

## Renewable power for China: Past, present, and future

Eric MARTINOT

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**Abstract** This paper briefly examines the history, status, policy situation, development issues, and prospects for key renewable power technologies in China. The country has become a global leader in wind turbine and solar photovoltaic (PV) production, and leads the world in total power capacity from renewable energy. Policy frameworks have matured and evolved since the landmark 2005 Renewable Energy Law, updated in 2009. China's 2020 renewable energy target is similar to that of the EU. However, China continues to face many challenges in technology development, grid-integration, and policy frameworks. These include training, research and development, wind turbine operating experience and performance, transmission constraints, grid interconnection time lags, resource assessments, power grid integration on large scales, and continued policy development and adjustment. Wind and solar PV targets for 2020 will likely be satisfied early, although domestic demand for solar PV remains weak and the pathways toward incorporating distributed and building-integrated solar PV are uncertain. Prospects for biomass power are limited by resource constraints. Other technologies such as concentrating solar thermal power, ocean energy, and electricity storage require greater attention.

**Keywords** renewable energy, wind power, solar power, sustainable energy policy, green industry

## 1 Introduction

Renewable energy continues to play an increasingly important role in China's power sector development. For example, since a landmark renewable energy law was first passed in early 2005, wind power capacity grew 30-fold, from 0.8 GW at the end of 2004 to 26 GW by the end of 2009. This propelled China to second place globally, trailing only behind the United States and surpassing long-time wind-power leader Germany [1–4]. Although 26 GW accounted for merely 3% of China's total power generation capacity of 860 GW (end-2009), wind power is by far the fastest growing energy technology in the country [Footnote<sup>①</sup>]. Counting hydropower (197 GW), biomass power (3.2 GW), and grid-connected solar photovoltaic (PV) technologies (0.4 GW), there was a total of 226 GW of renewable power capacity at the end of 2009, or approximately 30% of China's total

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Received June 18, 2010; accepted July 9, 2010

Eric MARTINOT (✉)

Tsinghua-BP Clean Energy Research and Education Center, Tsinghua University, Beijing 100084, China

E-mail: martinot@tsinghua.edu.cn

<sup>①</sup>Martinot E., Li J. F. China's latest leap: An update on renewables policy. *Renewable Energy World*, 2010, 13(4) (in press).

power capacity. Power plant capacity factors for renewables are lower than that for coal. Thus, in terms of kilowatt-hours generated, renewables produced about 17% of China's power in 2008 [5].

Among all countries, China recorded the highest renewable power capacity in 2009. Its 226 GW surpassed the United States' 144 GW and Japan's 56 GW. Indeed, China accounted for approximately 20% of the 1230 GW world total renewable power capacity [1]. Considering only non-hydropower renewables, China (30 GW) ranked third, behind the United States (49 GW) and Germany (39 GW).

The current draft development plan of the Chinese government for 2020 calls for 300 GW of hydropower, 150 GW of wind power, 30 GW of biomass power, and 20 GW of solar PV in the future, for a total of 500 GW of renewable power capacity [Footnote ①]. This would represent one-third of the expected total power capacity of 1600 GW by 2020 (Official development targets for 2020 set in 2007 total 362 GW in renewable power capacity [6,7]). Irrespective of whether these higher numbers become new official development targets, the 500 GW of renewables capacity is also indicated by the existing renewable energy portfolio standards for major power utilities, or those with more than 5 GW capacity [Footnote ①]. These portfolio standards were established in 2007, requiring utilities to achieve 8% of capacity and 3% of power generation from non-hydro renewables by 2020.

## 2 Industry and technology development

China's efforts to build a renewable energy industry and invest in renewable power generation date back to the 1980s, with technology support for wind power, solar PV, biomass, ocean, and geothermal power technologies. Much of the early efforts went into using renewable energy for rural electrification, including using small hydro, small wind, and solar PV in isolated villages and rural mini-grids. One of the most significant programs was the Township Electrification Program that ran from 2003 to 2004, providing electricity to about 1.3 million people using small hydro and solar PV [8]. As China approached full electrification of rural areas, however, the focus on renewable energy development for 2004 to 2010 shifted to bulk power generation on centralized grids.

