

Table 7. Localization of wind energy technologies in China, 2008

	Manufacturing capacity	IP ownership
Turbine	Yes	Joint venture; licensing; joint design
Blade	Yes	Joint venture; licensing; joint design
Gearbox	Yes	Yes
Generator	Yes	Yes
Bearing	Yes	Joint venture
Control system	No	No

Source: Tsinghua Study 2009; Timken 2007

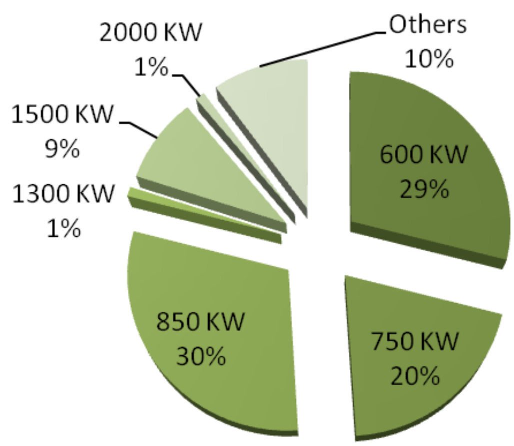
Figure 8. Market share of accumulative installed capacity by investment, 2004–2008



Source: China Mechanical Electrical Data Online

First, a majority of turbines erected in China are small, with 600–850 kW turbines accounting for 80% of the market share (Figure 9). In 2006 the average size of turbines in China was 830 kW, compared to 1634 kW in Germany, 1634 kW in the U.S., and 1100 kW in Spain. Today, the United States is developing 10 MW turbines, while China just tested 3 MW turbines. In February 2010, China's first 3 MW offshore wind turbines independently developed by Sinovel Wind Group Corporation passed the 240-hour test (Sinovel News 2010).

Figure 9. China's installed turbine capacity, 2006



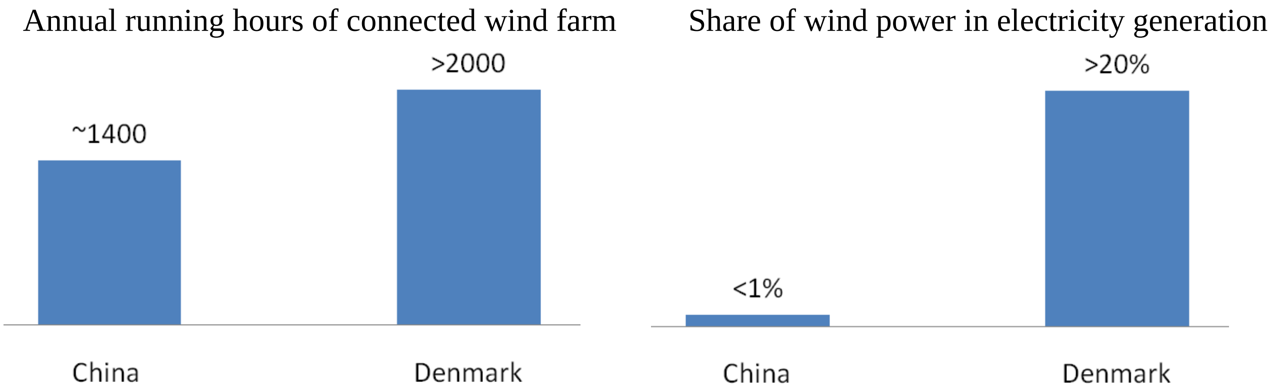
Source: Statistics on China's Wind Energy Installation, 2007

Second, the average capacity of wind farms in China is much smaller than that of the European Union and the United States. In 2007, there were 158 wind farms across 21 provinces, municipalities, and autonomous regions with an average installed capacity of 37.4 MW (Shi 2008). To reach the goal set by the NDRC in 2004 of building about thirty 100 MW to 200 MW wind farms, and five to six wind power bases providing a total capacity of 1000 MW before 2020, China has recently accelerated the construction of large-scale wind farms. In 2009 the NDRC approved the construction of China's first GW-scale wind base in Gansu province. The base will include eighteen 200 MW and two 100 MW wind farms (NDRC 2009). Simultaneously, a number of other 100 MW wind farms are being built in Shangdong and Liaoning provinces. While building more large-scale onshore wind farms, China has also started constructing an offshore wind farm. In February 2010 Shanghai Donghai Bridge Wind Farm completed the installation of 34 wind turbines with a total capacity of 100 MW. This is Asia's largest offshore wind farm (Xinhua 2010).

