# China and the Future of New Energy Technologies

## Trends in Global Competition and Innovation

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Clingendael International Energy Programme


Nederlands Instituut voor Internationale Betrekkingen
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**Clingendael**

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# Executive Summary

In the field of renewable energy and low-carbon technologies, Europe, Japan and the United States have traditionally been the global leaders in terms of innovation, industrial capacity and deployment. However, this dominance is coming under increasing competition from the one country that has often been portrayed as the world's most polluting: China.

Europe has been the natural home to many of the low-carbon technologies that have been deployed to date, especially with regard to the 'new' renewable energy technologies such as solar energy and wind energy that have grown rapidly in recent years. Also in the fields of other low-carbon technologies, including hydropower and nuclear energy in the power sector, and transport-related technologies such as high-speed rail and electric vehicles, Europe has enjoyed a strong position in terms of technological skills and global market share, together with the United States and Japan.

Supported by the European Union's key role in driving forward climate change policy both globally and internally, policy mechanisms to support the transition to a cleaner energy system have been put in place. The dominance of Europe in many clean energy fields is still readily apparent:

- Seventy-five percent of all installed solar photovoltaic power generation capacity is located in Europe.[1]
- More than forty-four percent of global wind power generation capacity is located in Europe.[2]
- Wind power topped the list of all various power sources installed in the EU-27 in 2008 and 2009, accounting for about one-third of total power sector capacity additions.[3]

The United States, despite the lack of a federal strategy on climate change, has seen a lot of activity at the state level and in the field of innovation and technology development. Its unrivalled entrepreneurial and innovation-focused business environment has led to an explosion of research & development efforts in the sustainable energy field, and it still is far in the lead in terms of venture capital investments and patenting in many low-carbon technology fields.[4]

Japan is a global leader in the development and deployment of hybrid and electric vehicles, as well as being a technology leader in various advanced energy technologies. It was the first country to develop high-speed rail technology and, in terms of patenting, it holds a particularly

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[1] European Photovoltaic Industry Association, *Global Market Outlook for Photovoltaics until 2015,* May 2011, p.4.

[2] Global Wind Energy Council (GWEC), *Global Wind Statistics 2010,* 2 February 2011. Europe-wide installed capacity at the end of 2010: 86,075 GW (of which 84,074 GW in the EU-27), compared to global total of 194,390 GW. Available at: http://www.gwec.net/fileadmin/documents/Publications/GWEC_PRstats_02-02-2011_final.pdf.

[3] European Wind Energy Association, *Wind in Power. 2009 European Statistics*, February 2010, pp. 3-6. Available at: http://www.ewea.org/fileadmin/ewea_documents/documents/statistics/100401_General_Stats_2009.pdf.

[4] According to Bloomberg New Energy Finance (BNEF), North America accounted for 67 percent of the global total invested venture capital and private equity in the renewable energy sector. Bloomberg New Energy Finance, *Global Trends in Renewable Energy Investment 2011*, 2011, p. 34; United Nations Environment Programme (UNEP), European Patent Office (EPO) and International Centre for Trade and Sustainable Development (ICTSD), *Patents and Clean Energy: Bridging the Gap Between Evidence and Policy*, 2010.

strong position in the fields of hybrid and electric vehicles, battery technology and solar photovoltaics.

However, the leadership position in low-carbon technologies of these countries cannot be taken for granted. In particular, a shift towards China is taking place: in terms of manufacturing and deployment, in terms of government support through targets, policy measures and investment and – possibly in future – also in terms of innovation and technological progress. A few observations are illustrative:

- In 2009 and 2010, China ranked as the country with the highest investment in renewable energy, totalling US$48.9 billion in 2010; ahead of Europe and North America, which invested US$ 35.2 billion and US$ 30.1 billion, respectively.[5]
- China has become the largest market for wind energy and in 2010 installed more wind power capacity than the United States and Europe combined in 2010.[6]
- China has become the leading producer of solar photovoltaic modules, now having a global market share of more than 50 percent, and four Chinese wind turbine manufacturers now rank in the top ten manufacturers worldwide.[7]

In fact, there are several compelling reasons why the future of low-carbon technologies could become even more of a Chinese affair. Outlined below are a few of the main elements as to why increasing global competition from China is likely to become more intense:

- There is an enormous potential for the further expansion of renewable energy, as China is the largest source of energy demand growth in general. Moving towards a less carbon-intensive energy system is seen as a necessity for China's long-term development.
- China has shown strong policy support for the development of renewable energy and low-carbon technologies that is irrespective of the limited progress of international climate change treaty negotiations and that has suffered less from the impact of the economic and financial crisis. Moreover, its approach to public-private cooperation is very pragmatic in order to encourage the development of new technologies and industries.
- China is rapidly increasing its technological capabilities in a number of ways, bringing it ever closer to the technological frontier and turning it into a formidable global competitor. One way in which it is doing this is by leveraging its expanding domestic market to gain concessions on technology transfer from foreign firms. Another contributing factor is a strong push to move its economy towards more advanced high-value-added and innovation-based industries, in which several low-carbon energy-related sectors have been designated as being 'strategic emerging industries'.
- Although real innovation in terms of developing indigenous breakthrough technologies has been lacking in China as of yet, the extremely competitive and cost-driven domestic market makes Chinese firms very skilled in further driving down costs – which is a key factor limiting the wider deployment of some of the low-carbon technologies globally.

This paper analyzes these trends and offers an in-depth investigation through case studies of six industrial sectors in the field of low-carbon energy and transportation. It assesses how China is increasing its technological capabilities, to what extent China is moving towards innovation and what role China might play in the future global markets for these technologies.

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[5] Bloomberg New Energy Finance, *Global Trends in Renewable Energy Investment 2011*, 2011.
[6] Global Wind Energy Council (GWEC), *Global Wind Report 2010*, April 2011.
[7] European Photovoltaic Industry Association, Global Market Outlook for Photovoltaics Until 2015, May 2011, p.36; BTM Consult, 2011.

# 1

## Introduction: Low-Carbon Technologies, Global Market Developments and China's Growing Role

This introductory chapter will sketch the background of global markets for clean energy and low-carbon technologies. After the global overview, two sections will devote particular attention to China's role within these global markets and its policies to develop and deploy such technologies domestically. Finally, we will comment on our selection of case studies for this report.

### Growth of Clean Energy Sectors Worldwide

The decade 2000-2010 saw a great push for clean energy development, and concerns about climate change have been an incentive to consider various ways of decarbonising the power and transport sectors. Although progress on international climate policy has been limited and achieving a global coordination framework with stringent targets has become unlikely in the short term, there has been a growing interest in low-carbon technologies. Many countries have set targets to promote renewable energy and have stated the intention to decarbonise their energy and transportation systems in the long run.[8]

As a consequence of government support, renewable energy and other low-carbon industries have been going through a rapid expansion phase. Investments have increased significantly, and in 2009 renewable energy sources accounted for 60 percent of newly installed power generation capacity in Europe and more than 50 percent in the USA.[9] Some of the new technologies which could have been considered niche markets up to a decade ago, such as wind energy, solar PV and hybrid electric vehicles, have reached a new scale in terms of global deployment (Table 1). Global installed solar PV capacity has grown by an average of 39 percent every year for the past decade, while annual production capacity has increased 100-fold since 2000.[10] Wind power saw an average annual capacity growth of 27% in the period from 2005 to 2010 and has emerged as the mainstay of 'new' non-hydro renewable energy sources.[11] In the EU more wind power capacity

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[8] In the 1980s and early 1990s there were only very few countries with specific targets for promoting renewable energy. This started to increase in the period 1998-2005, a trend which continued more rapidly in the period 2005-2011. The number of countries with some type of renewable energy policy target and/or support policy more than doubled from an estimated 55 in early 2005 to 118 by early 2011. REN21, *Renewables 2011 Global Status Report*, July 2011, pp. 48-49.

[9] UNEP, 'Global Trends in Green Energy 2009: New Power Capacity from Renewable Sources Tops Fossil Fuels', 16 July 2010. Available at: http://www.unep.org/Documents.Multilingual/Default.asp?DocumentID=630&ArticleID=6647&l=en.

[10] For grid-connected solar PV the growth of global installed capacity is even more pronounced, averaging 60 percent per year over the period 2000-2010. REN21, *Renewables 2011 Global Status Report*, July 2011, pp. 22-24; Earth Policy Institute, 'Solar PV Breaks Records in 2010', October 27, 2011.

[11] REN21, *Renewables 2011 Global Status Report*, July 2011, p. 19.

was installed than any other type of electricity generation in 2008 and 2009, as it accounted for more than one-third of the total newly installed capacity in those years.[12]

| | 2000 | 2010 |
|---|---|---|
| **Global Installed Capacity for Solar PV** | **1.5 GW** | **39.8 GW** |
| **Global Installed Capacity for Wind Power** | **18.5 GW** | **199.5 GW** |
| **Combined Global Market for Solar PV and Wind** | **US$6.5 billion** | **US$131.6 billion** |
| **Number of Hybrid Electric Vehicles on the Road in US** | **Less than 10,000** | **More than 1.4 million** |
| **Number of Hybrid Electric Vehicle Models Available Globally** | **2** | **30** |
| **Number of US States with Renewable Portfolio Standards (RPS)** | **4** | **29** |
| **Percentage of Total US Venture Capital Invested in Clean Tech** | **Less than 1%** | **More than 23%** |

**Table 1. Some statistics illustrating market growth for clean energy technologies 2000-2010.**
Source: Reproduction of the figure 'Ten Years in Clean Tech: At a Glance' in Clean Edge, *Clean Energy Trends 2011,* March 2011, p. 2. Additional installed capacity statistics for solar PV and wind energy taken from: *BP Statistical Review of World Energy,* June 2011 (online Excel database).

The rapid growth of these 'new' renewable energy sectors has also illustrated how change can sometimes occur rapidly, exceeding expectations. After several decades of small and almost indiscernible growth, global deployment of solar power stood close to 1 GW in 1999, with Germany having 32 MW of installed capacity. By the end of 2010, global capacity had reached approximately 40 GW, with cumulative installed capacity in Germany standing at 17,300 MW.[13]

A similar story holds for wind energy: it took about a decade to increase global capacity of wind power from 1 GW in the mid-1980s to 3 GW in 1994, but from that moment on it continued to grow explosively to reach nearly 200 GW by the end of 2010.

Since most forecasts are based upon more or less linear extrapolations of growth trends, it should not come as a surprise that this growth has surpassed all projections. Just as an example, the *World Energy Outlook 2004* projected 206 GW of global wind capacity and 29 GW of solar PV capacity by 2020. In reality, both thresholds were surpassed in 2010 and 2011. Six years later, in the *World Energy Outlook 2011*, the targets for 2030 were approximately tripled to 862 GW for wind (from 328 GW in the *WEO2004)* and to 294 GW for solar power (from 76 GW).[14]

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[12] European Wind Energy Association, *Wind in Power. 2009 European Statistics*, February 2010, pp. 3-6. Available at: http://www.ewea.org/fileadmin/ewea_documents/documents/statistics/100401_General_Stats_2009.pdf.
[13] *BP Statistical Review of World Energy,* June 2011 (online Excel database version).
[14] International Energy Agency, *World Energy Outlook 2004,* 2004, p. 432 (Reference Scenario projections) and *World Energy Outlook 2011,* 2011, p. 620 (New Policies scenario).

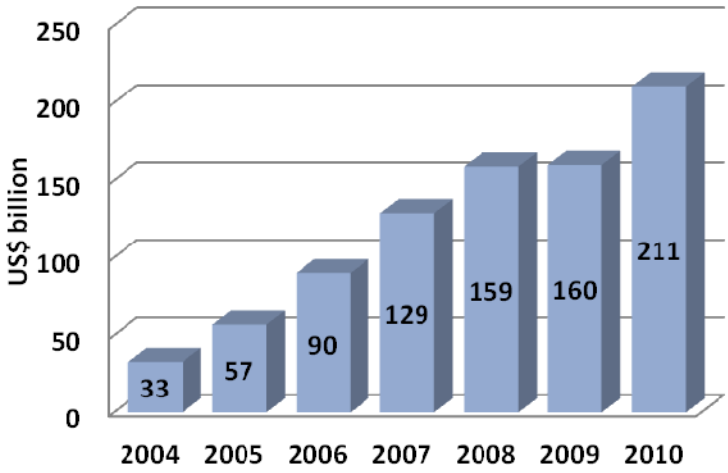


**Figure 1. Global New Investment in Renewable Energy, 2004-2010 (US$bn).**
Source: Bloomberg New Energy Finance, *Global Trends in Renewable Energy Investment 2011*, 2011, p. 12, Figure 1.

Despite this phenomenal growth these 'new' renewable energy sources still play only a marginal role in the energy sector from a global perspective: wind energy accounts for approximately 1.6 percent of global electricity and solar for about 0.1 percent.[15] From a total primary energy perspective (of which electricity is just a part) their share is even more insignificant. The interest which they have attracted has more to do with their future potential and capability for providing carbon-free energy. Due to the focus on lowering emissions of greenhouse gases, other more mature low-carbon industries, such as hydropower, nuclear power and high-speed rail, have also received renewed attention.

Overall, global investment in clean energy technologies has grown rapidly. According to statistics provided by *Bloomberg New Energy Finance,* total global new investment in renewable energy stood at US$33 billion in 2004 but had already grown to US$211 billion by 2010 (Figure 1).[16]

Optimistic reports expect investments to increase further, especially when including more low-carbon technologies than just those related to the renewable power sector. An assessment by the bank HSBC which encompasses the power sector, buildings, transport and industry expects the total investment in low-carbon energy technologies to grow by a compound annual growth rate of 11 percent – from US$740 billion in 2009 to about US$2.2 trillion per year by 2020 – despite all regulatory and policy uncertainties.[17]

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[15] Figures on electricity generation taken from *BP Statistical Review 2011* (online version), Review by energy type: solar capacity and wind capacity, 2011. Available at: http://www.bp.com/sectiongenericarticle800.do?categoryId=9037191&contentId=7068648 and http://www.bp.com/sectiongenericarticle800.do?categoryId=9037190&contentId=7068638.

[16] Bloomberg New Energy Finance, *Global Trends in Renewable Energy Investment 2011*, 2011, p. 12. Other report have slightly different figures: total clean energy sector finance and investment grew to US$243 billion, a growth of 630 percent since 2004, according to research by The Pew Charitable Trusts. 'Global Clean Energy Investment Reached Record $243 Billion in 2010', Pew Charitable Trusts, Press Release, 29 March 2011. Available online at: http://www.pewtrusts.org/news_room_detail.aspx?id=329368.

[17] The report was released after the 2009 COP-15 Copenhagen climate conference. HSBC, *Sizing the Climate Economy,* HSBC Global Research, September 2010. One key insight of the report is the forecast that low-carbon transport such as hybrids and full electric vehicles will overtake the low-carbon power sector as a major focus of investment.

The expansion of the clean energy sector is, however, facing severe challenges and its continued growth has become more uncertain as of late. The key reason is that recent growth has been completely dependent upon direct financial government support, given that many of the clean energy technologies are not yet cost-competitive. Government support has taken many different forms, such as renewable energy support schemes with feed-in tariffs or renewable portfolio standards that are used to promote wind energy and solar energy, as well as subsidies to promote the use of hybrids and electric vehicles.

Concerning the future global growth of low-carbon energy technologies, the following observations should be made:

- **For clean energy technologies that are not yet commercially competitive, continued support for their deployment is under pressure due to the economic and financial crisis, especially in Western countries.** Recent growth has been driven almost purely by direct government support, which has become more constrained. This is true in particular for the most expensive low-carbon energy technologies, such as solar power, offshore wind energy and electric vehicles. The crisis has had a very real impact on renewable energy investment, which dropped in both Europe and the United States following the crisis.

- **Although support has grown for climate change policies, progress on internationally coordinated climate policy is likely to remain very limited in the short term.** The current international negotiations on a global framework on climate change remain in a gridlock that seems unlikely to be resolved in the near future.[18] Naturally, this hampers the push for low-carbon technology deployment worldwide, since taking unilateral action runs the risk of criticized as being ineffective and having economic disadvantages. In particular, there is a concern that the extra costs incurred by government and society to support climate policy might be detrimental for economic competitiveness relative to other countries, as it might raise energy and carbon prices. Nonetheless, quite ambitious climate policy initiatives have recently been undertaken in the United Kingdom, Australia and several other countries.

Amidst these challenging circumstances, another development is taking place which has been accentuated by the economic and financial crisis that hit clean energy investments around the world:

- **China has emerged as a major growth market for clean energy technologies in recent years, alongside the 'traditional' markets of Europe, the United States and Japan.** As was remarked earlier in this chapter, in 2009 and 2010 China ranked as the country investing the

[18] Essentially the absence of strong climate policy in the United States very much limits the possibility of having any global climate policy pact. Accounting for roughly one-fifth of global greenhouse gas emissions (roughly that of China), the US did not ratify the Kyoto Protocol and acknowledgement of climate change as a global problem is still controversial within the US. As a consequence, it is highly improbable that the United States will be playing a leading role in addressing climate change, despite various regional initiatives. Progress on centralized federal policy has become even more unlikely as of late: given its newfound (unconventional) fossil fuel supplies and low energy prices due to the abundance of gas, oil and coal, it also does not have the incentive to develop low-carbon energy from an energy security point of view. Edward Luce: 'America is entering a new age of plenty', *Financial Times,* 20 November 2011. Available online at: http://www.ft.com/intl/cms/s/0/a307107c-1364-11e1-9562-00144feabdc0.html#axzz1eX81M9NK.
For a detailed analysis of global climate policy see: Bram Buijs, *Three Observations on Global Energy and Climate*, Clingendael Briefing Paper, July 2010. Available online at: http://www.clingendael.nl/publications/2010/20100705_CIEP_BriefingPaper_BBuijs_Three_Observations_Energy_Climate.pdf.

most in renewable energy, with investment totalling US$48.9 billion in 2010, ahead of Europe and North America at US$ 35.2 billion and US$ 30.1 billion, respectively (Figure 2).[19]

We will elaborate upon the growth of clean energy investment in China in the next section.

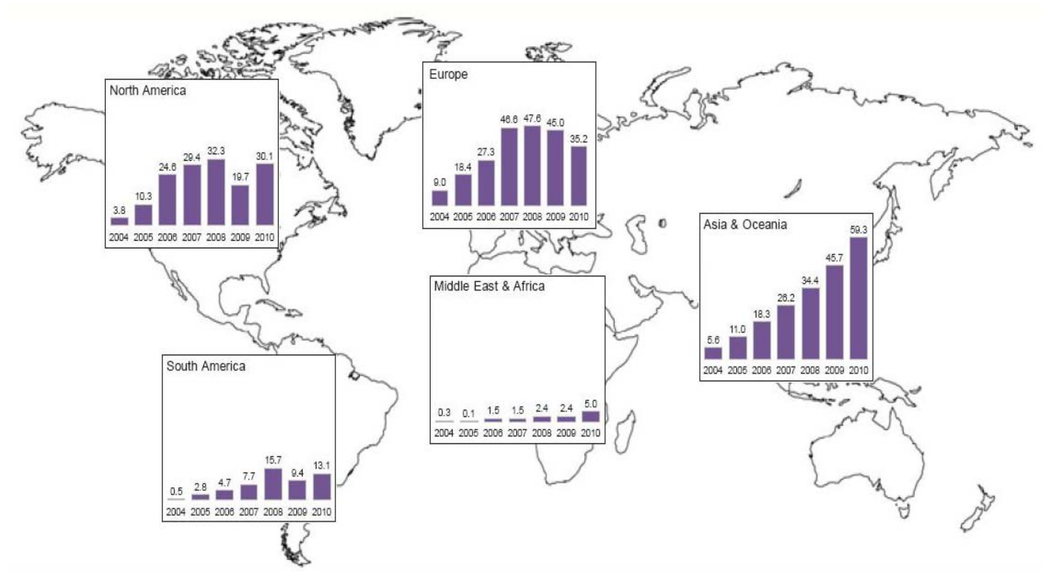


**Figure 2. Financial New Investment in Renewable Energy by Region, 2004-2010, in US$ billion.** Source: Bloomberg New Energy Finance, *Global Trends in Renewable Energy Investment 2011*, 2011, p. 19, Figure 14.

## Clean Energy Investment in China

Depending on which industrial sectors are included in the evaluation, China already enjoys a top ranking as far as clean or low-carbon energy investments are concerned. In terms of renewable energy investment, for instance, China already ranked as the largest investor worldwide for both 2009 and 2010 according to *Bloomberg New Energy Finance*.[20]

In an HSBC report that includes a broad spectrum of industrial low-carbon sectors, the top three of regional market shares for 2009 stood at 33 percent for the European Union, 21 percent for the United States and 17 percent for China. Yet the report projected this to shift by 2020 with China gaining ground, changing the top five ranking to: the EU (27%), China (24%), the US (20%), India and Japan.

For many technologies, such as wind energy, nuclear energy and high-speed rail, China now figures as the largest growth market. This does not hold for all technologies we are evaluating, however. For instance, for both solar PV and hybrid and electric vehicles, the Chinese market occupies only a very small share of the global market as of yet.

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[19] Bloomberg New Energy Finance, *Global Trends in Renewable Energy Investment 2011*, 2011.