China's commercial wind power industry emerged in the late 1990s, with a few fledgling companies, such as Goldwind, which began to produce 600-kW and 750-kW turbine models [4]. In 2003, a new "concession" policy promoted domestic projects through competitive bidding, requiring wind turbines to be manufactured with 70% domestically produced content (the so-called "localization" provision). This policy marked a turning point in wind industry and technology development in China. By 2007, four major domestic manufacturing firms were in operation, as well as dozens of other firms developing prototypes and aspiring to commercially produce turbines [2]. By 2010, China has emerged as the dominant global manufacturer of wind turbines.

In 2009, three Chinese wind power firms ranked among the top 10 global manufacturers: Sinovel (no. 3), Goldwind (no. 5), and Dongfang (no. 7) [1] (Vestas of Denmark and GE Wind of the USA were the top two manufacturers globally.). From 2008 to 2009, Chinese firms began to export turbines and components abroad (for example, to India and the United States). They likewise announced plans to open manufacturing plants abroad, particularly in the United States. A majority of the turbines manufactured in China in 2009 belonged to the 1.5–2 MW class, compared with earlier years when sub-1 MW models accounted for a sizeable share of domestic production. Thus, the Chinese industry is catching up with manufacturers in other countries, where 2–5 MW

turbines are typical. Chinese firms produced most of the 26 GW added in 2009. The period spanning 2007 to 2009 likewise witnessed the beginning of offshore wind power development; the Shanghai Dongdaqiao 100 MW project commenced construction in 2009, and several hundred megawatts are planned in other projects [1].

The Chinese government continues to promote domestic manufacturing and technology development through a number of initiatives, including competitive bidding. In 2009, for example, the government selected seven domestic manufacturers to supply over 5 GW of wind turbines to 25 projects in three sites in Inner Mongolia and Hebei provinces [1].

China has also emerged as a global leader in PV manufacturing. Mainland China became the global leader in solar PV production in 2009, producing almost 40% of global PV production that year [1]. This is a huge increase from its 15% global share in 2006 [10]. The top three Chinese producers were Suntech (705 MW produced in 2009), Yingli (527 MW), and JA (Jingao) Solar (504 MW). By the end of 2009, 4 GW/year of manufacturing capacity was in place and over 500 solar PV firms were established. However, virtually all solar PV production was intended for export before 2008 because the domestic market was considerably smaller at less than 50 MW per year. However, the domestic market for grid-connected solar PV gained momentum in 2008 and 2009, and approximately 160 MW of grid-connected PV was added in 2009 [9,10]. This placed China's domestic solar PV market in seventh place worldwide.

In other parts of the world, solar PV power generation has mostly developed on the basis of distributed generation on residential and commercial rooftops—typically < 5 kW for residential installations and < 50 kW for commercial and public buildings. By contrast, solar PV power generation development in China has emphasized large-scale stand-alone (ground-mounted) utility projects and large-scale (> 50 kW) installations on buildings.

Development of other renewable energy technologies continues, but at smaller scales compared with those for wind and solar energy. In 2009, biomass power capacity increased by 0.4 GW to 3.2 GW. A number of small (25 MW) biomass power plants were developed. Meanwhile, hydropower capacity rose by 22 GW to 197 GW. There were small capacity amounts existing for geothermal (34 MW) and marine energy (4 MW), as well. Finally, plans to develop projects for concentrating solar thermal power (CSP) were initiated.

### 3 Policy development

In 2005, China's State Council and National People's Congress approved a comprehensive law for developing and promoting renewable energy [2,6, and footnote<sup>②</sup>]. This "Renewable Energy Law" provided basic principles, which were subsequently followed by detailed implementing regulations. The law was intended to achieve five overriding goals: ① establish the importance of renewable energy in China's national energy strategy; ② remove market barriers; ③ create markets for renewable energy; ④ establish a financial guarantee system; and ⑤ create awareness, skills, and understanding. At its core, the Renewable Energy Law is designed to establish a framework of responsibility, requiring the national government to formulate development targets, strategic plans, and financial-guarantee measures for renewable energy. The law also established a framework for sharing the extra costs of renewable energy among designated segments of consumers, and created economic incentives and

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<sup>②</sup>The Renewable Energy Law of the People's Republic of China, adopted at the 14th Session of the Standing Committee of the 10th National People's Congress, Beijing, China, 28 February 2005.

penalties to motivate companies to act consistently with plans and targets. It likewise provided a long-term development plan, government research and development (R&D), resource surveys, technology standards, and building codes for integrating solar hot water into new construction.