Finally, a more damaging aspect in China's wind energy development is the low utilization rate. The rapid growth in installed capacity has not gone hand in hand with growing generation capacity. According to Xinhua, only 8 GW of the 12 GW of installed turbines were grid connected at the end of 2008 (Xinhua 2009). Grid connected wind turbines are additionally hampered by poor reliability. A comparison between China and Denmark demonstrates China's weak position (Figure 10).

Overall, China has made enormous progress in wind energy development over the past 10 years. However, it still has a learning curve to climb. Its domestically made wind turbines are less competitive in terms of quality and reliability; the scale of its numerous wind farms is comparatively small; and its rapidly growing installed capacity doesn't go hand in hand with growing generation capacity. All these issues can be explained by how wind turbine technology was transferred and deployed in China as well as what drives or impedes the technology transfer and deployment.

Figure 10. Wind energy generation capacities, 2008



Source: McKinsey & Company, 2009

Wind energy technology transfer and its barriers and drivers

China's rapid development of wind energy technologies has primarily relied on technology transfer as opposed to domestic innovation. This is achieved through three mechanisms: joint venture; joint design; and license purchasing. Wholly foreign-owned investment, viewed by Western economists as an effective way of transferring knowledge and skills to local labors, however, is not considered a technology transfer mechanism by the Chinese.

Joint ventures

In 1996 China initiated the "Riding the Wind Program," aimed at promoting the development of domestic technical capacity through joint ventures. Joint ventures are limited companies incorporated by at least one Chinese party and at least one foreign party to conduct business approved by the Chinese government. They are an important form of foreign direct investment (FDI) in China. The first of these two joint-venture manufacturers were Xi'an-Nordex and Yitou-MADE. They were established with the agreement that Nordex and MADE would transfer wind turbine technology in return for preferential treatment in the Chinese market. The technology transfer was initially carried out with a requirement of 20% local content that gradually increased to 70% (Lewis 2006, 2007). In 2010 China dropped the local content requirement entirely.

However, the joint-venture program has not been successful in meeting the goal of enhancing wind energy technology transfer. Most international wind energy companies have chosen to invest in China as wholly foreign-owned enterprises rather than joint ventures. Vestas, for example, maintains 100% ownership of its subsidiary company in China. By 2008 joint ventures only occupied 3.3% of the Chinese turbine market (Figure 8). In addition, these joint-venture turbine manufacturers often function only as a provider of maintenance and post-sale services, with little R&D and innovation. This is also the case of the joint-venture automobile industry in China (Gallagher 2006).

The joint ventures' failure to acquire advanced wind energy technology can be attributed to many factors. A main reason is foreign partners' concerns over China's IP protection; they are reluctant to give out proprietary information to companies that could become competitors one day. The Danish wind turbine manufacturer Vestas, for example, licensed its turbine technology to Gamesa in 1994. After years of development, Gamesa became Vestas's most important competitor in the international market. This led to an early termination of the technology transfer agreement (Lewis 2007). Vestas's experience has discouraged leading turbine manufacturers from transferring core technologies.

Licensing agreements

Purchasing production licenses from the international market is a more popular alternative to the joint-venture approach. The top three Chinese turbine manufacturers, representing 50% of the cumulative market share in 2008, purchased production licenses from foreign counterparts (Table 8).

Table 8. China wind power: sources of production licenses, 2008

	Specification	License source	Production stage
Goldwind	Gold Wind 50 750 kW	Repower of Germany	Batch production
Sinovel	70/77 FL 1500 kW	Fuhrländer of Germany	Batch production for markets abroad
Dongfang	FD70B/77FLB 1500 kW	Repower of Germany	Batch production for markets abroad

Source: Li & Hu, 2007; Statistics on China's Wind Energy Installation, 2008

By paying an initial license fee and subsequent royalties (a portion of profits or set price from each sale), Chinese manufacturers can acquire wind turbine technology and therefore manufacture their own turbines. Compared to joint ventures, this approach imposes fewer constraints on Chinese manufacturers. They can then quickly adapt the technology to meet local needs. Meanwhile, the license holders benefit from the technology transfer through guaranteed revenue and expanded market share. While the Chinese manufacturers may eventually become a competitor in the global marketplace, they will have to continue paying royalties to the original IPR owners, eliminating some of the risk faced by partners in joint ventures.