[20] Bloomberg New Energy Finance, Global Trends in Renewable Energy Investment 2011, 2011.

The fact that China has become the largest investor in renewable energy and many other low-carbon technologies should be seen in the context of China's enormous growing demand for energy and transportation.

Its rapid economic growth over the past three decades has led to a surging energy demand, mostly from industry but also from its population which is enjoying a steady rise in welfare levels. Both overall primary energy consumption and electricity consumption stand at approximately one-third of OECD levels when measured on a per capita basis, indicating the enormous potential for further demand growth.[21]

Already, China has witnessed a huge power sector expansion in the past few decades: its total installed capacity for power generation grew from less than 66 GW in 1980 to 962 GW at the end of 2010.[22] This growth has exceeded all expectations: as recently as 2004, the International Energy Agency forecasted that China's total installed capacity would only reach 855 GW in 2020 and 1187 GW in 2030.[23]

Projections from the China Electricity Council show that electricity consumption is expected to approximately double by 2020 to 8.2 trillion kWh. Installed capacity might then reach 1885 GW by 2020, of which 36.3 percent will likely be renewables or nuclear power, according to their estimates. In terms of policy they assumed hydropower development and optimizing thermal power plants are being given priority, apart from pushing forward nuclear power and new energy resources such as wind and solar power.[24]

The International Energy Agency has slightly more conservative estimates and projects Chinese power capacity to reach 1764 GW by 2020 and 2294 GW by 2030 in the 'Current Policies Scenario' of the *World Energy Outlook 2011*.[25] As Figure 3 illustrates, about 60 percent of global growth in the electricity sector is expected to take place in the emerging economies of non-OECD Asia, and China alone accounts for nearly 40 percent of the global total.

In terms of transportation, an important driver is the urbanization that is taking place in China on a massive scale. Only half of the population of 1.3 billion people now live in cities, and this percentage is increasing steadily as 15 to 20 million Chinese move from the countryside to urban areas every year. Its urban population is projected to surpass the 1 billion mark between 2025 and 2030. This urban growth means that China could have almost 110 cities of over 1 million inhabitants by 2015, and this number could grow to more than 220 cities by 2025.[26] This massive urbanization process has caused China to become one of the major centres of global demand

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[21] International Energy Agency, *Key World Energy Statistics 2011*, 2011, pp. 48-49.

[22] Electricity consumption grew by nearly 15% year-on-year, to reach 4.2 trillion kWh in 2010. Investment amounted to 705.1 billion RMB ($105.24 bn US dollars). Power-generating capacity rose with 10% to 962 GW end-2010 according to the China Electricity Council. Energy Information Administration (EIA) of the US Department of Energy, International Energy Statistics, available online at: http://www.eia.doe.gov/cfapps/ipdbproject/iedindex3.cfm?tid=2&pid=28&aid=7&cid=&syid=1980&eyid=2007&unit=MK (accessed at 20 October 2010). China Daily, 'China's Electricity Consumption Jumps 14.56% in 2010', 17 January 2011. Available online at: http://www.chinadaily.com.cn/bizchina/2011-01/17/content_11864978.htm (accessed 6 February 2011).

[23] International Energy Agency, *World Energy Outlook 2004*, 2004, p. 484.

[24] *China Daily*, 'China Electricity Consumption to Almost Double by 2020', 22 December 2010. Available online at: http://www.chinadaily.com.cn/bizchina/2010-12/22/content_11737519.htm.

[25] The corresponding figures for the 'New Policies Scenario' are 1728 GW by 2020 and 2179 GW for 2030. International Energy Agency, *World Energy Outlook 2011*, 2011, pp. 594-595.

[26] McKinsey, *Preparing for China's Urban Billion*, 2009. Available at: http://www.mckinsey.com/mgi/reports/pdfs/China_Urban_Billion/MGI_Preparing_for_Chinas_Urban_Billion.pdf.

growth for inter- and intra-city transportation. The use of air travel is for instance increasing very rapidly, with Beijing-Shanghai already ranking as the fifth most crowded air route worldwide.[27]

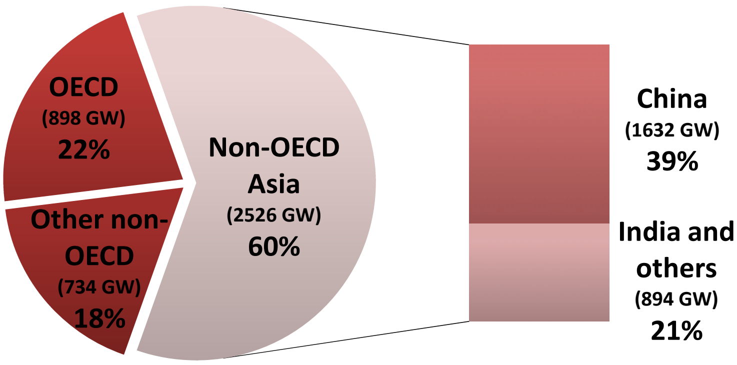


**Figure 3. Projected global power sector expansion up to 2035 (4158 GW).** According to the International Energy Agency, *World Energy Outlook 2011*, Current Policies Scenario. Source: IEA, WEO2011.

One of the key factors underlying China's economic success has been its ability to expand the necessary infrastructure. To address the challenge posed in terms of transportation, China is investing massively in public transport. Most large Chinese cities now have extensive metro line systems, and public car ownership has been discouraged by various measures including the auctioning of a limited amount of number plates per month. Nonetheless, together with rising incomes, private car ownership is increasing rapidly. Currently only 3 out of 100 Chinese own a car, a very low figure compared to about 50 and 75 out of 100 people in Europe and the United States, respectively. However, a growing number of middle class Chinese can now afford to own cars, and China has overtaken the United States as the largest car market in the wake of the crisis. More than 18 million vehicles were sold in China in 2010, and car ownership is expected to increase five-fold: up to 15 car owners per 100 Chinese by 2020.[28]

China faces an enormous challenge in trying to accommodate the growing demand for energy and transportation that inevitably accompanies its economic success. Because of its sheer size, it will need to find a different developmental path than other Asian economies such as Japan and South Korea, which went through a phase of rapid economic development before China did. For China, the global impact of its growing energy needs is simply much larger.[29] For example: if China were to reach the same per capita oil consumption level as the United States, it would need all of the global total oil production to satisfy its domestic oil demand. There are also increasingly severe negative impacts of the use of coal in terms of air pollution, public health and environmental degradation. The need to make the further growth of its energy sector sustainable

[27] Beijing-Shanghai ranked fifth with 690,000 seats per month both ways. Centre for Aviation, 'World's Top 50 Busiest Routes (Seats per Month Both Ways', updated July 2010. Available online at: http://www.centreforaviation.com/profiles/hot-issues/route-changes.

[28] *Bloomberg,* 'China 2010 Auto Sales Reach 18 Million, Extend Lead', 10 January 2011. *China Daily*, 'China Car Boom Could Last a Few Years: Analysts', 9 July 2009. Available at: http://www.chinadaily.com.cn/china/2009-07/09/content_8401265.htm.

[29] Bram Buijs, 'Why China Matters', Chapter 15 in: Fereidoon Sioshansi, *Energy, Sustainability and the Environment - Technology, Incentives, Behavior*, 2011.

in the long run is recognized by the Chinese government and is in fact driving much of its energy policy.[30]

China's energy system is currently anything but low-carbon: on average, carbon emissions from electricity and heat production stood at 743 $gCO_2$ per kWh in 2009, more than double that of the average of the EU-27 at 339 $gCO_2$ per kWh.[31] The main reason for this is the dominance of coal in its energy system, which accounts for nearly 80 percent of all generated electricity and 67 percent of China's total primary energy demand.[32] In fact, the stunning growth of coal consumption in China is the key factor that has caused the share of coal in the global fuel mix to increase, making the global energy system more carbon-intensive rather than moving it towards a low-carbon future.[33]

Nonetheless, China has set out to constrain the growth of coal consumption in its energy system. Regarding policy measures that are driving low-carbon energy technology deployment, we mention the following key points:

**(1) China has set clear targets to decarbonise its economy and increase low-carbon energy sources in its energy system.**

The country's most crucial targets were announced in the lead-up to the COP-15 Copenhagen summit in 2009:

- **Decarbonizing the economy** by lowering emissions of $CO_2$ per unit of GDP by 40-45% by 2020 as compared to 2005.
- **Increasing the share of non-fossil fuels,** which in China denotes renewable and nuclear energy, in its primary energy consumption to 10% by 2010 and 15% by 2020.

These central targets have also been translated into target at lower levels of governments and for specific energy industries.

[30] Jiang Zemin (President of the People's Republic of China from 1993 to 2003), 对中国能源问题的思考 ('Reflections on Energy Issues in China'), Journal of Shanghai Jiaotong University, 2008, Vol. 42 No. 3, pp. 263-4: 'To meet the ever-increasing energy demand by one billion plus people in the course of building a moderately prosperous and modern society in an all-round way, China will build the world's largest energy supply and consumption system in the coming 10 to 20 years. Therefore, the urgent task before us is to blaze a new path in energy development with Chinese characteristics, in order to achieve the nation's strategic goal of modernization with a minimal cost of energy resources and impact on the environment.'

[31] China's current emissions level per kWh stand at 743 $gCO_2$/kWh compared to 430 $gCO_2$/kWh in Germany and 90 $gCO_2$/kWh in France (data for 2009). IEA, *$CO_2$ Emissions from Fuel Combustion Highlights (2011 Edition)*, 2011, pp. 109-110. Available online at: http://www.iea.org/co2highlights/CO2highlights.pdf.

[32] International Energy Agency, *World Energy Outlook 2011*, 2011, pp. 592-595.

[33] Bram Buijs, *Three Observations on Global Energy and Climate*, Clingendael International Energy Programme (CIEP) Briefing Paper, July 2010. Available online at: http://www.clingendael.nl/publications/2010/20100705_CIEP_BriefingPaper_BBuijs_Three_Observations_Energy_Climate.pdf.

| Renewable energy source | 2005 | Targets for 2015 | | Targets for 2020 | |
|---|---|---|---|---|---|
| | *Installed capacity* | *Disclosed early 2011* | *Latest Targets** | *Medium-Long Term Plan (2007)* | *Latest Targets** |
| **Hydropower** | 117 GW | 250 GW | 260 GW | 300 GW | 300 GW |
| **Wind Power** | 1.26 GW | 90 GW | 100 GW | 30 GW | 150 GW[1] |
| **Solar PV** | 70 MW | 5 GW | 15 GW[1] | 1.8 GW | 20 GW[1] |

(*): As of November 2011. ([1]): These targets are not fully official yet but have been suggested by government officials and seem likely.

**Table 2. Key Chinese Renewable Energy Targets for 2015 and 2020.**
Source: National Development and Research Commission, Medium- and Long-Term Development Plan for Renewable Energy in China (draft), September 2007; Eric Martinot and Li Junfeng, 'China's Latest Leap: An Update on Renewables Policy', July 21, 2010; The Climate Group, 'China Amps Up Renewables Targets', 1 September 2011. Available online at: http://www.theclimategroup.org/our-news/news/2011/9/1/china-amps-up-clean-energy-targets/.

In its push for clean energy development, China has actually exceeded not only the expectations of others but also those of its own policy-makers.

Wind power is the most impressive example. In the *World Energy Outlook 2004*, the International Energy Agency projected 10 GW of Chinese wind power capacity in 2020 and 22 GW by 2030.[34] In *China's Medium and Long-Term Development Plan for Renewable Energy*, released in 2007, the National Development and Reform Commission (NDRC) set a target of 5 GW of wind capacity by 2015 and 30 GW by 2020. These targets have been spectacularly exceeded as Chinese installed capacity reached 44.7 GW by the end of 2010.[35]

For solar PV the same *Medium and Long-Term Development Plan* announced a target of 1.8 GW for 2020. However, since China introduced a nation-wide feed-in tariff for solar PV projects, it seems it was already able to reach 2.5 GW of installed solar PV capacity in 2011.[36]

In the meantime China has adjusted its own targets: Table 2 shows the official 2015 and 2020 targets for hydropower, wind power and solar PV and how they have been revised over time.

Also for nuclear power the target for 2020 was raised from 40 GW to 70-80 GW following a very rapid expansion of construction projects, although in the aftermath of the Fukushima accident it is likely to be scaled back slightly to 60-70 GW.[37] The 12$^{th}$ Five-

[34] International Energy Agency, *World Energy Outlook 2004*, 2004, p. 484.
[35] The rapid growth of China's wind energy sector has not been without its problems however, as we will discuss in Chapter 2.
[36] IMS Research, 'Global PV Installations to Hit 24 GW in 2011 Predicts IMS Research', Press Release, 15 November 2011. Available online at: http://imsresearch.com/press-release/Global_PV_Installations_to_Hit_24_GW_in_2011_Predicts_IMS_Research&from=.
[37] World Nuclear Association (WNA), 'Nuclear Power in China', updated November 2011. Available online at: http://www.world-nuclear.org/info/inf63.html.

Year Plan includes a target of 42.9 GW by 2015, although this might not be met in time due to the temporary halt of approvals.[38]

**(2) China has made its climate and renewable energy policy independent from the international climate treaty negotiations and UNFCCC process.**
Although China has included its pledges in the Copenhagen Accord, which was later formally adopted in the UNFCCC at the COP-16 meeting in Cancún, these pledges were made unilaterally and do not depend upon a result achieved within the UNFCCC process. This is a quite important aspect, as many other countries made their pledges contingent upon reaching a global deal in which all countries would take up commitments.[39]

China's goals have already been incorporated in its recently adopted 12th Five-Year Plan which runs from 2011 to 2015.

**(3) Although China has also felt the impact of the economic and financial crisis, it has not reined in its support for clean energy deployment.**
Even though China has been impacted by the economic crisis and its export sector would be further hit by an economic downturn in Europe or the United States, it has not scaled back its support for renewable energy and other low-carbon technologies due to financial constraints. Although the cost of financing clean energy growth is a concern in China as much as it is in Western countries, China is still pushing forward to meet its long-term targets for clean energy.[40] One key factor is the availability of funding for low-carbon technology deployment: whereas in Western countries capital constraints are limiting the financing options, in China much of the investment is being done by state-owned companies with the support of the government and state-owned banks. This gives China more financial freedom to execute its plans.

As a consequence of the above factors, China is gaining an increasingly important role in the future development of low-carbon technologies. The rapid growth of the market, combined with the clear and consistent policy support for renewable energy deployment, also makes it an attractive country for investments, as indicated by the fact that China has in recent years been leading the *Renewable Energy Country Attractiveness Index* by Ernst&Young, ahead of European countries and the United States.[41]

The enormous expansion of China's clean energy sector is offering opportunities for all companies active in that field, yet there is also an industrial aspect to China's policy on new energy technologies which we will discuss in the following section.

## Chinese Policy Aimed at Building Up 'Strategic Emerging Industries'

The effort of China to build a cleaner energy system is particularly powerful because it is pursued as part of a broader Chinese effort to develop a series of industries that are considered strategically important for the longer term. It also coincides with a key policy objective of the Chinese government: shifting from a low-cost manufacturing-based economy towards a more

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[38] *Caixin Magazine*, 'China May Revise Nuclear Power Target', 28 March 2011. Available online at: http://english.caixin.com/2011-03-28/100241757.html.
[39] Bram Buijs, *Three Observations on Global Energy and Climate*, Clingendael International Energy Programme (CIEP) Briefing Paper, July 2010. Available online at: http://www.clingendael.nl/publications/2010/20100705_CIEP_BriefingPaper_BBuijs_Three_Observations_Energy_Climate.pdf.
[40] We will come back to the cost issue in Chapter 9.
[41] Ernst&Young, *Renewable energy country attractiveness indices*, Issue 29, May 2011. Available online at: http://www.ey.com/Publication/vwLUAssets/Renewable_energy_country_attractiveness_indices_-_Issue_29/$FILE/EY_RECAI_issue_29.pdf.

high-tech, high-value-added, innovative economy. These objectives reinforce each other and make for a strong combination.

The following statement made by China's Premier Wen Jiabao at the World Economic Forum in Davos on 10 September 2009 is illustrative:

> *'We should see scientific and technological innovation as an important pillar and make greater effort to develop new industries of strategic importance. Science and technology is a powerful engine of economic growth . . . We will make China a country of innovation. . .We will accelerate the development of a low-carbon economy and green economy so as to gain an advantageous position in the international industrial competition.'*[42]

Recognizing that the challenge of securing sufficient energy in a sustainable manner is crucial to its further development, China has made a strategic decision to embark on the development of a series of domestic industries in several key energy-related industrial sectors.[43] In a policy document issued in October 2010, the following key strategic industries selected for special favourable policies in the 12th Five-Year Program (2011-2015) were introduced: [44]

- new-generation information technology
- energy savings and environmental protection
- new energy
- biology
- high-end equipment manufacturing
- new materials
- new-energy cars

As can be seen, energy-related sectors figure prominently in this list. The category 'new energy' includes renewable energy sectors such as wind and solar energy, but also nuclear energy development is strongly supported. In relation to transportation China is pushing for high-speed railway technology, and within the automotive industry it is promoting the development of 'new energy vehicles', which include hybrids and electric vehicles (EVs).

Support for these industries has been very clear, which will be illustrated by the case studies in the next chapters. Apart from various policy measures, financial support for these industries has been significant. In response to the economic and financial crisis, the stimulus package of the Chinese government provided an additional push to accelerate the development of some industries, such as high-speed rail and nuclear power.[45]

The goal is not only to build domestic manufacturing industries but also to pursue self-dependent innovation. This has been formulated explicitly with regard to renewable energy technologies, as

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[42] Quote taken from: Julian L. Wong, 'China's Innovation Model and its Role in the Global Clean Energy Market', *Green Leap Forward [绿跃进 ]*, 31 July 2010. Full text of Wen Jiabao's speech is available at: http://news.xinhuanet.com/english/2009-09/11/content_12032065_2.htm.

[43] Yanrui Wu, 'Indigenous innovation for sustainable growth in China', *East Asia Forum,* 2 September 2010. Available online at: http://www.eastasiaforum.org/2010/09/02/indigenous-innovation-for-sustainable-growth-in-china/.

[44] *Xinhua News*, 'China to Nurture 7 New Strategic Industries in 2011-15', 27 October 2010. Retrieved at: http://news.xinhuanet.com/english2010/china/2010-10/27/c_13578293.htm on 26 January 2011.

[45] *Reuters,* 'China Mulls $1.5 Trillion Strategic Industries Boost: Sources', 3 December 2010. Available online at: http://www.reuters.com/article/2010/12/03/us-china-economy-investment-idUSTRE6B16U920101203; *Reuters,* 'China Plans to Spend Big on Nuclear Power, High-speed Rail', 1 February 2011. Available online: http://www.reuters.com/article/2011/02/01/us-china-industries-idUSTRE7103KW20110201.

illustrated by the section in the *Medium and Long-Term Development Plan for Renewable Energy in China,* issued by the National Development and Reform Commission, September 2007:[46]

> *'China will actively promote the development of renewable energy technologies and industries, building up a renewable energy technology innovation system. By 2010, China will basically have achieved the ability to produce domestically the main renewable energy equipment it uses. By 2020, local manufacturing capability based mainly on home-grown Intellectual Property Right (IPR) will be achieved.'*[47]

Various policies and measures are described in order to 'accelerate technology improvement and industry development':

> *'Renewable energy technology improvement and industry development should be promoted through the integration of various renewable energy technology resources (e.g. research institutes), improvement of the technology and industry service systems, speeding up of human resource development, and increasing in all aspects technical innovation capabilities and service levels. Innovation capabilities of China's research organizations and enterprises in core renewable energy technologies will be raised by putting scientific research related to renewable energy, technology development, and industrialization into all kinds of national scientific and technological development plans and by arranging for renewable energy projects to be included in the nation's high technology industrialization programs and its programs for supporting manufacturing of key equipment. On the basis of bringing in foreign technology from abroad, the capacity to absorb and innovate should be strengthened, so that, as soon as possible, self-dependent innovation capabilities are achieved.'*[48]

The support for domestic deployment is furthermore driven by the idea that this will lead to the increased competitiveness of renewable energy sources.[49] Apart from domestic concerns over energy security and the environmental impact of its coal-dominated energy system, China is acting upon the economic opportunities it perceives to exist in these industrial sectors. Since the same energy challenge is confronting countries across the globe, it counts on economic opportunities for marketing these technologies abroad, and Chinese firms are clearly quite aware of the export potential of low-carbon technologies.

We will return to China's efforts to develop its innovative capacities in more detail in Chapter 8, but the above outline of Chinese policies can serve as a background to our case studies.

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[46] National Development and Reform Commission (China), *Medium and Long Term Development Plan for Renewable Energy in China,* 2007. English (abbreviated version) available online at: http://www.cresp.org.cn/uploadfiles/2/967/medium%20and%20long-term%20development%20plan%20for%20re%20in%20china%20eng.pdf.
Original Chinese version (规划可再生能源中长期发展) available online at: http://www.ccchina.gov.cn/WebSite/CCChina/UpFile/2007/20079583745145.pdf.

[47] National Development and Reform Commission (China), *Medium and Long Term Development Plan for Renewable Energy in China,* 2007, Section 3.2 (Specific Objectives), p. 7 in English version.