The Renewable Energy Law took effect in 2006. One of its key provisions required power utilities to purchase power from renewable-energy generators—an obligation that formerly did not exist. The law likewise stipulated a national cost-sharing mechanism whereby power consumers must pay for the extra (incremental) costs of renewable power. Fixed premium prices (often called “feed-in tariffs”) and pricing mechanisms for biomass and wind power were established. For biomass, the law stipulated a RMB 0.25 yuan (3.2 US cent) per kilowatt-hour (kW • h) feed-in tariff premium added to province-specific average coal tariffs. This premium resulted in

biomass feed-in tariffs typically of RMB 0.55 to 0.60 yuan/kW • h, which was considered sufficient to attract private investment. The same implementing regulations specified a “government-guided price” for wind power.

Furthermore, the law specified that a “mandated market share” of renewable power should be required of the major national generating companies. Each of these companies must generate or purchase specific shares of their total power from renewable sources. In 2007, the exact mandated shares were announced as part of the finalized “Medium and Long-Term Development Plan for Renewable Energy in China.” According to the plan, the share of non-hydro renewables should reach 1% of total power generation by 2010 and 3% by 2020 for regions served by centralized power grids. In addition, any power producer with capacity greater than 5 GW must increase its actual ownership of power capacity from non-hydro renewables to 3% by 2010 and 8% percent by 2020.

The original 2005 renewable energy law was updated by the National People’s Congress at the end of 2009. The update took effect in April 2010. The update contained three main provisions [Footnote ①]:

1) More detailed planning and coordination is mandated, including coordination of renewables with overall electric power sector development and transmission planning, and coordination of local (provincial) level development with national development plans. Additionally, the roles and responsibilities of electric power companies are to be further elaborated in relation to grid-interconnection of renewable energy generators and definition of different classes of renewable generators (including small-scale generators with positive net power production). The law revisions likewise address areas such as energy storage and smart grids. One reason for this provision is that the renewables sector, especially wind power, has experienced such rapid growth that transmission planning and interconnection began to fall behind wind turbine installations. Although not widespread, some completed wind capacity lacked transmission access, mostly in cases where projects lacked official approval and thus were not coordinated with national planning. Moreover, there were growing lags in the operational status of completed turbines due to the time required for normal interconnection, testing, and certification.

2) Strengthened provisions guarantee that electric utilities must purchase all renewable power generated. Previously, utilities were only obligated if there was sufficient power demand on the grid. In the 2009 update,

utilities must purchase power in all circumstances; but they can then transfer the renewable power to the national grid company for use elsewhere. The 2009 update also added deadlines and economic penalties for utilities that fail to comply with this guaranteed-purchase requirement.

3) A renewable energy fund under the Ministry of Finance as part of the 2005 law was strengthened and consolidated. Previously, the fund collected a RMB 0.4 fen/(kW • h) surcharge on electric power sales nationwide (with some customer classes exempt), and these funds were tapped to cover the costs of government-supported renewable energy projects, as well as the added costs of feed-in tariffs. However, the surcharge failed to cover expenditure. Thus, the 2009 update allowed the Ministry of Finance to supplement the renewable energy fund from general revenues.

Beyond the original 2005 law and its updated version in 2009, there were several other significant changes to the renewable energy policy from 2008 to 2009 [Footnote ①].