To the Chinese, the disadvantages of buying licenses include the contingency of the technology providers' willingness to allow a third party to sell and support their technology, as well as high licensing and royalty costs for technology seekers. In fact, the Chinese government is concerned about high licensing costs for wind technology and how it will impact the industry's future development. According to a report published by the Chinese Ministry of Finance (MOF) in 2009, the costs of production licenses for 1–1.5 MW wind turbines had increased from US$1.4 million–2.8 million in 2005 to US$11 million–12.4 million in 2007. This is equivalent to

US$689,000 for each turbine (MOF 2009). This is about 6% of the total cost of a 1 MW wind turbine.[3]

The report further pointed out that the rapidly rising licensing fees were directly triggered by high demands from Chinese turbine manufacturers. Since 2005 a number of Chinese turbine producers have started to mass-produce 1–1.5 MW turbines. A majority of them have turned to the overseas market, especially Europe, for production licenses. European technology providers took advantage of the high demands and quickly raised the licensing price. Some providers even sell the same model to several different Chinese manufacturers. While this situation would be typical in an entirely free-market setting, the MOF report expressed dissatisfaction over the Chinese wind industry's uncoordinated license purchasing efforts, compared with the often more coordinated approach taken by state-owned enterprises in other parts of the power sector.

Joint design

To overcome the drawbacks of joint ventures and license purchasing, some Chinese turbine producers started to explore a new approach: joint design. In 2006 Goldwind Science & Technology Company (Goldwind) signed an agreement with Vensys of Germany to jointly develop the 1.5 MW 70/77 series. Vensys has an edge in knowledge and technical capacity, but lacks capital and manufacturing capacity. By paying Vensys consultation fees, Goldwind acquired direct involvement in the design of the series. After two years of successful cooperation, in February 2008 Goldwind acquired a 70% stake in Vensys. As a result, the IPR obtained from the collaboration belongs to Goldwind and the turbines were named the 1.5 MW Goldwind 70/77 series. Currently Goldwind and Vensys are jointly developing 2.5 MW Goldwind models.

The joint design approach draws upon each partner's strengths and appears to have been beneficial to both Goldwind and Vensys. Some other Chinese manufacturers have since followed suit (Table 9). Through a joint program with Austria Windtect, Sinovel developed a 3 MW double feedback, variable shift, and constant frequency wind turbine system. Shanghai Electric is partnering with Aerodyn of Germany to jointly develop a 2 MW double feedback, shift control, and constant frequency turbine system. Shanghai Electric will own the IPR. In the near future, joint design is likely to replace license purchasing as the most popular approach to technology transfer.

Table 9. Joint design: a new approach to wind technology transfer in China, 2007

	Specification	Foreign partner	Production stage
Goldwind	GoldWind 70/77 1.5 MW	Vensys, Germany	Batch production for markets abroad
Shanghai Electric	SEC82 2 MW	Aerodyn, Germany	Design
Sinovel	SN 3 MW	Windtec, Austria	Design
Minyang Wind Technology	83/MY1.5se	Aerodyn, Germany	Testing

Source: Li & Hu, 2007

[3] The average cost of wind turbine is 8,500 Yuan/kw. This is based on an interview with the CEO of China Guodian Corporation. Available at: http://news.xinhuanet.com/fortune/2009-06/25/content_11598999.htm

Policy instruments

In its pursuit of advanced wind energy technology, the Chinese government has designed many policy instruments to strengthen foreign investors' confidence in the Chinese wind market (Zhang et al. 2009). The first is laying a legal foundation for wind energy investments and the government's interventions. China enacted its Renewable Energy Law in 2005. The law recognizes the strategic role of renewable energy in optimizing China's energy mix. It sets the policy frameworks for the government's role in pricing, supervision, allocating cost burdens, and incentivizing investors. In December 2009, the law was amended to ensure the state-owned grid companies accepted wind power when it was available:

> "Grid enterprises shall enter into grid connection agreements with renewable power generation enterprises that have legally obtained administrative licenses or for which filing has been made, and buy the grid-connected power produced with renewable energy within the coverage of their power grid, and provide grid-connection service for the generation of power with renewable energy." (Renewable Energy Law Amendments)

In addition to the law, the central government has promulgated over 10 measures and regulations relevant to wind energy (Table 10).