[48] National Development and Reform Commission (China), *Medium and Long-Term Development Plan for Renewable Energy in China,* 2007, Section 5 (Policies and Measures), p. 13 in English version.

[49] 'Through the large-scale development and establishment of wind farms, China aims to accelerate wind energy technology improvement and industrial development, thus promoting the market competitiveness of wind power.' National Development and Reform Commission (China), *Medium and Long-Term Development Plan for Renewable Energy in China,* 2007, Section 4.3 (Wind Power), p. 9 in English version.

## An In-Depth Look at Six Industrial 'Low-Carbon' Sectors

In the following six chapters, we will discuss a number of industrial sectors: not all are clean energy sectors in the strict sense, but they are all industries which are somehow related to low-carbon growth. These industries are in varying stages of their learning curve and maturity in terms of technology development, commercialization and market deployment.

**Hydropower** is by far the largest source of renewable energy worldwide, accounting for 83 percent of all electricity generated from renewable sources.[50] It is generally cost-competitive with fossil fuel-based power generation and has been deployed for power generation since the end of the 19th century.[51] For this technology, China is both the largest market and the most important player worldwide in hydropower construction projects.

**Wind energy** is the largest and most mature of the 'new' non-hydro renewable energy sources and has experienced tremendous growth in the past decade. China has become both the largest growth market and the leading country in terms of installed capacity. Although Chinese wind turbine manufacturers are focused mostly on the internal Chinese market, they have the intention to develop their global export potential.

**Solar PV** is the other non-hydro renewable energy technology, alongside wind, that has attracted a lot of attention and experienced unprecedented exponential growth in the past decade. In terms of technology it is still very much in development, with new experimental techniques being used for the photovoltaic material, cells and panels as well as for processing and manufacturing methods. Although it has traditionally been by far the most expensive renewable energy option, very significant cost reductions have been achieved in the past years as deployment reached a new order of magnitude. Installed capacity is concentrated in Europe while China has gained a dominant share in the production of solar panels.

**Nuclear power** is a more controversial form of low-carbon energy due to concerns about operational safety and nuclear waste management. It experienced rapid growth especially in the 1970s and 1980s and currently provides 13 percent of the world's electricity. Next generation nuclear reactors aim to address the safety issues, and China is the dominant growth market, accounting for more than one-third of all reactors being constructed and planned.

**High-speed rail** is a mature technology for long-distance travel that was originally developed in Japan in the 1960s and '70s and that is relatively low-carbon. Although Japan and Europe have been the two main regions for its deployment, in recent years China has laid more high-speed rail track than all of Europe and has tried to assimilate the technology in order to export it to other markets.

**Hybrids and electric vehicles** currently receive much attention as an alternative to petroleum-based transport and a possible way of decarbonising road transport. Although the use of fully electric vehicles on a global scale is still negligible, hybrid electric cars are becoming more mainstream. On the technological side there are a lot of developments taking place, especially concerning battery technology. China lacks a well-developed automobile industry as of yet but has ambitious plans to develop "new energy vehicles" including hybrids and electric vehicles.

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[50] Hydro accounted for 3252 TWh of electricity globally, versus 650 TWh for all other renewables combined. Biomass and waste (288 TWh) and wind (273 TWh) are the largest of the non-hydro category. Both account for little over 1 percent of the world's total electricity generation of 20.043 TWh, whereas hydro totals 16 percent. International Energy Agency, *World Energy Outlook 2011*, 2011, p. 546.

[51] International Energy Agency (IEA), 'What is Hydropower's History?', IEA Hydropower site, accessed 10 September 2011. Available online at: http://www.ieahydro.org/What_is_hydropower's_history.html.

The common characteristic of the industrial sectors listed above is that they can make a contribution to low-carbon growth, whether it is in power generation or transport. A second common characteristic – on which we will focus in this paper – is that these industries and technologies are actively being pursued by China in order to provide itself with the means to achieve sustainable growth, to move toward a more high-value-added economy and to make its mark in global clean energy markets worldwide.

Inevitably, the above selection of industrial sectors is in a sense arbitrary, and other sectors could have been included. Hydropower, for instance, is a rather traditional and cost-competitive form of renewable energy. However, since it provides one of the earliest examples of China's strategy of providing market access in exchange for technology and is the major source of low-carbon energy in China and worldwide, it is nonetheless included. When discussing newly emerging energy technologies, the progress which China is making on advanced coal technologies would be one obvious candidate.[52] In China there is a lot of research going into advanced coal utilization techniques, such as integrated gasification combined cycle (IGCC) plants and carbon capture and storage (CCS). Given the very important ramifications for global action on climate change, these efforts are also supported by a number of international institutions and collaborative projects. CCS is a main focus of both EU-China and US-China cooperation in the energy sector, and there is also support from the Asian Development Bank, amongst others.[53] Although China's purposeful pursuit of technology is very clear here as well, we have decided to omit these, as with other efforts on the conventional and unconventional fossil fuel side, such as extraction technologies for unconventional gas (both shale gas and coal-bed methane) which can play a significant role in China's energy future. Of course, the general strong policy drive towards increasing domestic technological capabilities is also taking place outside of the energy sector in many other industries.

Yet we have limited ourselves to the six industrial sectors in the field of low-carbon energy and transport as listed above. In the following we will look at these sectors and the role China is playing in the global market. For two of the markets that are still the most immature and most dynamic in terms of their technological development – solar PV and (semi-)electric vehicles – we will also take a closer look at the global technological development as they stand. We will then address the question of what role China is playing in these markets, both as a sales market as well as a potential exporter.

After we have analyzed China's technological capacities in the case studies, we will examine China's drive towards more innovation. Finally, challenges for both Chinese and Western industries are evaluated and we will present our conclusions.

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[52] China is very keen on developing advanced coal technologies, where it is already leading with the introduction of state-of-the-art ultra-supercritical power plants and the development of integrated gasification combined cycle plants. Its demonstration project GreenGen also aims to develop carbon capture and storage technologies – not so much with a view of domestic deployment but rather the export potential. For China's advances in coal technology, see: Bram Buijs, *China, Copenhagen and Beyond,* Clingendael Energy Paper, 2009, pp.65-72. Available at: http://www.clingendael.nl/publications/2009/20090900_ciep_report_buijs_china_copenhagen_beyond.pdf ; Richard K. Morse, Varun Rai, Gang He, *Real Drivers of Carbon Capture and Storage in China and Implications for Climate Policy*, Stanford Program on Energy and Sustainable Development, Working Paper no. 88, August 2009. Available at: http://iis-db.stanford.edu/pubs/22621/WP_88_Morse_He_Rai_CCS_in_China.pdf; S. Julio Friedmann, 'Carbon Capture and Green Technology', *Foreign Affairs*, 11 September 2011. Available online at: http://www.foreignaffairs.com/articles/68256/s-julio-friedmann/carbon-capture-and-green-technology.

[53] Wenying Chen, Ruina Xu, 'Clean Coal Technology Development in China', *Energy Policy*, Vol. 38, 2010, pp. 2123-2130.

# 2

## Case Study I: Wind Energy

The history of wind power's growth is often quoted as the exemplary success story of the 'new' renewable energy development in China. As recently as one decade ago, China had only about 350 MW of installed capacity and a domestic wind industry was practically non-existent.

Today, China has emerged as the leading growth market for wind power and due to its explosive growth it has surpassed all other markets in total cumulative size. In the year 2010 its wind power capacity additions of 16.5 GW accounted for 46.1% of all newly installed wind capacity worldwide, ranked it as the world's largest growth market for wind power for the second year in a row.[54] For 2011, Chinese capacity additions are estimated have accounted for almost half of the global market again.[55] As a consequence, China surpassed the United States to become the country with the largest amount of installed wind power capacity base by end of 2010.

Wind power has now emerged as the second largest source of renewable electricity, after hydropower. When looking at the historical development of modern wind power, it was pioneered especially by the United States, Denmark and Germany. The United States was the first to break the 1 GW threshold of installed capacity in 1985, at which time it accounted for 95% of all installed capacity worldwide. Denmark was the second country following suit in the 1980s and beginning of the 1990s, increasing its capacity 20-fold from 27 MW to 539 MW between 1984 and 1994. As of the mid-1990s rapid growth started to take place in several countries: first of all in Germany, which became the leading country for wind power development during that decade, followed by Spain and India, and again just a few years later Italy, United Kingdom, Portugal, France and China. Global installed capacity started increasing exponentially from around 1 GW during the 1980s to reach the 3 GW threshold in 1994, 6 GW by 1996, 10 GW by 1998, 31 GW by 2002, 74 GW by 2006, 120 GW by 2008 and nearly 194.4 GW by the end of 2010 (Figure 4). In the 15-year period between 1995 and 2010, the annual growth rate of the wind energy market has hovered around the 28%.[56]

At the moment, wind power is dominated by onshore installations, which still make up about 98 percent of all installed capacity. However, an expected new field of expansion is offshore wind energy. Some of the countries that have already developed their best onshore wind resources have started to take interest in offshore installations.[57] Especially the United Kingdom, Denmark and Germany have taken leading roles, but France is among several other countries planning to expand rapidly as well.

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54 Global Wind Energy Council (GWEC), *Global Wind Report 2010*, p. 12.
55 Global Wind Energy Council (GWEC), *Global Wind Statistics 2011,* 7 February 2012. Available online at: http://www.gwec.net/fileadmin/images/News/Press/GWEC_-_Global_Wind_Statistics_2011.pdf.
56 Statistics in this section are based upon data from the Earth Policy Institute, 2011. Available online at: http://www.earth-policy.org/data_center/C23. The data for 2010 are taken from: Global Wind Energy Council (GWEC), Wind Report 2010, p. 11.
57 Li Junfeng, Shi Pengfei, Gao Hu, *China Wind Power Outlook 2010*, October 2010.

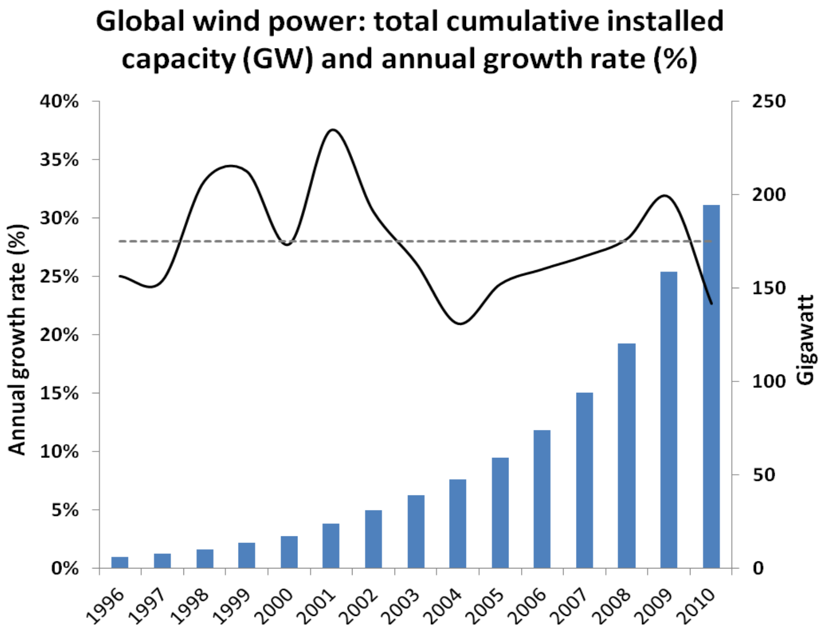


**Figure 4. Global wind power: total cumulative installed capacity and annual year-on-year growth rate.** Source: GWEC, 2011.

China, too, has unveiled ambitious offshore wind expansion plans and – perhaps symbolically – the first offshore wind park outside of Europe was built in China, not the United States.

However, economic and financial difficulties have placed the support mechanisms underpinning the expansion of wind energy under pressure, especially for relatively expansive offshore wind projects. This constraint is mostly felt in Europe and the United States, while at the same time China's role both as a major growth market and as a potential competitor in global markets is becoming increasingly pronounced.

## The Growth of Wind Energy in China

In the ten years leading up to 2010 installed wind power capacity in China increased from 350 MW to 42.3 GW, a more than 100-fold increase.[58] As in Europe and the United States, the main driver for this enormous growth has been the support policies of the government. After some small-scale demonstration projects in the '80s, the former Ministry of Electricity introduced a *Wind Power Industrialization Program* in 1993.[59] As a part of this, grid utilities were ordered to facilitate the connection of wind farms to the grid and purchase all electricity produced by them. Growth remained slow, however, even though there was a system that ensured that the extra costs of the electricity generated by wind energy would be shared across the whole grid.

A real breakthrough towards rapid growth followed in 2003. In that year, the National Development and Reform Commission (NDRC) launched a concession programme for wind farm development with the objectives of: (1) promoting the manufacturing capacity of domestic wind turbines and component industry, and (2) lowering costs by enhancing price competition. Through a bidding process, specific concession projects were allocated to investors and

[58] Li Junfeng et al., *China Wind Power Report 2007*, p. 5.

[59] This regulation was later elaborated upon by the 2005 Renewable Energy Law. Li Junfeng et al., *China Wind Power Report 2007*, p. 5.

developers.[60] More transparent power sector regulation on pricing, cost-sharing, grid connection and other issues created the necessary conditions for large investments in the sector.[61] A secondary objective of this concession phase was to gain insight in what prices would be reasonable for wind farm development, which played a role in determining China's later feed-in tariffs.

All in all, five rounds of concession tendering were held between 2003 and 2007. The concession tenders included a total of 18 projects with a total combined capacity of 3.35 GW.[62] Main investors have been the state-owned power companies. Perhaps surprisingly, these utilities often proposed extremely low bidding prices: for example, in the concession bidding rounds between 2003 and 2006, the contract bidding price was consequently under the average price of feasibility studies on the relevant wind farm locations, hovering between 0.38 RMB/kWh and 0.6 RMB/kWh.[63] The explanation for this phenomenon is that the power companies sought to secure a sufficient portfolio of renewable energy capacity, as the government also announced the introduction of *renewable portfolio standards* (or *mandated market shares*) that would require them to have a fixed amount of renewable energy capacity. The exact targets were set by the *Medium and Long-Term Development Plan for Renewable Energy in China*, which was released in September 2007: for all power producers with a total generating capacity larger than 5 GW, a target of 3 percent of non-hydro renewables capacity by 2010 and 8 percent by 2020.[64]

Second to this concession tendering process, the government stimulated wind farm development through a project-by-project 'government approval' process. Since price competition in the concession tendering was so intense, it was only through this second route that international wind turbine manufacturers found the opportunity to sell their turbines.

A next major step was made by the *Renewable Energy Law* which was approved by China's State Council and National People's Congress in February 2005 and came into force in early 2006. The law placed the obligation on power utilities to purchase power from renewable energy generators, and introduced a national cost-sharing system that determines that the extra costs of renewable power are to be distributed equally over all power consumers by means of an electricity price surcharge.[65] Furthermore, the law established a pricing mechanism with a fixed

[60] On the procedure: '1. (…) The bidder who offers the lowest price wins the bid. In 2005 the criteria were revised so that the electricity price was given 40% of the total weight in deciding the winning bids. This was further reduced to 25% in 2006, and then in 2007 the winning criterion was set as the bid closest to the average bidding price, excluding the highest and lowest bids. 2.The concession period is set at 25 years.' Li Junfeng et al., *China Wind Power Report 2007*, p. 5.

[61] For instance: 'The government promised a fixed price for a specific amount of electricity generated (30,000 full load hours); the grid company is obliged to purchase all the electricity generated by wind power; the difference between the wind power price and the conventional power price is shared among the provincial grids; the grid company is responsible for investment in the construction of transmission lines and the connection between wind farms and the nearest network; (..)', Li Junfeng *et al*., *China Wind Power Report 2007*, p. 7.

[62] CREIA, GWEC and Greenpeace, *China Wind Power Outlook 2010,* October 2010, pp. 44-45.

[63] Li Junfeng et al., *China Wind Power Report 2007*, p. 9.

[64] This should then achieve the goal of increasing the total share of non-hydro renewables to 1 percent of the total power generation by 2010 and 3 percent by 2020. Eric Martinot and Li Junfeng, *Powering China's Development. The Role of Renewable Energy*, Worldwatch Institute, 2007, p. 15.

[65] This is the same system as is used in Germany in their Renewable Energy Law (*Erneuerbare-Energien-Gesetz*; EEG). In Germany the surcharge is set to reach 3.592 eurocent/kWh in 2012 (it was 3.53 ct/kWh in 2010 and 2.047 ct/kWh in 2010). The expectation is that the German surcharge will increase with the years to 5-6 ct/kWh in due time, relative to an average retail consumer electricity price of about 25-26 euro cents/kWh. Germany Energy Blog, '2012 EEG Surcharge Increases Slightly to 3.592 ct/kWh', 14 October 2011. Available online at: http://www.germanenergyblog.de/?p=7526. The Chinese renewable energy surcharge for electricity users stood at 0.004 RMB/kWh (0.047 eurocent/kWh) in 2010 and is expected to

| Year | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 |
|---|---|---|---|---|---|---|---|---|---|---|
| MW | 404 | 470 | 468 | 765 | 1,272 | 2,559 | 5,871 | 12,024 | 25,828 | 44,733 |

**Table 3. Total Installed Capacity of Wind Energy in China, 2001-2010.**
Source: Global Wind Energy Council (GWEC), Global Wind Report 2010, April 2011, p. 31.

premium, or "feed-in tariff", for wind power.[66] Following the introduction of the *Renewable Energy Law*, wind capacity has grown rapidly: by 60 percent in the year the law was passed, followed by four consecutive years up to 2009 in which Chinese installed wind capacity doubled in size each year (Table 3).[67]

The two-track system was superseded in 2009 by a feed-in tariff that divides regions into four different categories depending on general wind resources and which ranges from 0.51 RMB/kWh to 0.61 RMB/kWh. The only exceptions to this feed-in tariff system are the 'wind base' projects and the development of offshore wind energy.[68]

## The Emergence of the Chinese Wind Industry

The enormous expansion of wind energy in China has been accompanied by another trend, namely the emergence of Chinese domestic manufacturers.

Domestic manufacturers of wind power equipment hardly existed in China even a decade ago. At the end of 2000, there were a total of about 10 wind turbine manufacturers in China, of which only five were able to produce turbines larger than 600 kW. Together they held a domestic market share of less than 10 percent.[69] Yet in reaction to the explosive growth of the Chinese wind energy market, a whole field of domestic producers has appeared. At the end of 2009, there were at least 80 Chinese wind turbine manufacturers operating on the Chinese market, and this has led to an extremely competitive market in which consolidation appears inevitable.

As a consequence of rising competition from local firms, the market share in China of foreign or foreign-funded enterprises decreased from 75% to 13% in the time span of just 5 years. By 2009, less than 10 of the 24 foreign enterprises that have been active in the Chinese wind market still remained, of which only Vestas and Gamesa were in the top five of cumulative market share of completed wind turbine systems in China.[70] In the meantime the three major Chinese

increase to 0.006 RMB/kWh (0.070 eurocent/kWh) in 2012. *Shanghai Daily,* 'Clean Power Fee Set to Go Up', 1 April 2011. Available online at: http://www.china.org.cn/business/2011-04/01/content_22274183.htm.

[66] Eric Martinot and Li Junfeng, *Powering China's Development. The Role of Renewable Energy*, Worldwatch Institute, 2007, p. 14.

[67] Global Wind Energy Council (GWEC), *Global Wind Report 2010*, April 2011, p. 31. Available online at: http://www.gwec.net/fileadmin/documents/Publications/Global_Wind_2007_report/GWEC%20Global%20Wind%20Report%202010%20low%20res.pdf.

[68] The tariff is comparable to the government-approved tariffs of the past years in most regions, substantially higher than tariffs granted under concession system. Also higher than tariff paid for coal-fired electricity, making it an attractive investment. Feed-in tariffs apply for the entire operational period of a wind farm. Global Wind Energy Council (GWEC), *Global Wind Energy Outlook 2010*, 2010, p. 24. Available online at: http://www.gwec.net/fileadmin/documents/Publications/GWEO%202010%20final.pdf.

[69] Gardiner, G. 'High Wind in China', *High-Performance Composites*, 1 July 2007. Available online at: http://www.compositesworld.com/articles/high-wind-in-china.aspx (accessed 5 September 2010).

[70] Global Wind Energy Council (GWEC), *Global Wind Energy Outlook 2010*, 2010, p. 37. Available online at: http://www.gwec.net/fileadmin/documents/Publications/GWEO%202010%20final.pdf.

manufacturers (Sinovel, Goldwind and Dongfang) have entered the global top ten in terms of global market share (Figure 5).