*New wind power feed-in tariffs.* The 2005 renewable energy law authorized feed-in tariffs for wind power based on “government guided” prices; these prices evolved annually as competitive bidding for wind power capacity (the “concession” program) revealed quasi-market prices, and as “approved” tariffs were established provincially depending on historical project and bidding experience. In August 2009, a new feed-in tariff regime was established for wind power. Four specific tariffs were established nationwide, to be applied on a regional basis depending on geographic wind resources. The lowest tariff is now at RMB 0.51 yuan/(kW • h) for the best resource regions of the Inner Mongolia Autonomous Region and parts of the Xinjiang Uighur Autonomous Region. The next level is RMB 0.54 yuan/(kW • h) for parts of Western and Northeastern China. A RMB 0.58 yuan/(kW • h) tariff is imposed in regions in Central and Northern China with less favorable wind resources, and finally, RMB 0.61 yuan/(kW • h) for the least favorable regions. These tariffs are consistent with prices from previously approved projects in these provinces or regions over the past three years. They apply to onshore wind projects only; tariffs for offshore wind projects have yet to be established.

*New biomass power feed-in tariffs.* The previous feed-in tariff for biomass, established under the 2005 law, was a RMB 0.25 yuan/(kW • h) premium added to the province-specific coal power generation price. The premium was increased to RMB 0.35 yuan/(kW • h).

*Elimination of wind turbine domestic content requirement.* Wind turbines installed in China were previously required to have at least 70% “domestic content” in terms of the value of incorporated materials and components. In 2010, this requirement was deemed and declared unnecessary because virtually all turbine installations were Chinese-produced products.

*Exemption from local income taxes.* Renewable energy projects were exempted from local (provincial) income taxation. This produced the (perhaps unintended) effect of reducing incentives for provincial governments to support renewable energy projects, unless local manufacturing enterprises benefit, as well.

*New solar PV subsidies.* The “Golden Sun” program was initiated in 2009, providing capital subsidies for solar PV installations through 2011 on a project-by-project basis. Under this program, off-grid (stand-alone) installations receive 70% capital subsidies, and grid-connected installations receive 50% subsidies. Grid-connected installations must be 300 kW or larger in peak capacity. There are program caps that limit the overall quantity of systems installed; installations in any given province under the program are limited to 20 MW in total. To date, almost 300 projects have been proposed under the Golden Sun program, totaling 640 MW and entailing about RMB 20 billion yuan in investments. As a separate component of the Golden Sun program, the Ministries of Finance and Construction are providing subsidies of RMB 15 yuan/W for grid-connected solar PV and RMB 20 yuan/W for building-integrated PV, but only for installations measuring 50 kW or larger and projects utilizing solar PV modules of minimum specified efficiency levels (16% for monocrystalline, 14% for polycrystalline, and 6% for amorphous). For 2010, subsidy levels were reduced to RMB 13 and 17 yuan/W, respectively.

*New solar PV bidding program.* Similar to the early development of the wind power industry, the government initiated a competitive bidding program for solar PV projects, which has resulted in new tariff structures for solar PV. The government has established benchmark tariffs, or “approved price levels,” on the basis of competitive bidding for specific quantities of solar PV. An example is the bidding in Dunhuang, Gansu Province in 2009. This bidding process resulted in prices as low as RMB 0.69 yuan/(kW • h), and an approved price of RMB 1.09

yuan/(kW • h) for two 10 MW projects. In April 2010, another approved price was RMB 1.15 yuan/(kW • h) for

four projects in Ningxia Hui Autonomous Region, for a total of 40 MW.

*New provincial-level solar PV preferential tariffs.* The provinces of Zhejiang and Jiangsu have established province-wide preferential tariffs for solar PV. In Zhejiang, the tariff was set as a premium of RMB 0.70 yuan/(kW • h) added to the province-average coal power generation price (RMB 0.46 yuan/(kW • h) in 2009), in

a similar manner to the national biomass feed-in tariff premium mentioned above. The tariffs in Jiangsu are similar in design to conventional feed-in tariffs in other parts of the world, with graduated tariffs differentiated by technology type: ground-based systems received RMB 2.1 yuan/(kW • h) in 2009; roof-top systems received

RMB 3.7 yuan/(kW • h); and building-integrated systems received RMB 4.3 yuan/(kW • h). These tariffs were set to decrease progressively to RMB 1.7/3.0/3.5 yuan in 2010 and RMB 1.4/2.4/2.9 yuan in 2011. In both provinces, these local tariffs are not “approved” prices at the national level, indicating that in practice, the money to cover the additional costs of feed-in tariffs must originate from provincial budgets (because the extra costs are paid by the provincial government) and not from national funds.