Table 10. China energy policy relevant to wind

Tier	Wind Energy Policy
First tier	**Provide general direction and guidance, including speeches by state leaders and the Chinese government's general standpoint on the global environment**
	• 2003 Renewable Energy Promotion Law • 2005 Renewable Energy Law • Amendments to Renewable Energy Law, 2010
Second tier	**Specify goals/objectives and development plans, with a focus on rural electrification and renewable energy–based generation technologies**
	• 1996 Ride the Wind Program • 2003 Rural Energy Development Plan for Western China • 2006 Medium to Long-Term Development Plan on Renewable Energy • 2006 11th Five-Year Plan for Renewable Energy • 2007 National Plan for Renewable Energy Development • 2007 International Science and Technology Cooperation Program on New and Renewable Energy
Third tier	**Provide practical and specific incentives and managerial guidelines, aimed at reaching the goals and objectives set by the second-level policies**
	• 2006 Management Regulations on Electricity Generation from Renewable Energy • 2006 Notice on Management Requirements for Wind Power Construction • 2006 Provisional Management Measures on Construction Land Usage and Environmental Protection of Wind Power Stations • 2006 Interim Measures for Renewable Energy Development Special Funds • 2008 Tariff Adjustments for High-Power Wind Turbines and its Key Components • Circular on Preferential Tax Policy Issues for Developing the Western Region

Source: Li, 2006

The second policy instrument the Chinese government is using is a concession program as a pricing mechanism. According to the NDRC regulation, any wind power projects of over 50 MW have to go through a concession tendering procedure. The procedure is managed by the NDRC, whose role includes choosing a project site for bidding, determining bidding criteria, evaluating bidders' offers, and announcing bidding winners. From 2003 to 2008, five rounds of concession biddings have been organized and 49 wind power projects have been approved.

The third policy instrument Beijing has deployed is a mandatory renewable energy share. In 1997, the Chinese government released the Medium and Long-term Renewable Energy Development Plan. This mandates that renewable energy will account for 10% of total energy consumption by 2010 and 15% by 2020. Power generators with an installed capacity equal to or more than 5 GW are required to have a renewable share (excluding hydropower) of 3% by 2010 and 8% by 2020. This quota system in part drives power companies with large coal portfolios to bid very low on wind concessions and subsidize the loss, as described above.

The fourth policy instrument is feed-in tariff and a power surcharge for renewables and premium. The Interim Measure of Renewable Energy Tariff and Cost Sharing Management, released by the NDRC in 2006, mandated a 0.25 Yuan/kWh (US$0.04/kWh) surcharge to subsidize biomass. For wind power, the feed-in tariff offered to cover the difference between the contracted wind price and local coal-fired power price to ensure parity between wind and coal. However, when combined with the artificially low bids in the concession process, wind farms remain unprofitable for foreign investors.

The last policy instrument to boost wind energy deployment is R&D funding. The Chinese government has made substantial efforts to support wind power technology R&D. The National Basic Research Program (973 program), the National High-tech R&D Program (863 program), and the National Key Technology R&D Program are the driving force of technological innovation in the wind sector. The development of Goldwind Science and Technology Company, China's second largest wind turbine manufacturer, highlights how the Chinese government leverages its authority to encourage the wind industry to undertake a greater role in R&D and innovation.

In 1997 Goldwind purchased licenses from Jacobs of Germany to manufacture 600 kW wind turbines. Because of this deal, Goldwind was appointed to undertake the 9th Five-Year Plan National Key Science & Technology (S&T) Project and Xinjiang Autonomous Region Key S&T Project—amounting to R&D for 600 kW Wind Turbine Localization. During the 10th Five-Year Plan period, Goldwind was further tasked with commercializing 600 kW wind turbines. By the end of the 10th Five-Year Plan period, over 90% of the 600 kW wind turbines manufactured in China were domestically produced and Goldwind continued to pay Jacobs licensing fees for the IPR.

In 2001 Goldwind purchased 750 kW production licenses from Repower of Germany. Again, the central government assigned it to carry out the localization R&D for 750 kW turbines. This was structured under the 10th Five-Year Plan National Key S&T Project. Two years later Goldwind started to mass-produce 750 kW turbines and their domestic production rate reached over 80%. Licensing royalties continued to flow to Repower.