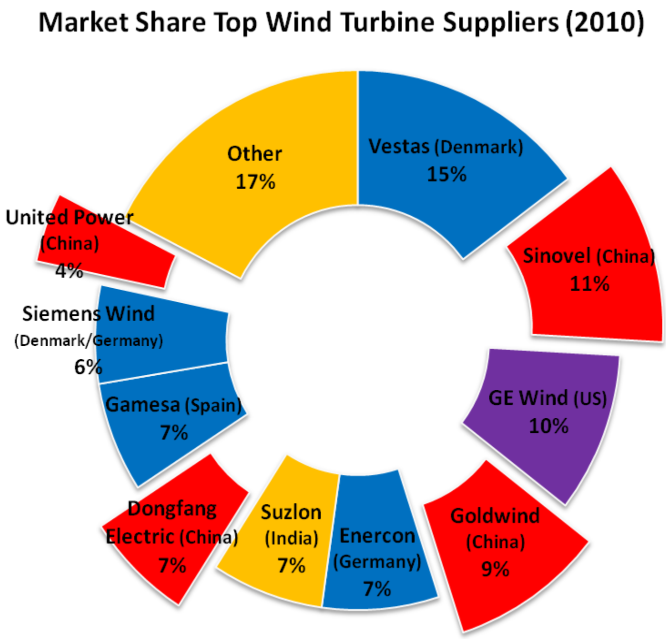


**Figure 5. Market Share Top-10 Global Wind Turbine Suppliers for 2010.**
With Chinese manufacturers highlighted. Source: BTM Consult, 2011.

As in the rest of the world, expansion in market size was accompanied by a steady increase of technological capacities. At the end of 2006, only one-tenth of all installed turbines in China were larger than 1 MW.[71] The domestic turbines still had a rather simple design and were less efficient than larger and more advanced Western turbine models.[72] Yet in 2009 the share of MW-scale wind turbines that were installed in China reached more than 85 percent.[73]

The technological capabilities of the emerging Chinese wind turbine industry have increased in several ways:

- Licensing,
- joint ventures,
- acquisition of foreign companies,
- foreign companies setting up factories in China, and
- government promotion of R&D and innovation.

The first step for Chinese domestic wind turbine manufacturers has been to license foreign technology. For this, they mostly partnered with smaller European wind turbines manufacturers that could offer suitable technology (Box 1). It is important to note that the European companies that licensed their technology to Chinese firms were SMEs not active on the Chinese market,

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[71] Li Junfeng et al., *China Wind Power Report 2007*, p. 5.
[72] For instance, initially Chinese turbines featured fixed-pitch, constant speed control systems as opposed to the more advanced variable-pitch, variable-speed control systems used by Western manufacturers. Gardiner, G. 'High Wind in China', *High-Performance Composites*, 1 July 2007. Available online at: http://www.compositesworld.com/articles/high-wind-in-china.aspx (accessed 5 September 2010).
[73] CREIA, GWEC and Greenpeace, *China Wind Power Outlook 2010,* October 2010, pp. 16.-17.

which is why concerns about IP violations or possible future competition from Chinese firms were less of an obstacle for agreeing on the terms of technology transfer.[74]

### Box 1: Wind Turbine Technology Licensing by Chinese Companies

Purchasing production licenses from Western wind turbine technology companies has been a strategy that has been followed by many Chinese manufacturers, and in fact most of the technology currently being used by Chinese wind turbine manufacturers is identical to (or based upon) European wind turbine technology.

Goldwind, the oldest Chinese domestic manufacturer – and initially the most successful – was founded in 1997 when its parent company Xinjing Wind Energy Co. Ltd. bought a license to produce 600-kW wind turbine from the German firm Jacobs Energie GmbH (later part of REpower Systems AG of Hamburg). It continued with licensing 750-kW turbine technology from REpower in 2002 and purchased a license from Vensys Energiesysteme GmbH (Saarbrücken, Germany) in 2003 for its Vensys 62 1.2 MW turbine. Together with Vensys it set out to develop 2.0 to 2.5 MW turbines. Later on, in 2008, it acquired Vensys, transferring the intellectual property rights of the advanced 2.5 MW direct drive wind turbine that was under development to Goldwind.

German companies Führländer, Aerodyn and REpower have supplied the licenses for the first 750 kW turbines for Goldwind, Sinovel and Dongfang Electrical (DEC). REpower also licensed 600-kW and 750-kW production technology to Zhejiang Yunda Windey (located in Hangzhou City, Zhejiang Province) in 2002, and 1.5 MW wind turbine technology to Sichuan-based Dongfeng in 2005. As for REpower: this German firm has been one of the most prominent wind turbine developers in Europe and was the first company to install a 5 MW wind turbine prototype in 2004. After the French nuclear conglomerate Areva unsuccessfully tried to acquire it, the Indian wind turbine manufacturer Suzlon took a controlling stake in the firm.

In the context of the *China Renewable Energy Scale-up Program* (CRESP), Chinese wind turbine manufacturers cooperated with Western firms to increase their technological capacities. The programme has been developed by the Chinese government in cooperation with the World Bank (WB) and the Global Environment Facility (GEF). Within this programme, Zhejiang Windey developed a 1.5 MW wind turbine supported by the UK wind consultancy Garrad Hassan. The Austrian company Windtec (later acquired by US firm ASMC) has partnered with Sinovel to help it develop its 3 MW turbine and also provided technical support for Dongfang Electric in its development of a 2.5 MW turbine.

The Global Wind Energy Council has estimated that the royalties for the technical transfer licenses paid by the Chinese firms amount to roughly 420 million USD per year.

Sources: Gardiner, G. 'High Wind in China', *High-Performance Composites*, 1 July 2007. Available online at: http://www.compositesworld.com/articles/high-wind-in-china.aspx; *China Renewable Energy Scale-up Program* (CRESP), 'Significant Progress has been made by Wind Turbine Local Manufacturing Projects', updated 17 April 2009. Available online at: http://www.cresp.org.cn/english/content.asp?id=1054; CREIA, GWEC and Greenpeace, *China Wind Power Outlook 2010,* October 2010, pp. 56-57.

[74] Joanna Lewis, "Building a National Wind Turbine Industry: Experiences from China, India and South Korea," *International Journal of Technology and Globalisation,* issue 5 no. ¾, 2011, pp. 281-305. Excerpt available online at: http://www.gispri.or.jp/english/symposiums/images110706/AsstProf_Lewis.pdf.

Joint ventures were pursued in some other cases, although they have generally not been very successful on the Chinese market. In December 2005 the German firm Nordex launched a joint venture with two companies in the Chinese Ningxia province for the production of MW-class turbines.[75] REpower, also from Germany, set up a joint venture in 2006 called REpower North with a Chinese state-owned steel- and machinery-building company and a British wind farm developer.[76] The Spanish wind turbine manufacturer Acciona started a joint-venture with a state-owned aerospace conglomerate (CASC) which was reasonably successful for a few years but sold its stake in 2009 after disagreement over the JV company strategy.

Direct acquisition of foreign companies is another avenue by which intellectual property rights of advanced wind turbine technology are obtained. In 2008 Goldwind acquired 70 percent of the German wind technology developer and turbine manufacturer Vensys, from which it earlier had already licensed technology. In 2009, Hunan-based XEMC bought Darwind, a wind technology firm from the Netherlands that developed a 5 MW direct drive turbine dedicated to offshore use. Some of the ways that have benefited domestic technology development have been strongly encouraged and facilitated by the Chinese government. Establishing a domestic Chinese wind energy industry has been a clear objective of the Chinese government, and various policies have been implemented to support this goal.

- **Government support for domestic wind technology R&D.** For example, specific research into large-scale wind turbines was undertaken in the context of the *Chinese National High-Tech Development Program*, also known as the *863 Program* in the period of the Tenth Five-Year Plan (2001-2005). More recently, funding from the governmental *Special Fund for the Industrialization of Wind Power Equipment* was made available to support the National Offshore Wind Power Technology and Equipment R&D Center which was set up by the Chinese market leader Sinovel.[77]
- **Regulation has helped to create demand for local manufacturers over foreign firms.** The wind farm concession tendering system placed an emphasis on the lowest bidding prices rather than quality and hence favoured the extremely low bids made by Chinese developers in combination with local wind turbine manufacturers. Also, the targets for wind energy deployment are set in terms of installed capacity (gigawatts) rather than generated electricity (gigawatt-hours), which has led to the rapid construction of less expensive domestically manufactured turbines with less regard for whether this would generate the most wind-powered electricity over the whole project lifetime period. Furthermore, the extra stimulus package funding that was made available for wind energy development in the wake of the financial crisis included preferential conditions for domestic products.
- **Localization requirements enabling technology transfer.** The most controversial measure has been the 70 percent local content requirement for all wind power equipment installed in China (measured in terms of value of the components) that was issued by the National Development and Reform Commission in July 2005. Such local content requirements had been used in the past for more specific projects and in particular for the concession programme.[78] Yet this new regulation basically required all international companies that wished to be active in the Chinese market to either form

[75] Gardiner, G. 'High Wind in China', *High-Performance Composites*, 1 July 2007. Available online at: http://www.compositesworld.com/articles/high-wind-in-china.aspx (accessed 5 September 2010).
[76] REpower Press Release, 'REpower signs Joint Venture contract in China', 4 September 2006.
[77] Dewey & LeBoeuf LLP, *China's Promotion of the Renewable Electric Power Equipment Industry*, Report for the US National Foreign Trade Council, March 2010, pp. 20, 32. Available online at: http://www.nftc.org/default/Press%20Release/2010/China%20Renewable%20Energy.pdf.
[78] Dewey & LeBoeuf LLP, *China's Promotion of the Renewable Electric Power Equipment Industry*, Report for the US National Foreign Trade Council, March 2010, pp. 47-75. Available online at: http://www.nftc.org/default/Press%20Release/2010/China%20Renewable%20Energy.pdf.

joint ventures with Chinese partners or set up manufacturing facilities in China, allowing for indirect technology transfer. The latter has been done by almost all the large international players, except a few major own-equipment-manufacturers (OEMs) like Enercon. Market leader Vestas, for instance, established several factories in China including its largest integrated manufacturing centre outside of Denmark (in Tianjin); for recent turbines the localization percentage has exceeded 90 percent.[79] The localization requirement was dropped in January 2010, but by that time the shift towards localization of manufacturing by foreign firms had already been made.[80]

The key result of these policies has been that the international wind turbine manufacturers have been losing market share in the Chinese market, even though their sales have increased in absolute numbers – that is, for the successful ones that have a significant presence in China.[81] Even though the international wind turbine manufacturers in China maintain that they have a significant lead in terms of technology, quality and reliability, this is not changing the trend.

## Future Outlook

Since the impact of the economic and financial crisis is being felt in Europe and the US, growth projections have been reduced somewhat.[82] While the binding renewable energy targets for 2020 in Europe give some certainty for further growth, the ambitious yet expensive offshore programmes that have been presented might still be reconsidered.

In the US no progress has been made on a federal all-encompassing energy and climate bill that could drive wind energy growth. Instead, an important regulation offering Production Tax Credits for wind farm developers will expire at the end of 2012. Combined with the extremely fierce debate on budget cuts, there is a real chance that financial support for renewable energy development will be scaled back in the US.[83] China is expected to continue to be the largest growth market for wind energy for the foreseeable future, even though it is also facing severe challenges. In the course of the past years it has spectacularly exceeded its targets. As recently as 2007, the Chinese government had set official targets for installed wind capacity of 5 GW by 2010 and 30 GW by 2020. Yet the 5 GW mark was surpassed in 2007 and the 30 GW mark in the course of 2010 – eleven years before schedule.

Consequently, the targets for Chinese wind capacity expansion have been revised upwards several times. As of September 2011, the target for wind energy in 2015 had been raised to 100 GW, of which offshore wind is expected to account for 5 GW.[84] For 2020, the target for offshore wind has been set at 30 GW as part of a total target of 200 GW. The growth onshore will take place for a large part in designated Wind Bases which should deliver 138 GW of wind power capacity by 2020. The offshore growth will be developed in several tendering phases, similar to

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[79] Presentation by Peter Brun, Senior Vice-President Group Government Relations, Vestas Wind System A/S, 21 October 2009, at the China International Energy Forum 2009.

[80] Dewey & LeBoeuf LLP, *China's Promotion of the Renewable Electric Power Equipment Industry*, Report for the US National Foreign Trade Council, March 2010, pp. 47-75. Available online at: http://www.nftc.org/default/Press%20Release/2010/China%20Renewable%20Energy.pdf.

[81] This is illustrated, for instance, in the HSBC flashnote on Gamesa. HSBC, 'Gamesa Corp', 16 September 2010. Available online at: http://www.research.hsbc.com/midas/Res/RDV?p=pdf&$sessionid$=lK9_291sxm2SHqSmhz9KFMq&key=RsxW82iAzE&n=278268.PDF.

[82] See, for instance: HSBC, 'Becalmed? Is it all over for the global wind markets?', August 2010. Available online at: http://www.research.hsbc.com/midas/Res/RDV?p=pdf&key=mMI3Utw1Ir&n=276303.PDF.

[83] Felicity Carus, 'Wind Rush: Clean Revolution Changes Global Power Industry Dynamics', AOL Energy, 14 November 2011. Available online at: http://energy.aol.com/2011/11/14/wind-rush-clean-revolution-changes-global-power-industry-dynami/.

[84] The Climate Group, 'China Amps Up Renewables Targets', 1 September 2011. Available online at: http://www.theclimategroup.org/our-news/news/2011/9/1/china-amps-up-clean-energy-targets/.

the first onshore concession projects; in fact, there are similar concerns that developers are bidding prices that are too low to be able to develop the wind farms profitably.[85]

However, the Chinese wind power market is experiencing severe problems due to quality and grid integration issues. In fact, the government has stepped in to address quality problems and to prevent the market from overheating. New standards and certification requirements have been issued, while project approval has become stricter. Planning and permitting has become more difficult even as project financing has become harder to obtain. As a consequence, analysts expect China's growth to slow, and a situation of major manufacturing overcapacity is becoming more serious. As a result, consolidation in the Chinese wind energy sector is taking place, where 'excessive' competition is leading to very intense pressure on prices. According to some analysts, turbine prices have dropped to levels as low as 3.5 million RMB (€0.41 million) per MW from 6 million RMB (€0.71 million) per kW in 2008.[86] Since turbines are major cost component of the overall project (about 70 percent of total cost), the export potential for competitively priced Chinese wind turbines could be very significant. This would most certainly also hold for those markets other than Europe and the United States, which are also starting to develop their wind energy potential.

European market leaders such as Vestas are closely eyeing the price of imported Chinese turbines – or what they term "Asia plus freight": as soon as European manufacturing loses out in the cost competition against this benchmark it will have a problem. Already now, high manufacturing costs have led Vestas to close four production facilities in Denmark and Sweden, cutting 3,000 jobs. The importance of labour costs versus transport costs can be inferred from the remark by Vestas CEO Ditlev Engel that it is actually cheaper to produce turbines for Scandinavia in Spain and ship them, than to produce them in Denmark or Sweden.[87]

From a technology side, the Chinese companies are clearly catching up with Western firms. Although there might still be quality and reliability issues, major producers such as Sinovel, Goldwind and Dongfang Electric are developing large-scale turbines of 3 MW, 5 MW or more.[88] Regarding offshore wind technology, all major Chinese companies are investing heavily in R&D and the development of their capabilities.[89] Whereas there are new technological developments taking place that offer the chance for Western companies to remain ahead in terms of technology, competition is likely to become fiercer, as existing standardized models are now being produced in China 'on the cheap'.[90]

[85] For the first wind farm off the coast of Jiangsu province, tendering led to bids averaging less than 0.8 RMB per kWh. This is extremely low considering that the general view holds that offshore wind is approximately three times as expensive as onshore wind for the benchmark price is a bit over 0.5 RMB per kWh. *Caixin Magazine*, 'Competition Wavers in Offshore Wind Contracts', 19 October 2010. Available online at: http://english.caixin.cn/2010-10-19/100190437.html.

[86] *Caixin Magazine*, 'Ill Winds Blowing for Wind Turbine Industry', 28 April 2011. Available online at: http://english.caixin.cn/2011-04-28/100253640.html. These turbine prices levels are confirmed by Caitlin Pollock, China wind analyst at IHS Emerging Energy Research, in: Felicity Carus, 'Wind Rush: Clean Revolution Changes Global Power Industry Dynamics', AOL Energy, 14 November 2011. Available online at: http://energy.aol.com/2011/11/14/wind-rush-clean-revolution-changes-global-power-industry-dynami/.

[87] *Financial Times,* 'China Wind Turbines Turn as Europe Cuts Hit', 5 January 2011; *Financial Times,* 'China Set To Challenge Global Wind Industry', 28 August 2011.

[88] CREIA, GWEC and Greenpeace, *China Wind Power Outlook 2010,* October 2010, pp. 34-38.

[89] For instance, Sinovel has developed a 3 MW turbine that was installed at the first Chinese offshore wind farm near Shanghai. It is now working on a 5 MW turbine. Goldwind has set up a offshore wind power industrial base in Dafeng, Jiangsu province. *Caixin Magazine*, '海上风电开发升温 风电巨头各显神通' [Offshore Wind Power Development is Heating Up – Wind Power Giants All Show Their Prowess], 23 February 2010. Available online at: http://www.china5e.com/show.php?contentid=78187.

[90] Some of the new technologies that are being developed are aimed to improve reliability and decrease maintenance costs (for instance by direct drive/permanent magnet generators that use fewer parts and no

As for international disputes surrounding China's wind power sector: this had been relatively subdued until recently. Following the WTO case which was instigated by the US Trade Representative, Chinese subsidies for wind power were cancelled.[91] However, a new case on intellectual property rights has come up, as the US firm AMSC (American Superconductor) is suing Sinovel in China over alleged intellectual property theft. AMSC provided electrical components for Sinovel's wind turbines and had been a major trading partner.[92] The international export of wind turbines from China has been extremely limited to date. In 2009, four Chinese firms exported a total of 20 turbines to four different countries (the US, Thailand, the UK and India) with a total capacity of 28.75 MW.[93]

However, more exports are coming up. The largest Chinese wind turbine firms, such as Sinovel, Goldwind and Dongfang, have signed deals with US, Greece, Brazil, Canada and South Africa for exporting turbines. Although the total amount of exported wind power capacity is still small, the expectation is that this will increase in future. This will especially be the case since the Chinese internal market is slowing somewhat and regulation has become more strict in order to address the quality and grid connection problems that have been encountered.[94] The severe production overcapacity (estimated at approximately 5 GW) and a cut-throat price war in the domestic market is a strong incentive for Chinese manufacturers to seek overseas exports in order to survive.[95] One key issue for allowing their growth in Europe, however, will be to establish a track record for quality and reliability, especially in the offshore wind sector, where extremely high quality standards are critical.[96]

A final interesting new development is that Chinese wind energy firms are starting to use financing from Chinese banks in order to participate in overseas wind farm projects – an element that can give a distinct advantage in times when funding for investment is in short supply. It is reported that Sinovel and Goldwind have secured €8.7 billion from the China Development Bank for overseas expansion funding.[97]

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gearbox) and extract more energy from low-to-medium wind sites (for instance by featuring a much larger swept area compared to earlier turbines of the same size). Further progress is being made in the field of aerodynamics, drive trains, intelligent operation and cost reduction. Chris Varrone, 'Innovation in Wind Development', *Renewable Energy Focus*, 20 June 2011. Available online at: http://www.renewableenergyfocus.com/view/15802/innovation-in-wind-development/.

[91] *Caixin Magazine*, 'Analysts Say End to Subsidies Won't Jolt Wind Industry', 9 June 2011.

[92] Leslie Hook, 'AMSC to sue Sinovel in Beijing', 4 November 2011. Available online at: http://www.ft.com/intl/cms/s/0/b5e190c8-05db-11e1-a079-00144feabdc0.html#axzz1eX81M9NK.

[93] Specifically the following exports were made: Sinovel exported 10 turbines (model SL1500/82) to India, Sewind exported 3 turbines to the UK and 2 to Thailand of the W1250/64 model. Goldwind exported 3 GW77/1500 turbines to the USA; and New United (Changqian Xinyu) exported one SD77/1500 turbine to the US and a second one to Thailand. CREIA, GWEC and Greenpeace, *China Wind Power Outlook 2010,* October 2010, p. 35. Available online at: http://www.gwec.net/fileadmin/documents/test2/wind%20report0919.pdf.

[94] China Energy Network (China5e), " '过热'后是 '过剩'风电产业遭遇诸多绊脚石" [After "Overheating" Comes "Excess": The Wind Power Industry Encounters a Number of Stumbling Blocks], 5 December 2011. Available online at: http://www.china5e.com/show.php?contentid=201628.

[95] China Daily, 'Wind Turbine Makers See Fresh Breeze Abroad', 27 May 2011. Available online at: http://europe.chinadaily.com.cn/business/2011-05/27/content_12591920.htm.

[96] Daniel Yu, 'Chinese Wind Turbine Manufacturers' Global Expansion: The Dream and The Reality', 9 May 2010. Available online at: https://www.gplus.com/utilities/insight/chinese-wind-turbine-manufacturers-global-expansion-the-dream-and-the-reality-48260.

[97] Felicity Carus, 'Wind Rush: Asian Typhoon Hits Debt-Crisis Europe', AOL Energy, 15 November 2011. Available online at: http://energy.aol.com/2011/11/15/wind-rush-asian-typhoon-hits-debt-crisis-europe/.