*Revised targets.* In 2009, China revised its basic target for renewable energy share for 2020. The previous target, adopted in 2006, was for 15% share of primary energy to come from renewables. The new target is for 15% share of *final* energy to originate from non-fossil fuel sources (renewables and nuclear) (This is up from 9% of total final energy in 2008.). This change has three implications. First, a 15% share of final energy means a larger absolute quantity of renewables compared with a 15% primary energy-share target (For a full discussion of the differences between share of primary and final energy consumption, see [11].). Second, it places China’s target on the same basis as that of the European Union (EU), which likewise adopted a target in 2008 based on share of *final* energy. The EU target is for 20% by 2020. Third, nuclear power is now included in the target.

## 4 Current development issues

All of these policy changes and new policies lay the groundwork for the next phase of renewable energy development for the period 2010 to 2020. The coming years should see continued rapid development of onshore wind power, the beginning of offshore wind power development, a rapid acceleration in the use of solar PV for both building surfaces and stand-alone utility-scale power plants, modest growth of biomass for power generation, and new technologies such as ocean energy and solar thermal power. However, a number of development issues must be addressed during this period. Some of these are outlined in this section.

*Training of skilled engineers.* There is a huge need for skilled engineers in several areas of renewables development, including equipment design, manufacturing process engineering, system design, testing and verification, site selection, resource survey methods, project planning, construction supervision, performance monitoring, repair and maintenance, and operational management. Tens of thousands—if not hundreds of thousands—of skilled engineers and technicians will be needed. Consequently, academic departments that will provide training for engineers must be created and expanded.

*Renewable energy technology research and development institutions.* More institutions are needed to push the frontiers of renewable energy technology development and serve as focal points for innovation and learning. Examples of such an institution are the National Renewable Energy Laboratory in the United States, Risø Laboratory in Denmark, and the Energy Research Centre of the Netherlands. Such a national institution can support the Chinese industry, train engineers and scientists, follow international technology trends, and work with universities to strengthen academic research and development programs in critical technology areas. Increased innovation capacity at universities and other public institutions will be crucial.

*Wind power operational experience and performance.* China’s wind industry must undergo several cycles of operational experience, testing, and redesign, which may take several years. In the meantime, uncertainties in

quality and technical performance will continue to plague Chinese producers, even with foreign expertise incorporated into recent designs through contracted design services and licenses. Recent figures suggest that the operational performance (capacity factor) of existing wind turbines in China is generally not as high as that in other countries [6].

*Transmission constraints for wind power.* As wind power is increasingly developed in remote regions, such as the Inner Mongolia Autonomous Region, the areas in question will become saturated in terms of their own (often limited) power demand. Transmission capacity to far-off population centers will become a primary limiting constraint. Transmission planning that anticipates where future wind power development will occur, based on resources and other project development factors, will be crucial in preventing transmission bottlenecks from limiting renewable energy development. Such transmission bottlenecks are already occurring in a number of countries across the globe, particularly in parts of the United States. A number of areas in the United States have enacted policies that mandate such transmission planning, which anticipates regions of future wind development.

*Integration of wind power with overall electric power sector planning.* This is one of the provisions of the 2009 update of the renewable energy law. It relates to several other issues mentioned here and in the next section. The Chinese government has planned several geographic “bases” for both wind and solar PV development, which will aid in integrated planning, including transmission planning. (The seven planned wind power bases are Gansu/Yumen, Easter Inner Mongolia, Wester Inner-Mongolia, Xinjiang/Hami, North Hebei, West Jilin, and Jiangsu Coastline.)

*Time lags in connecting, testing, certifying, and approving wind power installations.* Time lags became a problem in 2009 as many projects were completed, requiring acceptance, testing, and certification prior to becoming operational. Approximately one-quarter of the wind power capacity added in 2009 suffered from these types of time lags [Footnote ①]. Bottlenecks can be in terms of both administration and availability of skilled manpower. There were reports in 2008 of utilities delaying or failing to complete needed transmission access or grid interconnection. The true extent of this problem, however, is difficult to gauge [6].