Through the development of domestic manufacturing capacity for the 600 kW and 750 kW wind turbines, Goldwind accumulated knowledge and technical skills. It therefore aspired to hold its own IP and the joint-design agreement signed with Vensys in 2006 made this possible. In 2008 Goldwind acquired a 70% stake of Vensys. This deal established Goldwind's status as the first domestic company owning IP for 1.5 MW wind turbines in China. The next product in the pipeline to be jointly designed by Vensys and Goldwind is a 2.5 MW direct drive-pitch regulation-stall wind turbine system. So far, Goldwind has completed the prototype definition related activities, including model load feature computation, tower design, mechanical system design, nacelle, pitch control system, main bearings, and pitch yaw bearings. Again, the IPR of the 2.5 MW model will belong to Goldwind. By the end of 2008 Goldwind occupied the largest share of the Chinese market and ranked tenth in the global market.

Goldwind's growing technological capacity benefited from the central government's R&D funding as well as local government's matching funds. Goldwind is headquartered in the Xinjiang Autonomous Region (XAR). The government of XAR also mobilized resources to support Goldwind (Table 11).

Table 11. Boosting domestic innovation: R&D and demonstration funding to Goldwind

Purpose	R&D program	Funder
R&D of 600 kW turbine localization	9th Five-Year Plan National Key S&T Program	MOST
Commercialization of 600 kW turbine	10th Five-Year Plan National Key S&T Program	MOST
R&D of 750 kW turbine localization	10th Five-Year Plan National Key S&T Program	MOST
R&D of MW-scale turbine system and its key components	10th Five-Year Plan 863 Program	MOST
R&D and demonstration of large-scale wind turbines	National Innovation Fund for Small, Technology-based Firms	MOST
Improvement and optimization of 1.2 MW turbines	Direct funding	MOST
Commercialization of 750 kW turbine	Direct funding	Bureau of Science & Technology and Bureau of Finance, XRA
R&D of 1.5 MW, 2.5 MW, and 3 MW turbines	Direct funding	Bureau of Science & Technology, XRA
Importation of foreign experts	Direct funding	Bureau of Foreign Experts, XRA
Commercialization of 1.5 MW turbines	Direct funding	Bureau of Finance and Bureau of Foreign Trade, XRA

Source: Tsinghua Study 2009

In addition to R&D supports, Goldwind also enjoys several favorable tax treatments. The first is an up to 15% income tax deduction for the years 2001–2010. This benefit is supported by two regulations promulgated by the NDRC: the Catalog for the Guidance of Industrial Structure Adjustment (2005) and the Circular on Preferential Tax Policy Issues for Developing the Western Region (2001). The 15% tax deduction was equivalent to, respectively, 7.8, 19.4, and 63.1 million Yuan (US$1.2 million; US$2.9 million; US$9.4 million) in 2004, 2005, and 2006.

The second is value-added tax (VAT). The VAT reform in January 2009 transformed the original production-type VAT to a consumption-type VAT. Under the new VAT regime, input VAT included in the purchase prices of fixed assets is allowed to be credited against output VAT when calculating VAT payable. This benefits the wind industry greatly, as the sector invests heavily in equipment purchases.

The third tax break is a favorable tariff. Up until the early 1990s, imported wind turbines and related equipment were exempted from customs duties. As China's domestic capacity grew, this favorable treatment was replaced by a selective system. The duties on turbine components range from 1% to 10%. Depending on their technology containment, high-tech components pay lower duties. For complete turbines, the duty ranges from 0% to 6%, depending on the ownership structure of the importing company. On April 23, 2008, two changes to tariff regulations were announced by the Ministry of Finance (MOF 2009). The first change implemented a tariff and VAT rebate program for imports of parts and raw materials used in turbine manufacture. This change was substantial because a large share of parts and raw materials used in China's turbine production are sourced from outside of China. The second change removed a free tariff for turbines less than 2.5 MW as a way to incentivize the domestic production of large wind turbines.

Summary

Overall the case of wind underlines how governments can incentivize business to be the driving force of technological innovation and deployment. In contrast with its central role in SC/USC technology deployment, the Chinese government was less directly involved in the transfer and deployment of wind energy technology. Instead, to assist the domestic wind industry, a series of technological infrastructural initiatives and programs were put into place by central and provincial governments. These include legislation such as the Renewable Energy Law, policies such as National Plan for Renewable Energy Development and local content requirements, an regulations such as the Management Regulations on Electricity Generation from Renewable Energy. In addition, both central and provincial governments directly invested in the wind sector's R&D efforts. These measures have effectively triggered a booming wind industry in China. However, the deployment of wind energy technology in China has not gone hand in hand with good quality. The low entry barrier for wind developers has underscored the importance of setting up high technology standards from the outset. It also resulted in an over-production of smaller turbines in China.