# 3

## Case Study II: Solar PV

Of all renewable energy sources solar energy is seen as the one holding the largest promise, as the potential use of its energy would even exceed the combined estimated global potential for hydro-energy, wind power and biomass. The energy content of the solar radiation falling upon the world's continents per year is estimated to be equivalent to 1800 times the global primary energy consumption, illustrating the fact that capturing and converting a minimal fraction of this total would be sufficient to meet the world's energy demand.[98] Although there are various technologies that utilize solar energy, we will focus here on solar photovoltaics (PV) that convert sunlight directly into electricity by means of photovoltaic materials.[99]

From the first real solar photovoltaic cell that was invented in 1954 and the first niche applications in which solar panels provided electricity to satellites, solar photovoltaic energy generation has come a long way. Until very recently, high costs had prohibited wide-spread deployment, and for a long time solar energy remained limited to niche markets where the extremely high costs were acceptable. After many decades of gradual technological improvements and only limited deployment, however, the last couple of years have seen a dramatic change in both the scale and economics of solar energy. The sector has been experiencing a boom in production and is in the process of becoming a different industry with a different scale.

Global installed solar PV capacity stood at circa 100 MW in 1992 and by 2000 had grown to 800 MW.[100] Yet from 2000 onwards, solar PV has gone through a phase of exponential growth (as indicated by Figure 6). Annual growth during the decade 2000-2010 stood at an average of about 40 percent. Cumulative installed capacity surpassed the 2 GW threshold in 2002, quadrupled in 5 years' time to 9.4 GW by 2007 and now stands at 39.5 GW, with almost 16.6 GW having been installed in 2010 alone.[101] Estimates for newly installed capacity in the year 2011 exceed 23GW.[102]

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[98] Nitsch, F., 'Technologische und energiewirtschaftliche Perspektiven erneurerbarer Energien, Deutsches Zentrum für Luft und Raumfahrt', 2007. Cited in presentation Teun Burgers and Jan Bultman (ECN Solar Energy), 'Solar Electricity in China' at *'China: Leading the Global Energy Transition?'*, Clingendael Energy Conference, 18 November 2009. Available online at: http://www.clingendael.nl/ciep/events/20091118/091118_clingendael_bultmanburgers.pdf.

[99] Other technologies include: concentrated solar power (CSP) and solar heating/ solar hot water). In the solar hot water collectors, China is a world leader, accounting for 70 percent of global capacity. REN21, *Renewables 2010 Global Status Report,* 2010, p. 10.

[100] IEA, *Technology Roadmap – Solar Photovoltaic Energy*, 2010, p. 6. Available at: http://www.iea.org/papers/2010/pv_roadmap.pdf.

[101] European Photovoltaic Industry Association, *Global Market Outlook for Photovoltaics until 2015,* May 2011, p.8. Figures do not match exactly with installed capacity figures by IEA and Earth Policy Institute.

[102] Personal communication Maarten Kwik, Roth & Rau, Hong Kong, January 2012.

Apart from rooftop solar installations, which can be purchased by individual consumers, and the deployment of solar energy off-grid in remote areas (where it often is a cost-competitive option), for the first time large on-grid solar farms have been built in various countries around the world. The largest solar PV farms are approaching 100 MW in size, still small compared to conventional power plants but illustrating the enormous up-scaling that the solar PV industry has gone through, given that the total global installed capacity of solar photovoltaics just two decades ago was in the order of a few hundred megawatts. Some of the larger solar farm installations can be found in Germany, Spain, Italy, Canada and the United States.[103]

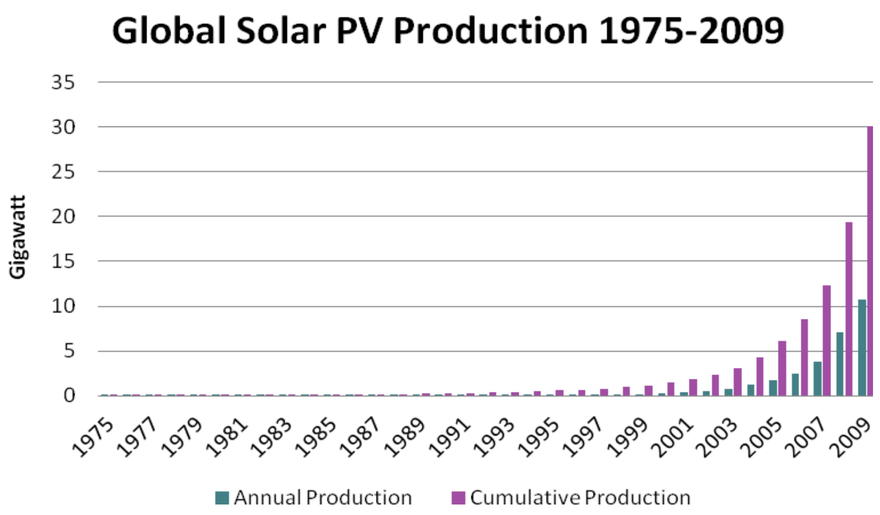


**Figure 6. Solar PV Annual and Cumulative Production Growth, 1975-2009.**
Source: Earth Policy Institute, 2011 (based upon various sources). Available online at: http://www.earth-policy.org/datacenter/xls/book_wote_energy_solar.xls.

In fact, three distinctive markets for solar PV have emerged, apart from off-grid usage: (1) residential PV systems, where investors are private customers that install (rooftop) solar panels for their own use; (2) commercial PV, where companies, factory owners or public authorities install either roof-mounted or building-integrated PV systems (BIPV) of up to a few tens of MW[104]; and (3) 'utility-scale' plants, such as discussed above that are subject to the same regulation as the construction of power plants.[105]

As Figure 7 shows, the regional distribution of solar PV is still very concentrated, since Europe has been the leading force behind its deployment. Europe's share of global installed capacity

[103] The largest solar PV plant as of April 2011 was the Sarnia Solar Project in the Canadian state of Ontario, with 97 MWp capacity (installed in September 2010). Other large PV plants are located for instance in Italy: Monalto di Castro (84 MW) and San Bellino (71 MW). In Germany, the largest plant Finsterwalde I-III totals 80 MW of capacity. Renewables Insight (RENI), *PV Power Plants 2011 – Industry Guide*, 2011, p. 8. Also see: *PV Resources,* 'Large-Scale Photovoltaic Power Plants, Ranking 1-50', updated 27 October 2011. Available online at: http://www.pvresources.com/PVPowerPlants/Top50.aspx.
[104] For examples of large roof-mounted PV and building integrated PV systems, see: http://www.pvresources.com/PVPowerPlants/LargestPVRoofs.aspx and http://www.pvresources.com/BIPV.aspx.
[105] Renewables Insight (RENI), *PV Power Plants 2011 – Industry Guide*, 2011, p. 9. The residential sector is still by far the largest (as of 2010) with an estimated market share of more than 60 percent. IEA, *Technology Roadmap – Solar Photovoltaic Energy*, 2010, p. 17.

increased to 75 percent in 2010, with Germany accounting for 43.5 percent of the global total. As for market growth in 2010, this dominance was only further accentuated. Of the 16.6 GW that was newly installed, more than 13 GW was installed in Europe, while the rest of the world accounted for only a little over 3 GW. Numbers two and three in terms of installed capacity, Japan (3.6 GW) and the United States (2.5 GW), are quite some distance behind, although both installed nearly 1 GW in 2010.[106]

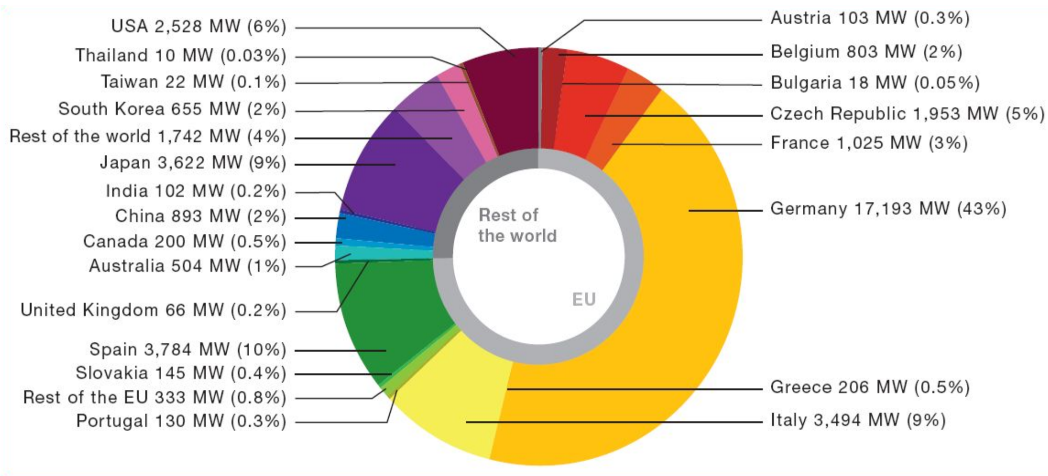


**Figure 7. Global Cumulative Solar PV Installed Capacity per Country (MW, %).**
Source: European Photovoltaic Industry Association, Global Market Outlook for Photovoltaics through 2015, May 2011, p.28, Figure 22.

## Global Technology Developments

Technology-wise the solar PV industry is extremely dynamic. Still a technology that is very much under development, there are several competing technologies on the market and a multitude of even more innovative technologies that are being developed. Two key factors for all different solar photovoltaic systems are: (1) the cell and module efficiency (i.e., the sunlight conversion rate into electric power; this will determine the potential output) and (2) their cost. The efficiency combined with other factors (temperature sensitivity, lifetime, etc.) will determine the power output of the solar panel during its lifetime. Combined with the cost of the solar PV module this in turn will determine its economic competitiveness relative to other electricity sources.

When looking at solar PV conversion efficiency rates there is still a wide gap between efficiency levels that have been achieved in controlled laboratory conditions and those of solar PV modules that are commercially available, indicating the potential for further improvement. Already the high-end efficiency rates of modules that are commercially available have increased significantly, while at the same time costs have decreased. We list several different technologies and their properties in Table 4.

As can be seen from the table, the ‘traditional’ crystalline silicon wafer-based solar panels are still by far the most dominant, having a combined market share of more than 85 percent. Yet both incremental and radical improvements regarding the concept, technology, used materials and production processes are being investigated.

[106] European Photovoltaic Industry Association, *Global Market Outlook for Photovoltaics Until 2015,* May 2011, p.4.

| Photovoltaic technologies | | | | | | | [*] |
|---|---|---|---|---|---|---|---|
| Technology | **Crystalline wafer based** (single-junction solar cells based on silicon wafers) | | **Thin Film** (single-junction) | | | **Multi-junction** | |
| | Monocrystal-line/ single crystal (c-Si) | Multicryst. silicon (mc-Si) | Amorphous silicon (a-Si) | Cadmium telluride (CdTe) | CI(G)S/ CuIn (Ga)$Se_2$ | | |
| Cell techno-logy shares (in 2007) | 42,2% | 45,2% | 5,2% | 4,7% | 0,5% | | [1] [2] |
| Cell Efficiency (at STC) | 16-19% | 14-15% | 5-7% | 8-11% | 7-11% | 49-51% | [2] [3] |
| Module Efficiency | 13-17% | 12-14% | | | | | |
| Module Efficiency** (laboratory) | 22,9% ± 0,6% | 15,5% ± 0,4% | 10,4% ± 0,5% | 10,9% ± 0,5% | 13,5% ± 0,7% | 55,9% | [4] [5] |

**Table 4. Photovoltaic technologies, with technology market shares and cell and module efficiencies.** Source: Climate Policy Initiative, *Survey of Photovoltaic Industry and Policy in Germany and China*, March 2011, p. 11. Underlying data: various sources, mostly dated 2007. Meanwhile cell and module efficiencies have improved.

For crystalline wafer-panels the basic processing steps along the value chain are the refining and production of silicon into highly purified (solar-grade) poly-silicon, cutting wafers from silicon ingots, making solar cells out of the wafers and then making the modules (solar panels) by interconnecting solar cells. The main advantage of crystalline wafer-based solar PV is the high efficiency level that is achieved per cell and module. However, they require a high purity grade of silicon (which is both energy-intensive and expensive to produce[107]) and use a lot more silicon per module than the second solar PV technology which has a significant market share at the moment: thin-film solar PV.

For thin-film solar PV other production techniques are used which are less costly, use less photovoltaic feedstock material and can be more easily adapted to mass production. In the thin-film production process thin layers of photovoltaic material (thin films) are deposited on another material, the substrate. They are typically 100 times thinner than Si wafers and are deposited on low-cost substrates such as glass, metal foils and plastics. Various photovoltaic semi-conducting materials are used for this purpose:

- Amorphous silicon (a-Si),
- Cadmium telluride (CdTe), and
- Copper-Indium (di-)Selenide and Copper-Indium-Gallium-Selenide (CIS/CIGS, or CuIn(Ga)$Se_2$).

[107] Given the high costs of (crystalline) solar-grade poly-silicon production, a lot of research is being dedicated to improving this process. The three main techniques current in use for poly-silicon production with their respective market share as of 2008 are: Siemens process (chemical deposition) (78%), Fluidized Bed Reactor (FBR) process (resulting in granular silicon) (16%), Upgraded MG-Si (UMG-Si) processes (5-6%). US Department of Energy, Energy Efficiency & Renewable Energy, *2008 Solar Technologies Market Report*, January 2010, pp. 30-32.

The cheaper production and feedstock costs have translated into low prices per Watt-peak of thin-film modules, such as those introduced to the market by the US firm First Solar. However, disadvantages are the lower efficiency levels (and hence higher surface area requirements and higher installation costs to reach the same amount of output compared to crystalline wafer-based modules), the potential scarcity of some input materials (e.g. indium and tellurium) and health hazards associated with some of them (e.g. cadmium).[108]

Which technologies will be the most successful in the longer run is still an open question.

For a period of several years, poly-silicon production was unable to keep up with demand that followed from the extremely rapid growth of the solar PV market. Refining capacity (converting silicon-dioxide into high-grade poly-silicon) proved to be a bottleneck, and spot prices for solar-grade poly-silicon increased from about $25/kg to more than $500/kg between 2003 and 2008.[109] As a result, prices of crystalline silicon panels increased and thin-film technologies became more cost-competitive, increasing their global market share from 5% to 14% in the same period (2003-2008).[110]

As a result of this price pressure, poly-silicon wafer (and cell) manufacturers were forced to make huge improvements in their poly-silicon usage per wafer to cut costs and decreased this ratio by circa 20 percent, from around 8 grams to 6.5 grams per Watt-peak ($g/W_p$)[111]. Since poly-silicon remains an important price component of the overall crystalline solar panel (even given lower p-Si prices), these improvements have contributed permanently to a decrease in the price of solar panels.[112]

Much research is being conducted toward even more experimental solar PV technologies. These include organic cells, dye-sensitized cells (that can be painted on surfaces), and nanotechnology that is being applied to solar PV cells.[113] Other research focuses on reducing costs in solar-grade poly-silicon production through other production methods and the improvement of existing techniques.

In laboratories, the highest efficiency levels so far have been reached using so-called multi-junction cells: here different solar cells are stacked on top of each other, ensuring that the entire

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[108] Climate Policy Initiative, *Survey of Photovoltaic Industry and Policy in Germany and China*, March 2011, p. 11. Underlying data: various sources.

[109] Nasdaq, Trefis Team, "Increase in Polysilicon Prices Could Hinder SunPower's Profitability", 2 February 2011. Available online at: http://community.nasdaq.com/News/2011-02/increase-in-polysilicon-prices-could-hinder-sunpowers-profitability.aspx?storyid=55973.

[110] In 2008 this 14% was divided into 5% a-Si, 8% CdTe, 1% other. First Solar is working mainly with CdTe. Overall CAGR between 1998 and 2008 was 86% for the combined thin-film technologies. US Department of Energy, Energy Efficiency & Renewable Energy, *2008 Solar Technologies Market Report*, January 2010, p. 24.

[111] '[W]hen p-Si was in short supply the industry aggressively drove p-Si usage efficiency (g/Wp) lower; great efforts were expended to trim wafer thickness, reduce kerf losses, and introduce alternative silicon purification techniques (e.g. upgraded metallurgical grade (UMG) silicon). Some wafer manufacturers drove thinner wafers, accepting yield loss due to breakage as it was offset by the exorbitant cost of polysilicon.' Deutsche Bank, *Solar Photovoltaic Industry 2010 Global Outlook: Deja Vu?*, 8 February 2010, pp. 12, 15. Available online at:
http://65.181.148.190/renewableenergyinfo/includes/resource-files/solar%20pv%20outlook%20fitt_8%20feb%2010_pdf.pdf

[112] Poly-silicon costs accounted for more than half of the total solar module cost in 2Q 2008, according to Deutsche Bank. In the meanwhile spot prices for poly-silicon have fallen to around USD 30/kg given substantial overcapacity as of January 2012.

[113] Solar PV patents in the field of organic/polyester, CI(G)S and nanotechnology have seen an especially rapid growth since 2000. Chatham House, *Who Owns Our Low-carbon Future?*, September 2009, p. 26.

solar spectrum can utilized. These multi-junction cells are then combined with concentration optics (e.g. adding lenses or a moving frame that mirrors additional sunlight into the cell; these methods are called *concentrating solar photovoltaics*[114]) to reach cell efficiencies exceeding 40 percent, with maximum efficiencies between 55 and 69 percent being expected (Figure 8).[115] Yet for the moment prohibitively high production costs are keeping these cells from being commercialized.

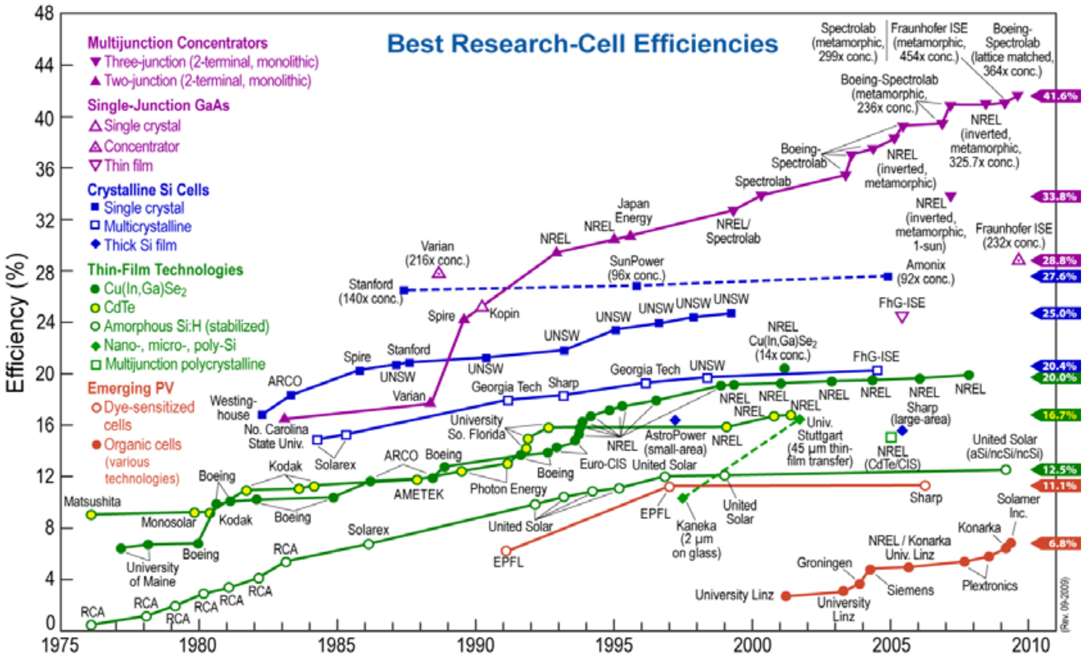


**Figure 8. Best Solar PV Research-Cell Efficiencies 1975-2009.** Image: US Department of Energy, Energy Efficiency & Renewable Energy, *2008 Solar Technologies Market Report*, January 2010, p. 59 (Figure 3.6). Source: Kazmerski, 2009.

## The Emergence of the Chinese Solar PV Industry

China did not play a significant role in solar PV in research, development, manufacturing or deployment up until a decade ago. However, since global PV deployment started taking off, China has been the most successful in capturing an increasing large share of this rapidly growing market. In the course of just a few years' time, it has managed to become the major producer of solar panels worldwide, its market share in terms of solar PV production growing from about 1 percent in 2001 to more than 50 percent in 2010.[116]

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[114] Kevin Bulls, 'Cheap, Superefficient Solar', MIT Technology Review, 9 November 2006. Available online at: http://www.technologyreview.com/energy/17774/.

[115] Climate Policy Initiative, *Survery of Photovoltaic Industry and Policy in Germany and China*, March 2011, pp. 11-12. Available online at: http://www.climatepolicyinitiative.org/files/attachments/112.pdf.

[116] US Department of Energy, Energy Efficiency & Renewable Energy, *2008 Solar Technologies Market Report*, January 2010, p. 16; European Photovoltaic Industry Association, *Global Market Outlook for Photovoltaics until 2015,* May 2011, p.36.

Two elements have been key to the success of Chinese firms in the global PV industry: their unrivalled price-competitiveness and ability to quickly scale up production.

Many Chinese solar PV firms have chosen to use existing standardized technology and manufacturing processes but deploy all kinds of cost-cutting measures. For instance, some firms have bought 'best of breed' equipment of each process step while in some cases replacing automation equipment by (cheap) labour, which decreased both overall costs and up-front capital investment costs.