*Detailed resource assessments.* Detailed geographic resource maps are essential for project planning and financing, as well as for minimizing investment risks. Using data collected from over 2000 meteorological stations as bases, the Chinese Meteorological Research Institute has produced national resource assessments. But such macro-scale assessments are often not adequate for local project planning and siting. Moreover, virtually no data exist on offshore wind resources, which offer considerable promise for future development.

*Domestic market demand for solar PV.* Domestic demand for solar PV remains weak and more policies will be required. China’s domestic demand for grid-connected solar PV was merely 160 MW in 2009, compared with Germany’s market of 3800 MW during the same year.

*Biomass resource collection.* New infrastructure and business models may be needed to ensure biomass resources for biomass power plants, particularly from agricultural residues. This includes transport contracting, long-term contracts, and pooling of resources into larger, more stable markets.

*Continued policy development and adjustment.* Policies for renewable energy require constant monitoring and adjustment. For example, feed-in tariff policies in Europe are reviewed and adjusted periodically by national governments to account for market evolution and reductions in technology costs. Feed-in tariffs must provide



adequate financial incentives to project developers, but not overly generous profits—this can be a careful balancing act. Review and adjustments of tariffs associated with China’s renewable energy policies will require continued attention, as will innovations for policy support and learning from renewable energy policy experience in other countries. A number of recent policy analyses have suggested further important policy changes necessary for renewable energy development to continue its growth in China [6,12,13].

## 5 Future prospects

It appears reasonable to expect that the proposed renewable energy development targets for 2020 introduced at the beginning of this paper will be achieved, perhaps even before 2020. However, prospects for renewables development through 2020 and beyond hinge on the degree to which renewable power technologies can be integrated into power systems on increasing scales, at both centralized and distributed levels, with managed and coordinated approaches among utilities, project developers, consumers, enterprises, and local governments.

Wind power appears to exhibit the most promise for China. Wind resources in China total at least 250 GW onshore and 750 GW offshore [14,15]. Thus, there is considerable scope for further development for at least another 15 to 20 years. However, offshore wind turbine technology and development planning will become increasingly important as the best onshore sites are used up. The main constraints to wind power development do not appear to be resources or costs, but rather power transmission constraints (between windy regions and population centers) and energy storage constraints. To approach 1000 GW of wind power in the long term would require significant amounts of electricity storage capacity to even out the variations in wind power output on minute-by-minute, hourly, daily, and even seasonal scales.

Many electricity storage technologies appear poised to become economically viable in the coming decade, which could be integrated with wind power on large scales [16–19]. Certainly, pumped hydro storage is a key technology available today. However, pumped hydro is only possible in selected geographical conditions. Other important technologies for utility grid-based storage include Vanadium redox-flow batteries, high-temperature sodium batteries, super capacitors, and compressed air storage.

In addition to stationary storage technologies, electric vehicles are ushering in the potential for a new era of “virtual” grid-connected electricity storage [20, 21]. Electric vehicles connected to the grid for charging can “soak up” renewable power when it is available, or merely smooth short-term variations in grid supply-demand balance, thus aiding in power system stability. Electric vehicles can even supply power back into the grid at peak times (this is also known as “vehicle to grid” or V2G). “Smart grids” would manage and coordinate these operations to provide both technical and economic efficiency, and ensure that vehicles retain adequate power stores for when their owners need to use them. This concept can be extended further to the idea of “load follows supply” operation. This is a radical concept indicating that vehicle charging adjusts to variations in renewable supply, which is possible if charging can be performed quickly; thus, there is large discretion as to when vehicle batteries are charged. Specifically, electric vehicles represent a controllable variable-demand component of the power system that can adjust itself automatically within pre-established parameters and limits, according to prevailing renewable power supply conditions (for example, from variable renewable power) [20–22]. With sufficient storage on a power system (for example, from millions of electric vehicles all connected simultaneously),

aggregate system demand can shift significantly in response to variable output from even large installations of renewables, such as centralized wind farms [21,22]. This will potentially offer considerable advantages for integration of renewable power on large scales.

Solar PV has the most growth potential of all renewable power technologies [23,24]. Policies enacted in 2009 to promote domestic development of grid-connected solar PV will begin to increase growth. However, additional policy support is needed, as well as attention to how distributed PV on building rooftops—on both small and large scales—can be best installed, connected, and technically integrated into power grids at the low-voltage distribution level. Because of the low power density of solar PV, land-covering utility-scale plants may not be very efficient uses of space. Solar PV can be installed on rooftops, on the sides of buildings, and on other municipal structures, such as parking areas and highway margins. Once solar PV costs decline further, there could be a rapid increase in these types of applications, particularly if the building materials industries begin to integrate solar PV into building construction materials (so-called “building integrated PV” or BIPV). This will be particularly true as thin-film and other film-based solar PV technologies enable innovations in covering surfaces with solar PV. Of course, widespread use of solar PV will require the same types of energy storage technologies discussed above for wind power.

Biomass power technology suffers from the problems of biomass resource collection (i.e., agricultural wastes), which is costly and transport-intensive. Although China continues to build new biomass power plants using both agricultural wastes and municipal wastes, this technology may be saturated by 2020 because of resource constraints and competing uses for the biomass resource, especially agricultural wastes. This is particularly true if cellulose-to-ethanol technology becomes commercial on large scales; the use of agricultural waste may prove more efficient and profitable for producing liquid ethanol fuel than burning for power generation.

CSP technology experienced a rebirth in the United States and Europe beginning in 2006, after having been essentially dormant for 20 years since several plants were constructed in California’s Mojave Desert in the 1980s. By 2009, there were close to 700 MW such plants operating globally, primarily in the Southwestern US and Spain; many more plants underwent construction and planning [1]. Recent CSP plants built in Spain incorporate several hours of thermal energy storage, essentially enabling plants to supply base-load power for most of the day, including several evening hours after sunset. China has conducted research on this technology and constructed prototype plants, but no large-scale plants have been built to date. This technology could be extremely important to China, particularly in the desert and semi-desert areas of the northern and western regions. A majority of these areas would be well-suited to CSP power plants. Greater attention can be directed at developing a low-cost and viable CSP industry in China and identifying the best geographic sites.

In the long term, China can reasonably obtain one-third to one-half of its total electric power from renewables if technology trends continue, costs decline, power transmission constraints do not become excessively serious, and energy storage can be integrated with renewables on a cost-effective basis on a large scale. This level of power from renewables is not unreasonable given other published scenarios for China and the world [2,25–28]. Indeed, the International Energy Agency’s “Blue Map” global scenario shows the world achieving half of its total power from renewable energy by 2050 [29]. China made highly significant progress with renewable energy from 2000 to 2010, and promises to make even greater progress in the 2010 to 2020 period and beyond.