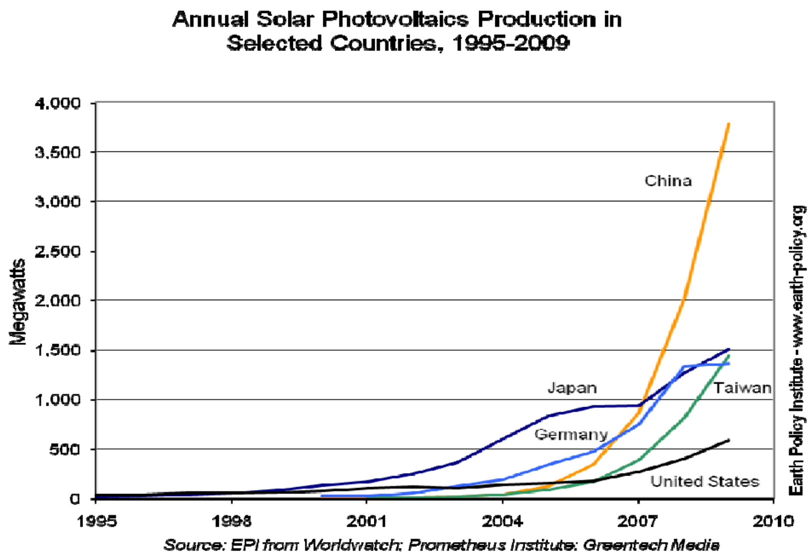


**Figure 9. Annual solar PV production capacity in selected countries, 1995-2009.**
Source: Earth Policy Institute (data collected from various sources). Available online at: http://www.earth-policy.org/datacenter/xls/book_wote_energy_solar.xls.

Most of the firms have focused on producing modules using crystalline wafer-based silicon cells, the dominant type in the market.[117] For such modules the advantages of cheaper labour and less overhead and electricity costs is estimated to yield them an advantage of a 30 percent lower price than US-manufactured modules.[118] Besides this, the scale these companies currently have provides them with purchasing power towards suppliers, resulting in additional cost benefits.

Some of the more well-known Chinese firms that have followed this strategy are Yingli Green Energy, Trina Solar and Suntech. To increase the quality of their modules and cell efficiencies, these companies have also engaged in licensing agreements with international firms and institutes. Yingli, for instance, is collaborating with the Energy Research Center of the Netherlands (ECN) in developing new highly efficient solar cells, which it has successfully

[117] A few Chinese companies have invested in thin-film technology processes. For thin-film solar PV production, turnkey manufacturing equipment is available from a number of Western suppliers, such as Oerlikon, Ulvac Technologies and Applied Materials. Boston Consulting Group (BCG), Sunrise in the East: China's Advance in Solar PV—and the Competitive Implications for the Industry, December 2010, p. 4.
[118] Boston Consulting Group (BCG), Sunrise in the East: China's Advance in Solar PV—and the Competitive Implications for the Industry, December 2010, p. 5.

introduced to the market. [119] Suntech, the largest Chinese producer, has invested significantly in R&D efforts in collaboration with the University of New South Wales in Australia, leading to high efficiency modules that are still very competitively priced.

A second reason for the success of the Chinese solar PV firms has been their ability to seize the opportunity and pursue rapid growth strategies, scaling up faster than many international competitors, partly due to the strong support of state and local governments (by means of preferential loans, factory sites and subsidized equipment). For instance, it took Yingli and Suntech only three and four years, respectively, to increase annual production capacity from 50 $MW_p$ to 500 $MW_p$.[120] Meanwhile these companies have both passed the 1 GW production capacity threshold. Daring investments in the large-scale expansion of production capacity paid off during the growth years; the question now is how the companies will fare in the current period of overcapacity.

Since global solar PV development is still dependent upon government support such as feed-in tariffs, the market remains policy-driven and thus subject to political developments. On the other hand, earlier poly-silicon shortages and fierce price competition have been key challenges to the success of solar PV firms. To guard against changes in their business environment, the largest Chinese manufacturers have also pursued vertical integration along the value chain, investing in production facilities for poly-silicon, wafer-cutting, and module manufacturing and sales. Trina Solar, for instance, now manufactures its own ingots, wafers, cells and modules and installs its own projects.[121]

## Impact of the Economic Crisis and Developing the Chinese Market

The solar PV industry is facing large challenges, as the economic and financial crisis is affecting renewable energy support schemes in some countries. Especially changes of support schemes in Europe, by far the largest market for solar PV, have been affecting the exports of the Chinese solar PV industry.

Suntech, one of China's global leaders in solar PV production, is one of the companies that have run into trouble. Its rapid expansion and ability to capture an increasingly large share of the global PV market was based in a large part on securing sufficient poly-silicon to be able to ramp up production. When demand and poly-silicon prices collapsed toward the end of 2008, it had already agreed to high prices for shipments of poly-silicon, which brought it into financial difficulties. However, although it had to lay off 10 percent of its staff at the beginning of 2009 and adjust its plans, it also received financial support from Chinese banks and managed to weather the difficult period.[122]

The Chinese government, however, has indicated strong support for the solar PV industry, which it considers to be a strategic sector for the country's further development. In 2010, both Suntech

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[119] Yingli Green and Energy Research Center of the Netherlands (ECN) jointly developed a 'N-type Metal Wrap Through (N-MWT)' PV cell and module with laboratory efficiency levels of 19.7% and 17.6%. Yingli Solar Press Release, 'Yingli Green Energy, ECN and Amtech Join Efforts to Develop N-type MWT High Efficiency PV Cell and Module', 7 September 2011.

[120] Trina Solar posted a revenue of more than US$840 million in 2009 with an operating margin of 16 percent. PRTM, *2010 Photovoltaic Sustainable Growth Index. A New Competitive Environment for PV Companies*, 2010, p. 12.

[121] PRTM, *2010 Photovoltaic Sustainable Growth Index. A New Competitive Environment for PV Companies*, 2010, p. 6.

[122] *Caijing Magazine [财经]*, 'Cloudy Forecast for China's Solar Pacesetter', 6 March 2009. Available online at: http://english.caijing.com.cn/2009-03-06/110114049.html; *Caijing Magazine [财经]*, '裁员　无锡尚德生产线停转一半10%'[Suntech's Production Scaled Back to Half Capacity and 10% Layed Off], 23 January 2009. Available online at: http://www.caijing.com.cn/2009-01-23/110050935.html.

and Trina Solar signed large loan agreements with the China Development Bank.[123] In total, loan guarantees worth US$32.5 billion were offered to 10 domestic manufacturers including LDK Solar, Yingli Green Energy and Suntech.[124] Moreover, in October 2010, the State Council issued a directive on "the acceleration and development of new strategic industries", which consisted of a package of fiscal and financial measures aimed at supporting a set of selected industries including solar PV.[125]

A second development, illustrative of China's strategic support for its renewable energy industry, is that China has accelerated the development of its own solar PV market in order to support its domestic industry. As for solar energy resources in China, surveys have shown that most promising resources are located inland but the total irradiation is reasonably good, ranging from 1050-2450 kWh per $m^2$, with more than 96% of land area having an irradiation level of over 1050 kWh per $m^2$.[126] Up until recently however, the very high costs associated with domestic solar PV deployment and the abundance of growing export markets gave China little incentive to start developing solar PV. Although plans to develop domestic solar PV further already existed, for a while these plans were not very ambitious (the 2007 *Medium and Long-Term Renewable Energy Development Plan* mentions a target for 2020 of 1.8 GW for solar PV) and more than 90 percent of solar panels were manufactured for export markets. Yet both the rapid cost reductions and the dire position of domestic solar PV firms have created an incentive for China to speed up its domestic deployment.

At the end of 2008, total installed PV capacity in China stood at 150 MW.[127] Of this, about 55 percent was off-grid, as most solar PV deployment up to 2009 had been focused on remote and rural areas where it supported the country's broader rural electrification programme.

Yet since the crisis, government policy on solar PV has started to shift. In 2009, the Chinese government initiated the *Golden Sun* programme, aimed at installing more than 500 MW of solar PV modules and demonstrating key technologies. Both PV deployment at commercial buildings, off-grid usage and large-scale on-grid PV projects are being supported in this programme, with subsidies being awarded through competitive tendering.

In a similar manner as that for wind power, competitive tendering is also used to choose the developers for large solar PV farm projects, and the experience of these tendering projects has been used to determine suitable feed-in tariffs. This started in earnest in 2009, with the first phase of a solar PV farm at Dunhuang in Gansu province.[128] An initial 10 MW project was

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[123] Suntech agreed on a loan up to 50 bn RMB (US$7.33bn) and Trina Solar 30 bn RMB (US$4.40bn); both loan agreements run for five years. *Reuters*, 'Suntech, Trina Solar Sign $11.7 bln Loan Deals', 14 April 2010. Available online at: http://www.reuters.com/article/2010/04/14/us-solar-loans-idUSTRE63D1VA20100414.

[124] Bloomberg New Energy Finance, Global Trends in Renewable Energy Investment 2011, 2011, p. 20.

[125] *People's Daily,* 'Fostering breakthrough for industries of strategic importance', 25 October 2010. Available online at: http://english.peopledaily.com.cn/90001/90780/91344/7176575.html

[126] The categorisation consists of the following: Zone I 'Most Abundant', more than 1750 kWh per m2 per year of annual solar radiation: Tibet, South Xinjiang, Qinghai, Gansu, West Inner Mongolia (17 percent of national total); Zone II 'Very Abundant', 1400-1750 kWh per m2 per year, 43 percent of total land area; Zone III 'Abundant', 1050-1400 kWh per m2 per year: hill areas in Southeast, Hanshui River basin, West Guangxi (36 percent); Zone IV 'Normal', less than 1050 kWh per m2 per year: Sichuan and Guizhou (4 percent). Li Junfeng and Wang Sicheng, *China Solar PV Report 2007*, 2007, p. 24. Available online at: http://www.greenpeace.org/eastasia/Global/eastasia/publications/reports/climate-energy/2007/china-solar-pv-report.pdf.

[127] Kan Sichao, 'Chinese Photovoltaic Market and Industry Outlook (Part 1)', Institute for Energy Economics Japan (IEEJ), April 2010, p. 5. Available online at: http://eneken.ieej.or.jp/data/3129.pdf.

[128] Two small on-grid solar PV farm projects were initiated in 2008: a 1 MW project on Shanghai's Chongming Island and a 255 kW project in the city of Eerduosi in Inner Mongolia. Climate Policy Initiative, *Survey of Photovoltaic Industry and Policy in Germany and China*, March 2011, p. 30.

allocated to a consortium including the China Guangdong Nuclear Power Company (CGNPC) and the Belgian renewable energy developer Enfinity, which together submitted the lowest bid. A feed-in tariff for the project was set at 1.09 RMB per kWh for a period of 25 years.

In June 2010 the Chinese National Energy Administration announced that another 280 MW of large-scale on-grid PV projects would be awarded by tendering: 60 MW in Inner Mongolia, 60 MW in Xinjiang, 60 MW in Gansu, 50 MW in Qinghai, 30 MW in Ningxia and 20 MW in Shanxi.[129]

Following these tendering projects and provincial feed-in tariffs, the National Reform and Development Commission unveiled a nationwide solar PV feed-in tariff system for China on 24 July 2011. The support scheme distinguishes between projects approved for construction before or after 1 July 2011, and offers feed-in tariffs of 1.15 RMB per kWh and 1.0 RMB per kWh depending on the category.[130]

## Future Outlook

There is a lot of optimism about further growth of the global solar PV sector. Support for solar PV deployment has increased greatly in many countries; although still small from a global power sector perspective, the sector has seen tremendous growth in recent years, leading to a different scale of industry. Furthermore, declines in cost have been very significant.

Over the past decades the costs of solar PV have dropped by 20 percent with every doubling of installed capacity, but this has accelerated even further in the past few years. Recently, the production overcapacity and fall in poly-silicon prices have caused very significant cost reductions: prices of solar modules fell from 3.50 US$/$W_p$ a few years ago to levels below 1.50 US$/$W_p$ in 2011, reaching nearly 1 US$/$W_p$ in the beginning of 2012.[131]

Concerning future developments, there are strong expectations that a large potential still exists for further cost reductions, given the dynamism of technology development (see the second section of this chapter), and several research institutes have issued projections that see solar PV power coming on par with fossil-fuel-based electricity within the next decade.[132] Some analysts have pointed to the similarities in production processes and materials usage with those of the semi-conductor industry and the enormous cost reductions which have been achieved there, as an indication of what might be possible.[133] The PV industry expects that costs to construct a large-scale PV plant in terms of €/$kW_p$ might already fall below the cost of offshore-wind in a couple of years.[134]

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[129] Climate Policy Initiative, *Survey of Photovoltaic Industry and Policy in Germany and China*, March 2011, p. 30.

[130] Qiong Xie, 'Will China's First Nationwide Feed-in-Tariff Become the Backbone of its Solar Industry?', *WorldWatch Institute Blogpost,* 26 September 2011. Available online at: http://blogs.worldwatch.org/revolt/will-china%E2%80%99s-first-nationwide-feed-in-tariff-become-the-backbone-of-its-solar-industry-2/.

[131] *McKinsey Quarterly,* 'The Economic of Solar Power', June 2008, p.2; *Financial Times*, 'Solar Power Peers Out of the Gloom', 1 September 2011.

[132] Institute of Electrical and Electronics Engineers (IEEE), 'Solar Photovoltaics Gaining Momentum and Poised to Challenge Fossil Fuels, Say IEEE Solar Experts', IEEE News Release, 15 June 2011. Available online at: http://www.ieee.org/about/news/2011/15june_2011.html.

[133] Ramez Naam, 'Smaller, Cheaper, Faster: Does Moore's Law Apply to Solar Cells?', *Scientific American*, *Commentary Blog,* 16 March 2011. Available online at: http://blogs.scientificamerican.com/guest-blog/2011/03/16/smaller-cheaper-faster-does-moores-law-apply-to-solar-cells/.

[134] In April 2011, the costs to build a large-scale solar PV plant in Germany were reported (by the solar energy industry) to be 2000 EUR per kilowatt peak (kWp) or less. In high-insolation areas large-scale PV plants could generate between 900 and 1100 kWh/kWp. Renewables Insight (RENI), PV Power Plants 2011 – Industry Guide, 2011, p. 4.

This means that for an increasing number of regions with good solar irradiation, the cost of solar PV could reach retail household electricity prices: so-called 'grid parity'. Estimates made in 2008 signalled that this could be the case by 2020 for at least ten regions including Australia, California, Texas, Spain, Japan and Germany.[135] Italy, for instance, is already close to reaching grid parity.

Consequently, also authoritative institutions such as the International Energy Agency have significantly revised upward their estimates of solar energy growth, even in the business-as-usual projections. As mentioned in the introductory chapter, the estimate for global solar PV for 2030 was revised upwards from 76 GW in the *World Energy Outlook 2004* to 294 GW in the *World Energy Outlook 2011*.[136]

There are significant challenges, however.

The first and foremost is that solar PV deployment is still very much reliant upon government support, and despite the enormous cost reductions in recent years, it is still one of the most expensive options for renewable energy deployment. Especially considering the very low load factors of solar PV installations (i.e., actual produced electricity per installed capacity), economic comparison with base-load electricity provided by coal-fired or gas-fired power plants on a levelized cost basis still shows a very large gap.[137]

Furthermore, questions have been posed regarding the financial viability of solar PV support schemes. Both Spain and the Czech Republic saw a solar PV market boom after instigating rather generous feed-in tariffs, but following the economic and financial crisis both countries cut back their generous solar PV support schemes abruptly and retroactively – which greatly unnerved investors. Within Europe, Italy has been the second leading nation in solar PV deployment following Germany, but it seems almost inevitable that its financial troubles will impact its support. For the moment, both Germany and Italy announced tariff reductions for new projects, also reflecting the fall in technology costs.[138]

Despite of slower growth, Europe will still dominate the global market for solar PV in the near future. As for global PV expansion, the European Photovoltaics Industry Association (EPIA) projects that in a 'moderate' scenario total installed capacity might increase to 131 GW by 2015, or even to 196 GW in a 'policy-driven' scenario. Europe will see its dominance in the market decline but is likely to remain the largest market, with a growth to 69 GW by 2015 in the 'moderate' scenario and 107 GW in a 'policy-driven' scenario.[139] For 2011, Europe might see its share in global solar PV demand slip to 65 percent from 82 percent in 2010.[140]

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[135] McKinsey Quarterly, 'The Economic of Solar Power', June 2008, p.3.

[136] International Energy Agency, World Energy Outlook 2004, 2004, p. 432 (Reference Scenario projections), and World Energy Outlook 2011, 2011, p. 620 (New Policies scenario).

[137] The International Energy Agency in its *Projected Costs of Generating Electricity – 2010 Edition* assumes load factors for solar PV between 10 and 25 percent. It puts the levelised cost of electricity of solar PV at 333US$/MWh for the high load factor, using a 10 percent discount rate. Comparable costs for coal-fired and gas-fired power generation (also with a 10 percent discount rate) within the OECD range between the 67-142 US$/MWh and 76-120 US$/MWh according to the same report. The calculations have been based on the simple levelised average (unit) lifetime cost approach using the discounted cash flow (DCF) method, incorporating a carbon price of 30 US$ per tonne. International Energy Agency, *Projected Costs of Generating Electricity – 2010 Edition,* 2010.

[138] Bloomberg New Energy Finance, Global Trends in Renewable Energy Investment 2011, 2011, p. 16.

[139] Estimates for other main markets by 2015: US 22 GW (moderate scenario) / 31.5 GW (policy-driven), Japan 11.2 GW / 12.7 GW, China 10.6 GW / 18.4 GW. European Photovoltaic Industry Association, *Global Market Outlook for Photovoltaics until 2015,* May 2011, p.41.

[140] Renewable Energy Focus, 'European Solar PV Demand Falling on Support Cuts', 23 June 2011. Available online at:

Following the introduction of its new support schemes, China is emerging as a significant growth market. Officials from the Chinese National Energy Administration have indicated the target for 2015 will be raised from 10 GW to 15 GW.[141] Nonetheless, it remains to be seen whether this can compensate for the loss of the export market in Europe for the Chinese solar PV industry.[142]

Although the market rebounded somewhat in 2011, for 2012 more difficult times are expected as long as key markets in Europe face uncertainties. In particular, the combination of the rapid expansion of production capacity by solar PV firms and the sudden slowing of market growth has resulted in an enormous overcapacity problem. Even while markets slowed, global production capacity expanded by 87 percent in 2010 and is estimated to have increased by another 80 percent in 2011.[143] Average utilization rates have dropped to below 50 percent and entire factories have been closed.

As a consequence, a major industry consolidation is expected to take place amidst fierce price competition. The main elements determining success in the global solar PV market going forward are price, quality and conversion efficiency.

Regarding technology development, our analysis showed that Western firms are still clearly ahead globally and that there is an important distinction between solar PV companies which are using proprietary technology and those which have focused on available standardized technology and which focus on cost reduction within these processes.[144] Despite an increasing focus on R&D and technology development, Chinese firms have focused on the latter while Western companies still dominate in customized and proprietary technologies and production processes.

How competition between them will play out in future will depend on whether new technological advances can translate into a quality improvement that can be cost-competitive. In the still young and very dynamic solar PV market, there continues to exist an opportunity for new entrants and new technology to be successful and gain a strong position in the market. The example of First Solar is illustrative of this point: it successfully developed its cadmium-tellerium thin-film technology and managed to scale up production from 50 $MW_p$ to 500 $MW_p$ in only two years, becoming the world's leading thin-film solar PV company, having a global market share of 44 percent in the thin-film segment (as of 2010).[145] On the other hand, import tariffs and barriers to entry – which were very low up until recently – are becoming more important and already a

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http://www.renewableenergyfocus.com/view/18861/european-solar-pv-demand-falling-on-support-cuts/.

[141] China Energy Network (China5e), '2015年太阳能发电目标再增50%' [2015 Solar Energy Target Increased by 50%], 10 November 2011. Available online at: http://www.china5e.com/show.php?contentid=198557.

[142] China Energy Network (China5e), '光伏产业岂能遍地开花' [How Can the Solar PV Industry Blossom Everywhere?], 9 November 2011. Available online at: http://www.china5e.com/show.php?contentid=198343.

[143] Ernst&Young, *Renewable Energy Country Attractiveness Indices*, Issue 29, May 2011, p. 2. Available online at: http://www.ey.com/Publication/vwLUAssets/Renewable_energy_country_attractiveness_indices_-_Issue_29/$FILE/EY_RECAI_issue_29.pdf.

[144] A BCG report distinguished between the following categories of firms with manuacturing technology: commodity p-Si; commodity thin-film; brand p-Si and customized thin film. Boston Consulting Group (BCG), *Sunrise in the East: China's Advance in Solar PV—and the Competitive Implications for the Industry*, December 2010, p. 5.

[145] PRTM, *2010 Photovoltaic Sustainable Growth Index. A New Competitive Environment for PV Companies*, 2010, p. 12. IMS Research, 'Global PV Installations to Hit 24 GW in 2011 Predicts IMS Research', Press Release, 15 November 2011. Available online at: http://imsresearch.com/press-release/Global_PV_Installations_to_Hit_24_GW_in_2011_Predicts_IMS_Research&from=.

difference in scale and financial stability is starting to emerge between global solar PV firms, with leading companies increasing their edge.[146]

For Chinese companies the cost advantages over European and American competitors is likely to stay. Yet access to export markets might become more of a problem, as political interference in the solar PV market appears to be on the rise.