## References

1. REN21 Renewable Energy Policy Network for the 21st Century. Renewables 2010 Global Status Report. Paris: REN21, 2010.
2. Martinot E, Li J F. Powering China's Development: The Role of Renewable Energy. Washington, DC: Worldwatch Institute, 2007.
3. REN21 Renewable Energy Policy Network for the 21st Century. Recommendations for Improving the Effectiveness of Renewable Energy Policies in China. Paris: REN21, 2009.
4. Li J F, Gao H, Wang Z Y, Ma L J, Dong L Y. China Wind Power Report. Beijing: Chinese Renewable Energy Industries Association, 2008.
5. China Electricity Council. China Annual Report on Electric Power Industry. Beijing, 2008.
6. Wang F, Yin H T, Li S D. China's renewable energy policy: Commitments and challenges. *Energy Policy*, 2010, 38(4): 1872–1878.
7. China National Development and Reform Commission. Medium and Long-Term Development Plan for Renewable Energy in China. Beijing, 2007.
8. Wallace W L, Wu H, Wang Z Y. Experience for sustainable development of rural energy in China. In: Proceedings of the Great Wall Renewable Energy Forum, Beijing, 2006.
9. Li J F. Chinese renewable energy industry outlook. Beijing: Chinese Renewable Energy Industries Association, 2008
10. National Energy Administration. China Energy Development Report [Solar PV stat]. Beijing, 2009.
11. Martinot E, Dienst C. Liu W L, Chai Q M. Renewable energy futures: Targets, scenarios, and pathways. *Annual Review of Environment and Resources*, 2007, 32: 205–239.
12. Cherni J A, Kentish J. Renewable energy policy and electricity market reforms in China. *Energy Policy*, 2007, 35(7): 3616–3629.
13. Zhang P D, Yang Y L, Shi J, Zheng Y H, Wang L S, Li X R. Opportunities and challenges for renewable energy policy in China. *Renewable & Sustainable Energy Reviews*, 2009, 13(2): 439–449.
14. China Meteorological Institute. Wind Resource Maps (in Chinese, Shi Pengfei). Beijing: China General Certification Center, 2007.
15. United Nations Environment Programme, Solar and Wind Energy Resource Assessment Project (SWERA). China Wind Energy Resource Assessment. Paris, 2006.
16. Hall P J. Energy storage: The route to liberation from the fossil fuel economy? *Energy Policy*, 2008, 36(12): 4363–4367.
17. Ibrahim H, Ilinca A, Perron J. Energy storage systems—characteristics and comparisons. *Renewable & Sustainable Energy Reviews*, 2008, 12(5): 1221–1250.
18. Hadjipaschalis I, Poullikkas A, Efthimiou V. Overview of current and future energy storage technologies for electric power applications. *Renewable & Sustainable Energy Reviews*, 2009, 13(6–7): 1513–1522.
19. International Energy Agency. Empowering Variable Renewables: Options for Flexible Electricity Systems. Paris: OECD, 2008.
20. International Energy Agency. Renewable Energy Technology Deployment, Transportation Sub-Group. Opportunities for the Use of Renewable Energy in Road Transport. Paris: OECD, 2010.
21. Sauer D U, Kleimaier M, Glaunsinger W. Relevance of energy storage in future distribution networks with high penetration of renewable energy sources. Presented at the 20th International Conference on Electricity Distribution (CIRED), June 2009, Prague.

22. Martinot E. Renewables benefit from co-evolution of power grids, energy storage, and electric vehicles. In: A Renewable World, Girardet H and Mendonça M, Devon, UK: Green Books, pp. 89-91.
23. Bradford T. Solar Revolution: The Economic Transformation of the Global Energy Industry. Cambridge, MA: MIT Press, 2006
24. Li J F, Wang S C. China Solar PV Report. Beijing: China Environmental Science Press, 2007.
25. He J K, Zhang X L. Strategies and policies on promoting massive renewable energy development. In: Proceedings of China Renewable Energy Development Strategy Workshop, Beijing: Institute for Nuclear and New Energy Technology, Tsinghua University, 2005, 81–92.
26. Ni W D, Johansson T. Energy for sustainable development in China. *Energy Policy*, 2004, 32(10): 1225–1229.
27. Kroeze C, Vlasblom J, Gupta J, Boudri J C, Blok K. The power sector in China and India: greenhouse gas emissions reduction potential and scenarios for 1990–2020. *Energy Policy*, 2004, 32(1): 55–76.
28. Smil V. *Energy at the Crossroads: Global Perspectives and Uncertainties*. Cambridge, MA: MIT Press, 2005.
29. International Energy Agency. *Energy Technology Perspectives: Scenarios and Strategies to 2050*. Paris, 2008.



Dr. Eric Martinot is senior research director at the Institute for Sustainable Energy Policies in Tokyo, research fellow at the Worldwatch Institute, and senior visiting scholar at Tsinghua University in Beijing. He served as research director and lead author for the widely read REN21 *Renewables Global Status Report* from 2005 to 2008, and continued as lead author from 2008 to 2010. He is on the editorial board of the journal *Energy Policy* and a chair of the World Council for Renewable Energy. From 2000 to 2003, he was a senior energy specialist at the World Bank in Washington, D.C. and renewable energy program manager for the Global Environment Facility. He likewise served as adjunct professor at the University of Maryland from 2002 to 2004. Author of 70 publications on sustainable energy, he holds degrees in Energy and Resources from the University of California at Berkeley and in Electrical Engineering from the Massachusetts Institute of Technology.