Both in Europe and the United States, political objections against solar PV imports from China have started to emerge and might signal that 'green protectionism' could become stronger in future. Following the WTO case filed against China by the United States Steelworkers Union that targeted Chinese support for domestic cleantech industries, seven US-based solar panel manufacturers filed an anti-dumping case at the Commerce Department in Washington against the Chinese solar panel industry in October 2011, requesting tariffs of more than 100 percent of the wholesale price of solar panels from China.[147] A similar 'anti-dumping' case is being prepared in Europe.[148]

On the other hand, it remains to be seen how important the domestic solar market in China will become. Expectations are running high given the experience with the wind energy sector, which saw a stunning growth after the government made the strategic decision to push it forward. Targets for installed capacity for wind energy were reached years before schedule and revised upwards several-fold.

However, the growth of solar PV in China is not without challenges. First of all, in China the development of solar energy will necessarily be completely driven by government. Whereas in Western markets such as Europe and the United States, this has been a public-private effort, as individual homeowners have been investing in the installation of solar panels with support of government subsidies, such a trend seems very unlikely in the Chinese market, where the gap between income levels and the investment needed for solar panels remains very large. Second, also in China there are strong concerns about the costs of supporting solar PV deployment.[149] Finally, as with wind energy, solar energy resources are located far from demand centres, and grid companies will need to be cooperative in order to bring projects online and integrate them.

The considerations above indicate that although China has been very successful in the global PV industry it still faces certain challenges in order to develop further. Both managing political sensitivities and improving its technological and innovative capabilities will be critical to ensuring its further growth in this global market.

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[146] Jacob Funk Kirkegaard, Thilo Hanemann, Lutz Weischer, Matt Miller,'Toward a Sunny Future? Global Integration in the Solar PV Industry', World Resources Institute and Peterson Institute for International Economics Working Paper, May 2010. Available online at: http://pdf.wri.org/working_papers/toward_a_sunny_future.pdf. PRTM, 2010 Photovoltaic Sustainable Growth Index. A New Competitive Environment for PV Companies, 2010, p. 10.

[147] Keith Bradsher, 'US Solar Panel Makers Say China Violated Trade Rules', *New York Times*, 19 October 2011. Available online at: http://www.nytimes.com/2011/10/20/business/global/us-solar-manufacturers-to-ask-for-duties-on-imports.html?_r=1&pagewanted=all.

[148] *Euractiv*, 'Chinese Solar Subsidy Storm Heads for Europe', 27 October 2011. Available online at: http://www.euractiv.com/specialreport-solarpower/chinese-solar-subsidy-storm-heads-europe-news-508585.

[149] Personal communication with Ma Lingjuan, China Renewable Enegy Industries Association, and members of the New and Renewable Energy Department, China National Energy Administration.

# 4

## Case Study III: Nuclear Power

The importance of China as one of very few major expansion centres for the nuclear power industry can hardly be overstated. Out of all 63 reactors that are under construction worldwide, 27 reactors (43%) are located in China, and the country accounts for about one-third of all nuclear power plants that are in planning or proposal stages globally.[150] Especially in the wake of the Fukushima disaster in Japan in March 2011, the perspectives on renewed growth for nuclear power have diminished in quite a number of places.[151] Even though it is not sure whether this reaction to the incident will be long-lasting or just temporary, the outlook for a 'nuclear renaissance' has dimmed.

China halted the approval of new nuclear power plants after the Fukushima incident and issued comprehensive safety checks on reactors in operation and those under construction to re-evaluate safety conditions. Resumption of approvals has been suspended until a new nuclear safety plan comes into force. However, the general expectation is that the ambitious targets that have been issued for nuclear power will remain in place, as they are an essential element for China to meet its carbon-intensity and non-fossil-fuel-share goals.[152]

The China's plans for nuclear power are ambitious indeed. As of 2011, it has 14 reactors in operation, together accounting for 11.3 GW of power generating capacity. The plans are to increase its nuclear capacity to 40 GW by 2015 and to 75-80 GW by 2020: by then it would have the second largest nuclear power fleet after the US (101 GW), surpassing France (63 GW) and Japan (49 GW).[153] This should then raise the share of nuclear power in China's electricity mix to 5 percent.

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[150] As of 2011, China has 27 reactors under construction out of 63 worldwide – equivalent to 43% – and another 51 reactors planned (out of 152 worldwide, or 34%). Finally, there are 120 reactors proposed in China out of a global total of 350 (34%). World Nuclear Association (WNA), 'World Nuclear Power Reactors & Uranium Requirements', updated 21 October 2011. Available online at: http://www.world-nuclear.org/info/reactors.html. The definitions used for this categorisation are: Operating = Connected to the grid; Building/Construction = first concrete for reactor poured, or major refurbishment under way; Planned = Approvals, funding or major commitment in place, mostly expected in operation within 8-10 years; Proposed = Specific programme or site proposals, expected operation mostly within 15 years.

[151] Most prominent has been the decision by the German government following the Fukushima disaster to phase out its nuclear power fleet. Yet even in France the future role of nuclear power has become a point of discussion in the lead-up to the presidential elections in 2012. *Platts EU Energy,* 'France Asks the Nuclear Question', Issue 270, 18 November 2011, p. 11.

[152] China Energy Net (China5e),' 张国宝：中国不可能放弃核电' [Zhang Guobao: 'China cannot abandon nuclear power'], 11 October 2011. Available online at: http://www.china5e.com/show.php?contentid=195314.

[153] The United States has 104 nuclear reactors, amounting to a combined installed capacity of 101 GW. Other countries with significant nuclear power capacities are France (63 GW installed capacity, providing 76% of all generated electricity), Japan (49 GW), Russia (22 GW), Germany (20 GW) and Korea (18 GW). International Energy Agency (IEA), Key World Energy Statistics 2011, 2011. Available online at: http://www.iea.org/textbase/nppdf/free/2011/key_world_energy_stats.pdf.

For the nuclear industry the message is clear: the choice is between being active in China and risking the loss of a lot of business. One of the consequences of the limited growth in nuclear power worldwide since the 1980s has been a trend towards consolidation. Only a limited number of firms are active as global players in the nuclear power industry, including Areva (France), Toshiba-Westinghouse (Japan-US), GE-Hitachi (US-Japan) and Atomstroyexport (Russia).[154] There is, however, the strong expectation that China will emerge as a major player in the nuclear industry, increasing global competition.[155]

## The Emergence of the Chinese Nuclear Industry

The choice between developing indigenous nuclear power technology versus importing more advanced technology from abroad has been a longstanding debate in China. In fact, ever since the very start of nuclear power development in China both tracks have been pursued, and tension between those who favour indigenous (but less advanced) technology and those in favour of imported more modern technology has continued since.

Of the first two reactors that were built, one was an indigenously designed 300 MW reactor at Qinshan that developed as part of the "738" government technology development programme.[156] Simultaneously, the Guangdong provincial government supported the acquisition of foreign technology for the construction of a nuclear power plant at Daya Bay, near Hong Kong. For this reactor, imported M310 technology from the French nuclear firm Framatome (later Areva) was used. Both reactors began commercial operations in 1994.

In the course of the next decades, both tracks were further pursued. The 300 MW indigenously designed Qinshan reactor was upgraded to a 600 MW reactor (the 'CNP-600'), of which several units were built at the same site. The Daya Bay reactor was emulated and used for additional units at the Ling Ao site nearby. They are considered to be virtual 'replicas' of the Daya Bay units and some core technology was supplied by Framatome – the localisation rate is estimated to be 30 percent.[157]

The China Guangdong Nuclear Power Corporation (CGNPC) that manages the Daya Bay reactors continued by developing the CPR-1000 reactor, which is an upgraded version of the 900 MW-class French M310 three-loop technology used in the Daya Bay reactors. This CPR-1000 reactor version, informally known as the 'improved Chinese Pressurized Water Reactor (PWR)', has been widely deployed in China, with another 57 likely to be built by the end of 2011 CGNPC managed to create an almost completely domestic supply chain, steadily increasing the localisation rate with every new unit of the CPR-1000 that was commissioned – reaching close to 90 percent in recent projects.[158]

However, the struggle was not yet over between those favouring indigenously developed technology, represented by the China National Nuclear Corporation (CNNC), and the State Nuclear Power Technology Corporation (SNPTC) that favoured imported technology.

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[154] Martin Taylor, 'Market Competition in the Nuclear Industry', *NEA News*, No. 26, 2008. Available online at: http://www.oecd-nea.org/pub/newsletter/2008/Market%20Competition.pdf.

[155] Presentation by Pierre Zaleski and Michel Cruciani, 'Nuclear Power: New Players, New Game, New Rules', IFRI 2011 Annual Conference, 9 February 2011.

[156] Xu Yi-Chong, *The Politics of Nuclear Energy in China,* 2010, pp. 28-32.

[157] World Nuclear Association (WNA), 'Nuclear Power in China', updated November 2011. Available online at: http://www.world-nuclear.org/info/inf63.html.

[158] Xu Yi-Chong, *The Politics of Nuclear Energy in China,* 2010, pp. 153-156. World Nuclear Association (WNA), 'Nuclear Power in China', updated November 2011. Available online at: http://www.world-nuclear.org/info/inf63.html.

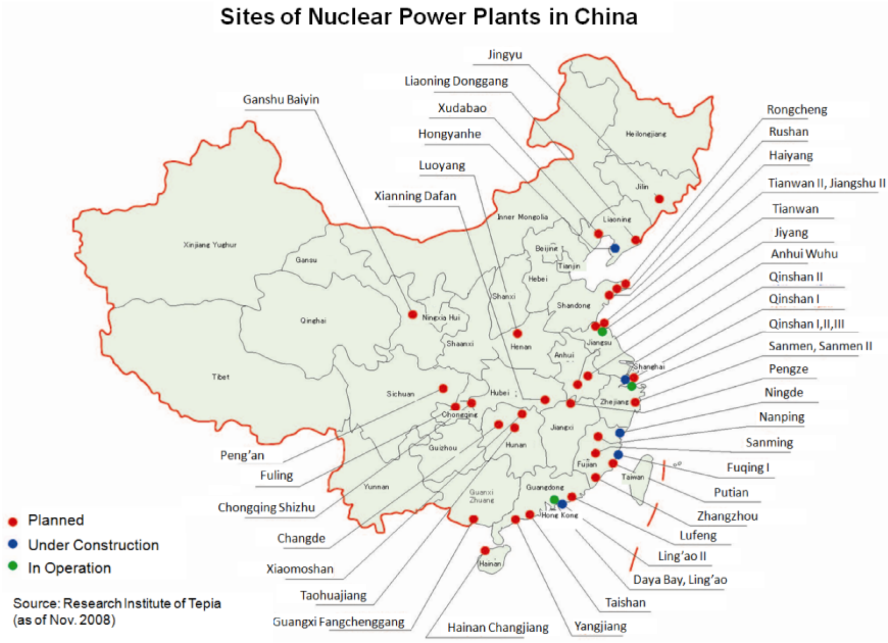


**Figure 10. Sites of Nuclear Power Plants in China.**
Source: Research Institute of Tepia (as of November 2008).

In September 2004, the Chinese State Council decided to set up an international tendering process to choose a third generation nuclear reactor design from one of the international nuclear firms that would then be used for two reactors at the Sanmen site in Zhejiang province, to be followed by at least two more reactors at other locations (see Figure 10 for map with reactor sites).[159] All major nuclear industry players took part in the tendering process: Westinghouse (with its AP1000 reactor), Areva (with the EPR) and Atomstroyexport (VVER-1000 model V392).

Technology transfer was made a key condition in the evaluation criteria for the bids. After a process which lasted several years, the formal decision was announced in December 2006, selecting the AP1000 reactor on the grounds of its passive safety systems, cost and the level of technology transfer offered.[160] The Shanghai Nuclear Engineering Research and Design Institute (SNERDI) was appointed as the main research institute to receive and adopt the technology.

Westinghouse accepted stringent conditions regarding technology transfer, which required it to cooperate with the State Nuclear Power Technology Corporation (SNPTC) in building the first four AP1000 reactors, in order to ensure that SNPTC could build following units by itself. Following the first four reactors at Sanmen and Haiyang, there are another 4 reactors planned and at least 30 proposed, all using the AP1000 design.

Moreover, it was agreed that if the Chinese parties were able to upgrade the capacity of the reactor design to 1350 MW or more, they would own the intellectual property rights for the

[159] At first the site for the second two reactors was designated to be Yangjiang in Guangdong province. However, in February 2007 – after the tender was awarded – the location for the second two reactors was switched from Yangjiang to Haiyang in the northern Shandong Province. World Nuclear Association (WNA), 'Nuclear Power in China', updated November 2011. Available online at: http://www.world-nuclear.org/info/inf63.html.

[160] The bidding process is described in: Xu Yi-Chong, *The Politics of Nuclear Energy in China,* 2010. For a Chinese rendition of the selection process see for instance: *Caijing Magazine [财经]*, '引进AP1000始末' [The Whole Story of the Introduction of the AP1000], 11 April 2011.

enhanced design.[161] Hence, this has become the major objective of the Chinese nuclear engineering programme led by SNERDI.[162] The desired reactor has already received the name CAP1400, as a shorthand for 'Chinese AP1400 reactor'

Despite Westinghouse having won the major tender, also AREVA – supplier of China's original first nuclear power technology at Daya Bay, by means of its predecessor Framatom – was awarded another couple of reactors. The China Guangdong Nuclear Power Corporation (CGNPC) agreed on a deal with Areva in November 2007 to purchase two 1700 MW EPR reactors for the site at Taishan, including contracts for the supply of fuel and other related services. An engineering joint venture was set up between Areva and CGNPC as a vehicle for technology transfer and the possible development of more EPR reactors in China and abroad. In this joint venture CGNPC and other Chinese parties together hold a 55 percent stake, against 45 percent held by Areva.[163]

The variety of different types of nuclear power plants that are being used in China has been criticized by some Chinese analysts. Earlier, still other reactor types were bought and installed, such as the Canadian-designed CANDU-6 heavy-water reactor and Russian VVER AES-91.[164] The decision to purchase these reactors appears to have sometimes been motivated by politics and the desire to create goodwill in international relations, rather than stemming from a well-thought-out nuclear power development strategy.[165] Opponents of these decisions argue that this practice is hampering standardization, which is one key factor in bringing down construction and operating costs, as it has been in France. On the other hand, those in favour of diversification argue that in this way China is hedging its bets and functioning as a testing ground for different nuclear reactor designs, being able to gain experience with all of them.

Concerning domestically designed reactors, the CPR-1000 is being deployed in large numbers alongside the 'new' standard of the AP1000. This CPR-1000 reactor is based on the French M310 technology used in the Daya Bay reactors. In the current expansion plans this CPR-1000 reactor also takes a prominent role; 20 of the 27 reactors under construction as of November 2011 are of this type. Of all the reactors that are either under construction or planned, the CPR-1000 accounts for almost half (34 reactors out of a total of 78) while another 30 are AP1000 reactors.

The development of the CAP1400 reactor is progressing, and China is also improving its capacity in building some of the core reactor components for the AP1000, such as the primary reactor coolant pipes.[166] Research has also started on a second, even larger version of the reactor, designated CAP1700 with an intended capacity of 1700 MW.[167]

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[161] Personal communication with SNERDI staff members, 2009; World Nuclear Association (WNA), 'Nuclear Power in China', updated November 2011.

[162] Personal communication with SNERDI staff members, 2009.

[163] World Nuclear Association (WNA), 'Nuclear Power in China', updated November 2011. Available online at: http://www.world-nuclear.org/info/inf63.html.

[164] For the two reactors at Qinshan Phase III, two 665 $MW_e$ CANDU-6 pressurized heavy-water reactors were purchased from Atomic Energy of Canada(AECL) on a turn-key construction project basis. Construction began in 1997 and the units came online in September 2002 and April 2003. Two Russian 1060 $MW_e$ VVER AES-91 reactors were build at Tianwan (Phase I) in Jiangsu province. An agreement on Sino-Russian cooperation on nuclear power was signed in 1992 but met with many difficulties: after construction had started in 1998 both reactors finally came online in 2007. Xu Yi-Chong, *The Politics of Nuclear Energy in China,* 2010, pp. 51-60. World Nuclear Association (WNA), 'Nuclear Power in China', updated November 2011. Available online at: http://www.world-nuclear.org/info/inf63.html.

[165] Xu Yi-Chong, *The Politics of Nuclear Energy in China,* 2010, pp. 56-58, 149-156.

[166] For instance: the Chinese Central Bohai Shipyard Shipbuilding Industry Corporation Group Co., Ltd. is supplying the primary reactor coolant pipe for the first AP1000 nuclear power plant at Sanmen. China Energy Net (China5e), AP1000核反应堆主管道实现国产化 [AP1000 Nuclear Reactor Primary Coolant Pipe Domestically Produced], 27 October 2011. Also see: China Energy Net (China5e),

Still further away from commercialization but indicative of China's push to become a world leader in advanced nuclear power technology are the efforts to develop alternative nuclear power technologies such as fast breeder reactors and high-temperature gas-cooled pebble-bed reactors. Fast neutron breeder reactors can be used to 'breed' plutonium from fissile materials and thus prolong the effective use of nuclear fuel supplies. The technology has been identified by the Chinese government as a longer-term objective, as it would allow China to continue its nuclear expansion without dramatically increasing its need for imported uranium.[168] A first experimental fast neutron reactor with a thermal capacity of 65 MW (and 20 MW of electric power output) was successfully connected to the grid in July 2011, partly using Russian imported technology.[169]

Finally, China is researching modular high-temperature gas-cooled pebbled-bed reactors, which operate using nuclear fissile material shaped in pellets, coated and encapsulated inside a ceramic material. The key feature of this design is that it has very strong passive safety characteristics, since the pebbles and ceramic material are designed in such a way that a total lack of cooling would not cause the overall structure to disintegrate. Moreover, it can be used to build small reactors at a modular design basis, which can be easily expanded. The technology was originally developed in South Africa but not further pursued there. A first small 10 MW experimental reactor was developed by Tsinghua University in the context of the *863 Program* for national research and reached criticality in 2003. Construction of a larger demonstration project with two reactor modules driving a 210 MW steam turbine was begun at the Rongcheng Shidaowan site in Shandong province in 2009 and is scheduled for completion in 2013. Regarding this Chinese effort, the report *China's Program for Science and Technology Modernization: Implications for American Competitiveness* prepared for the US-China Economic and Security Review Commission in 2011 remarks: 'Scientists predict that if the PRC program to make a commercially-viable pebble bed reactor is successful, it will represent a revolution in reactor technology—perhaps the largest advance in a quarter of a century.'[170]

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我国第三代AP1000核电产业体系基本成型 [The Basis of a National Third Generation AP1000 Nuclear Power Industry is Taking Shape], 15 September 2010. Available online at: http://www.china5e.com/show.php?contentid=128772.

[167] For a full and detailed overview of Chinese policies and recent technology development, see: Hideo Kubota, 'China's Nuclear Industry at a Turning Point', E-Journal of Advanced Maintenance, Vol.1, No.3, November 2009. Available online at: http://www.jsm.or.jp/ejam/Vol.1.No.3/GA/6/article.html.

[168] Xinhua, 'China to Build Commercial Fast Reactor by 2035', 8 June 2006. Available online at: http://www.china.org.cn/english/scitech/170802.htm.

[169] World Nuclear News, 'Chinese Fast Reactor Starts Supplying Electricity', 21 July 2011. Available online at: http://www.world-nuclear-news.org/NN-Chinese_fast_reactor_starts_supplying_electricity-2107114.html.

[170] Micah Springut, Stephen Schlaikjer, and David Chen, *China's Program for Science and Technology Modernization: Implications for American Competitiveness*, Report prepared for the US-China Economic and Security Review Commission, 2011, p.83. Available online at: http://www.uscc.gov/researchpapers/2011/USCC_REPORT_China's_Program_for_Science_and_Technology_Modernization.pdf.

## Future Outlook

A key driver for China's pursuit of nuclear power technology is to be able to fulfil its own expansion plans without being dependent upon foreign technology or imported components – even though it might still be quite some time before China will be completely self-reliant, given the complexity of some of the key components that are used in the advanced third generation nuclear power plants such as the AP1000. Chinese energy policy documents indicate that nuclear power has a long-term future in China's fuel mix, and targets have been suggested for nuclear capacity to reach 200 GW by 2030 and 400 GW by 2050. This could then possibly increase the share of nuclear power in China's electricity generation mix to 15 percent by 2030 and 22 percent by 2050. These expansion plans should be met by developing more inland-based nuclear power plants, for which the Westinghouse-designed AP1000 would be used 'in order to meet the stringent safety and environment standards'.[171]

Among nuclear industry leaders and analysts, there is little doubt that China will emerge as a major competitor. It is more a question of when, rather than if, China will start exporting domestically developed reactors.[172]

As the agreement with Westinghouse indicates, the Chinese nuclear industry firms are certainly interested in becoming global players in the nuclear power industry. There could be significant potential for the export of Chinese nuclear power plants if the Chinese firms can combine high quality and safety levels with cost-effectiveness in construction, although this will naturally depend on how other countries' policies towards nuclear power develop.

In fact, China already exported a nuclear reactor to Pakistan back in the early 1990s based on its first indigenously designed 300 MW Qinshan-I reactor. Construction started at the site in Chasma in 1993 and the reactor was completed in 2000. The reactor was an exact replica of the Qinshan-I: a two-loop pressurized water reactor, supplied by the China National Nuclear Corporation (CNNC) and designed by the Shanghai Nuclear Engineering Research and Design Institute (SNERDI). The first reactor was followed up by a second one that was constructed between 2005 and 2011.[173] China has also expressed an interest in exporting nuclear power plants to Southeast-Asian neighbours, such as Vietnam, Thailand and Malaysia.[174]

Future exports to OECD countries with their own nuclear industry, such as the United States, Europe or Japan, seem less probable, however. First of all, nuclear expansion plans are very limited in these markets for the medium term. Second, the requirements regarding safety, quality and reliability for new reactors are extremely high. Third, national preferences might very influence the choice of technology. Hence, such a scenario can only be envisaged if done in collaboration with established players and if it would entail significant cost reductions. Another route might be the supply of components for the AP1000 reactor.[175]

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[171] Targets for 2030 and 2050 as suggested by Ye Qizhen, Deputy Director of the Science and Technology Committee of the China National Nuclear Corporation (CNNC). *China Daily,* 'China Begins Construction of Inland Nuclear Power Stations', 4 November 2011. Available online at: http://www.chinadaily.com.cn/china/2009-11/04/content_8914645.htm.

[172] NERA Economic Consulting, 'Asia to Lead the Shift to Nuclear Power', September 2010. Available online at: http://www.nera.com/nera-files/PUB_Nuclear_Asia_Interview_0910.pdf.

[173] Xu Yi-Chong, *The Politics of Nuclear Energy in China,* 2010, p. 139; World Nuclear Association (WNA), 'Nuclear Power in Pakistan', updated August 2011. Available online at: http://www.world-nuclear.org/info/inf108.html.

[174] *Viet Nam Business News,* 'China to Export Nuclear Power Technology to Vietnam', 20 May 2011. Available online at: http://vietnambusiness.asia/china-to-export-nuclear-power-technology-to-vietnam/.

[175] *China Daily,* 'UK Expert: China's Nuclear Know-how Can Be Exported', 7 July 2011. Available online at: http://europe.chinadaily.com.cn/europe/2011-07/07/content_12851940.htm.

A major challenge for China will be to build up a record of excellence regarding safety management of nuclear reactors, especially those that are domestically designed and manufactured. There are also some who question how the Chinese government would deal with any nuclear incident. Although no serious problems have been encountered so far, there was a minor incident in May 2010 when a slight amount of radiation was released at the Daya Bay nuclear power plant. However, this incident was only admitted by local officials after the first news reports on the radiation finding were published outside of China.[176] Some parallels with the Wenzhou high-speed rail accident are clear, and in fact domestic concerns over nuclear safety – although muted as of yet – might increase in future. Officials have been criticized because of restricted media reporting and an initial lack of transparency in the wake of the high-speed rail accident. Most certainly the Fukushima disaster has led to a larger public debate about nuclear safety, and the general public is sometimes willing and able to protest its concerns about environmental safety, as illustrated by the public protests against chemical factories in Xiamen (in 2007) and in Dalian (in 2011). Yet there are few signs that public opposition might impact upon China's domestic expansion plans for nuclear power.

The recent bidding rounds in the Middle East, in which a consortium led by the Korean power company Kepco won the bid (mostly because of its competitive prices), can be seen as a signal that there might be good prospects for future Chinese exports of nuclear technology if it can combine quality with advantageous prices.[177] South Korea has shown that is has been capable of developing its indigenous nuclear industry in the course of 30 years or so; its APR1400 reactor (indigenously developed but based on a Westinghouse design) now competes with Western industry conglomerates.[178] From other nuclear power expansion plans, such as in Vietnam, Lithuania and Turkey, it can be inferred that cost-competitiveness plays a major role in the consideration of the final bids.

In fact, the emerging nuclear industry in China has certain advantages compared to traditional players like Areva and Westinghouse:[179]

- An assured market, as government-owned utilities are providing early orders – as opposed to Western vendors;
- National commitment to build up a nuclear industry, complete with investments in human resources and the whole industry supply chain. The experience with building and operating a large fleet of reactors will be essential for its success in gaining overseas orders;
- Financial resources that can be used for sales offers, e.g. to finance, build, own and operate nuclear power plants overseas;
- Being able to offer an integrated centralized nuclear power plant supply chain;
- Chinese utilities have fewer problems investing in nuclear power for base-load power, whereas liberalization policies in Western power markets has made it more difficult for companies to invest in nuclear power as it requires enormous high upfront capital costs against very low operating costs; and
- Government support and public opinion are less of an issue in China for nuclear power.

[176] *Caixin Magazine,* 'China Punches Pause Button for Nuclear Expansion', 25 March 2011. Available online at: http://english.caixin.cn/2011-03-25/100241163_2.html.
[177] *Financial Times,* 'S. Koreans Win $20bn UAE Nuclear Power Contract', 27 December 2009.
[178] NERA Economic Consulting, 'Asia to Lead the Shift to Nuclear Power', September 2010. Available online at: http://www.nera.com/nera-files/PUB_Nuclear_Asia_Interview_0910.pdf.
[179] NERA Economic Consulting, 'Asia to Lead the Shift to Nuclear Power', September 2010. Available online at: http://www.nera.com/nera-files/PUB_Nuclear_Asia_Interview_0910.pdf.

Finally, in the longer term, if China were to be successful in commercializing new nuclear technologies such as the pebble-bed reactor and fast breeder reactor this could give it another advantage in the global nuclear power market.[180] China has a high chance of success, as it is nearly impossible to successfully develop such novel technologies without a home market to deploy it. Ultimately, for players in the nuclear industry with new technologies, to be successful it is critical to construct as many units as possible and bring them into operation on schedule: this allows a company to gain experience and bring down costs while proving reliability and cost-effectiveness to customers.

[180] 'To really gain traction in global markets, China will have to continue to absorb third-generation reactor technology, and make licensing deals with Westinghouse or Areva to export the technologies that were transferred (transfer agreements are often made only for China's domestic use). In the longer term, advances in pebble-bed reactors may provide China with less expensive civilian nuclear technology, marketable to a wider range of nations.' Micah Springut, Stephen Schlaikjer, and David Chen, *China's Program for Science and Technology Modernization: Implications for American Competitiveness*, Report prepared for the US-China Economic and Security Review Commission, 2011, p.87.

# 5

## Case Study IV: Hydropower

Hydropower is the 'forgotten giant' of renewable energy. Dams have been deployed for electricity generation purposes for more than a century already, and hydropower currently accounts for 83 percent of all 'renewable' electricity generated globally.[181] Yet there is not much attention for this renewable energy sector, partly because dams are often very cost-effective and not in need of much government support.

China takes a central role in the hydropower sector in several ways: first of all, China is by far the largest generator of hydro-electricity worldwide, generating more or less as much as the countries ranking number two (Brazil) and three (Canada) combined.[182] This also immediately makes China the largest generator in the world of renewable energy.

Second, China has been the largest growth market for hydropower worldwide and is expected to remain so for the coming decade. It accounted for 64 percent of the global growth in hydroelectricity production in the decade 2000-2010, and its projected hydropower capacity expansion between now and 2020 is projected to account for 46 percent of the global total.[183]

Third, Chinese companies such as Sinohydro have become world leaders in the construction of hydropower projects, which we will discuss in the following sections.

As for its domestic role: hydropower currently generates approximately 16 percent of China's electricity, which makes it the second most important fuel in China's electricity fuel mix after coal, which accounts for 79 percent. In contrast, the contribution of wind power in China is still less than 1 percent and that of solar PV is negligible.[184] Consequently, it can be safely said that whether China will meet its non-fossil energy share targets for 2015 and 2020 will depend for a large part upon its further hydropower development rather than that of wind or solar power.

Apart from large-scale hydropower projects, China has also vigorously developed small-scale hydropower (units smaller than 50 MW), mostly in rural areas. By the end of 2007, China had built around 45,000 small hydropower stations with a combined capacity of more than 47 GW, accounting for about one-third of China's total hydropower capacity at that time.[185] This is also

[181] International Energy Agency (IEA), 'What is Hydropower's History?', IEA Hydropower site, accessed 10 September 2011. Available online at: http://www.ieahydro.org/What_is_hydropower's_history.html. Hydro accounted for 3252 TWh of electricity globally, versus 650 TWh for all other renewables combined. Biomass and waste (288 TWh) and wind (273 TWh) are the largest of the non-hydro category. Both account for little over 1 percent of the world total electricity generation of 20,043 TWh, whereas hydro totals 16 percent. International Energy Agency, *World Energy Outlook 2011*, 2011, p. 546.

[182] According to the BP Statistical Review of World Energy 2011, China generated 721 TWh of hydro-electricity in 2010, Brazil 396 TWh, Canada 366.3 TWh and the United States 259.6 TWh. *BP Statistical Review of World Energy 2011* (online Excel database), 2011.

[183] International Energy Agency (IEA), *World Energy Outlook 2011*, 2011.

[184] International Energy Agency (IEA), *World Energy Outlook 2011,* 2011, p. 594.

[185] REN21, *Chinese Renewables Status Report*, Background Paper, October 2009, pp. 76-77. Available online at:

approximately equivalent to the total small-scale hydropower capacity of the rest of the world combined.

## The Emergence of the Chinese Hydropower Industry

Hydropower development in China had already begun early in the 20th century, and it has been a mainstay of China's power sector expansion since.[186] However, with electricity demand growing rapidly following the successful economic reforms of the early 1980s, a major expansion programme was launched which included several extremely large-scale projects. The largest and most controversial of these was the Three Gorges Dam [*Sanxia Daba*, 三峡大壩] on the Yangtze River, which boosts a total power generating capacity of 22.5 GW and is still the largest dam worldwide as of 2011.[187]

The Three Gorges Dam turned out to be a turning point in the development of the domestic hydropower industry, since it offered Chinese manufacturers the chance to gain experience and increase their technological capabilities by partnering with foreign suppliers to the project. International firms active in the hydropower sector were keen to become involved for two reasons. First, the construction of the largest hydropower dam in the world was an enormous and prestigious project. Second, China had already become the most dynamic growth market for hydropower worldwide and market access was considered crucial in order to take part in upcoming orders.

Trading market access for technology transfer, the Chinese government used a tendering process to select foreign partners which included strong requirements on technology transfer. Orders for the main equipment for the project, including 14 turbines of 700 MW capacity each, were divided between two consortia of foreign companies, one consisting of Alstom, ABB and Kvaerner, the other of Voith, Siemens and General Electric (GE).[188] Two domestic Chinese turbine and generator manufacturing companies, Dongfang Electrical Machinery and Harbin Power Equipment, were partnered with each of the groups to gain experience: Harbin with the Alstom-ABB-Kvaerner consortium, and Dongfang with the Voith-Siemens-GE group. In the course of the project the Chinese manufacturers were increasingly able to manufacture the complete turbines independently and the agreements on technology transfer ensured that the last units were almost entirely constructed in China.[189]

In the course of the past decades, Dongfang Electrical Machinery and Harbin Power Equipment have developed into major state-owned industrial conglomerates. Apart from being leading Chinese turbine and hydropower equipment manufacturers they are also active in other power

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http://www.ren21.net/Portals/97/documents/Publications/Background_Paper_Chinese_Renewables_Status_Report_2009.pdf.

[186] The first hydropower dam in China was built in 1909 with Siemens providing the turbines. In 1980, hydropower accounted for 20 GW out of a total of 66 GW of installed power generation equipment. Mark Godrey, 'A Global Hydropower', China International Business, 6 March 2009. Data on 1980 installed capacity from the US Energy Information Agency (EIA), 2011.

[187] The Three Gorges Dam consists of 32 main power generators: 12 sets on the right bank and 14 on the left bank (installed in 2006 and 2008, respectively) as well as six underground generators. The plant took about 17 years to construct: initial work began in 1993 and the last underground generators should become operational in end of 2011. Power-Technology.com, 'Three Gorges Dam Hydroelectric Power Plant, China', 2011. Available online at: http://www.power-technology.com/projects/gorges/.

[188] For the exact division of orders between the companies, see: Power-Technology.com, 'Three Gorges Dam Hydroelectric Power Plant, China', 2011. Available online at: http://www.power-technology.com/projects/gorges/. During the course of the project, Alstom acquired ABB's power division and GE Hydro acquired Kvaerner, a Norwegian firm. Siemens and Voith later formed a joint venture.

[189] Power-Technology.com, 'Three Gorges Dam Hydroelectric Power Plant, China', 2011. Available online at: http://www.power-technology.com/projects/gorges/.

generation sectors than hydropower alone. Dongfang Electric, for instance, is the same firm that produces wind turbines, and Harbin Power Equipment also constructs thermal power plants and electricity transmission grids. Their expertise in hydropower equipment manufacturing has been put to use both domestically and abroad.[190]

The construction firms Sinohydro and Gezhouba have been two other companies that have benefited from the experience provided by the Three Gorges Dam project and the rapid expansion of hydropower in China.

In particular, the Chinese state-owned Sinohydro Corporation [中国水利水电建设集团公司国] has emerged as a national champion: this gigantic hydropower construction and engineering conglomerate has built 65 percent of China's hydropower capacity and is the major Chinese dam constructor overseas. It is involved in 107 dam building projects in 49 countries outside of China. Its major markets (in terms of revenue) are: Africa (44 percent), Asia (33 percent), the Middle East (22 percent) and the Central Americas (1 percent).[191] Sinohydro is now among the world's largest construction firms, ranking number 24 on a global industry ranking list of international contractors.[192] Its global strength lies in being cost-competitive, having talent and experience from large-scale construction projects in its home market and in having diplomatic and financial support from government and state-owned banks.[193]

## Future Outlook

Since hydropower is a cost-competitive source of energy relative to conventional power generation by fossil-fuels, the expansion and development follows a different pattern than that of the 'modern' non-hydro renewables.

First of all, most of the expansion is taking place in non-OECD countries because in OECD countries the potential for hydropower is often already utilized to a large extent. Also, social and environmental opposition to large-scale hydropower projects has grown, making expansion less easy. Hence, it is projected that 85 percent of the expected hydropower expansion up to 2035 will take place in non-OECD countries. China, India and Brazil play a major role in this expansion, accounting for almost 60 percent of the non-OECD hydro additions.[194]

China has been the largest hydropower market lately and is expected to continue to be so up to 2020, when according to government targets it should reach at least 300 GW of installed hydropower capacity. In fact, the former head of China's National Energy Administration Zhang Guobao has indicated that even more hydropower capacity – 380 GW including 50 GW of pumped storage – would be needed to meet the 2020 targets on carbon intensity and non-fossil fuel shares, requiring the construction of 120 GW of new capacity in the period 2010-2015 due to the long construction time required for large dams.[195]

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[190] Harbin Power Engineering exported 600 MW generators to India, Indonesia, Pakistan and Laos, while Dongfang has been manufacturing 770 MW generators for the Chinese Xiluodu Dam and 300 MW pumped-storage generators. Personal communication, Dr. Eduard B. Vermeer, Affiliated senior fellow at the International Institute for Asian Studies, Leiden.
[191] International Rivers, 'China's Leading Hydropower Dam Company', updated 3 December 2010. Available online at: http://www.internationalrivers.org/node/3600.
[192] ENR Engineering News, 'The Top 225 International Contractors 2011', 2011. Available online at: http://enr.construction.com/toplists/InternationalContractors/001-100.asp.
[193] Boston Consulting Group, *Companies on the Move. Rising Stars from Rapidly Developing Economies Are Reshaping Global Industries*, 2011 BCG Global Challengers, January 2011, p. 14. Available online at: http://www.bcg.com/documents/file70055.pdf.
[194] International Energy Agency (IEA), *World Energy Outlook 2011,* p. 185.
[195] China Daily**, '**China Approves More Hydropower Amid Clean Energy Push', 30 November 2010. Available online at: http://www.chinadaily.com.cn/business/2010-11/30/content_11628983.htm.

After 2020, expansion might gradually become more difficult as suitable sites become harder to find. Opposition against large-scale hydropower projects in China due to their social and environmental consequences is also increasing. In 2009, construction on a major hydropower dam project was halted due to environmental objections that were raised by the newly established Ministry of Environmental Protection.[196] In recent years the construction of quite a number of dams has slowed or been delayed, which will likely decrease the amount of new hydropower capacity coming online from 2012-2015 onwards.[197] This has led some observers to questions regarding whether China will in fact be willing and capable of implementing the ambitious expansion plans.[198]

As for global competition and exports, China is having a clear impact. Dam-building projects are often included in bilateral deals between China and developing countries, since they often contain a package deal on infrastructure development. Some of these hydropower projects have been quite controversial due to their environmental impact. Yet these deals are an important reason why Sinohydro has become the most important player in hydropower projects worldwide. According to a consultancy report, Sinohydro has captured more than half of the global market share for hydropower construction projects, with a particularly strong position in Southeast Asia, Africa and the Middle East.[199]

Yet the case of the hydropower industry also shows that despite technology transfer requirements and emerging Chinese domestic competition, there can still be opportunities for international firms to benefit from China's growing market. Following the Three Gorges project, practically all foreign turbine and hydropower equipment manufacturers established manufacturing bases in China: Alstom in Tianjin, GE in Hangzhou and Siemens-Voith in Shanghai.[200] Although their involvement in more recent hydropower construction projects has in some cases become less intensive, most of them still appear to be reasonably successful on the Chinese market.[201] Alstom, for instance, is active in China in a whole range of industries and claims to have a large share of the Chinese hydropower market. Also Siemens-Voith is still working on several hydropower projects, with high quality and advanced R&D being their main selling point.[202]

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[196] China.org, 'Hydropower Projects on Jinsha River Ordered to Halt', 22 June 2009. Available online at: http://www.china.org.cn/environment/features_analyses/2009-06/22/content_17992826.htm.

[197] *Caixin Magazine*, 'Hydropower Slowly Rows Upstream in China', 12 October 2010. Available online at: http://english.caixin.cn/2010-12-10/100206366.html.

[198] Eduard B. Vermeer, 'The Benefits and Costs of China's Hydropower: Development or Slowdown?', *China Information*, Volume 25, No. 1, March 2011, pp. 1-32.

[199] Boston Consulting Group, *Companies on the Move. Rising Stars from Rapidly Developing Economies Are Reshaping Global Industries*, 2011 BCG Global Challengers, January 2011, p. 14. Available online at: http://www.bcg.com/documents/file70055.pdf.

[200] Grainne Ryder, 'Three Gorges Dam Building Industry Goes Global', Probe International, 15 June 2009. Available online at: http://www.probeinternational.org/three-gorges-probe/three-gorges-dam-building-industry-goes-global.

[201] Dewey & LeBoeuf LLP, *China's Promotion of the Renewable Electric Power Equipment Industry*, Report for the US National Foreign Trade Council, March 2010, pp. 39-42. Available online at: http://www.nftc.org/default/Press%20Release/2010/China%20Renewable%20Energy.pdf.

[202] China CSR, 'Alstom Eyes China's Green Energy Sectors', October 26, 2010. Available online at: http://www.chinacsr.com/en/2010/10/26/8058-alstom-eyes-chinas-green-energy-sectors/;
Voith Hydro, 'Current Opportunities for Hydro Power in China. Interview with Aage Dalsjoe, President of Voith Siemens Hydro Power Generation Shanghai', August 2007. Available online at: http://www.voithhydro.com/media/HyPower16_S.24-27.pdf.

# 6

## Case Study V: High Speed Rail

Until recently, high-speed rail was primarily a Japanese and European phenomenon. The technology was originally developed by the Japanese to manage traffic congestion between Tokyo and the Osaka metropolitan area and the first *shinkansen* bullet-train line was officially opened in 1964 just before the Tokyo Olympics. After this success, European countries also started to become interested in high-speed rail systems and implemented their first national high-speed rail systems in the 1970s and 1980s. The main lines of the French TGV system were built in the 1980s and 1990s, while Germany developed its high-speed rail industry following the French and implemented most of its high-speed railways in the 1990s.[203] The most recent European growth market has been Spain, where in the time span of only 7 years a high-speed rail network of more than 1,500 km was constructed, making it the largest European network as of 2011.[204]

Growth of the industry has generally followed market developments, with many national high-speed rail manufacturers emerging in the countries that supported the domestic development of high-speed rail. The original *shinkansen* was developed by a consortium of Japanese firms, including Kawasaki Heavy Industries and Hitachi, both industrial conglomerates with a variety of activities in the energy and transportation sector.[205] In Europe, the French industrial conglomerate Alstom was involved in developing the French TGV (*Train à Grande Vitesse*) technology and in Germany Siemens introduced its own high-speed train technology after cooperating for several years with the Canadian train manufacturer Bombardier.[206] Also in Spain, a new high-speed rail manufacturing firm emerged in the form of Talgo following earlier cooperative arrangements with Siemens, Alstom and Bombardier.[207]

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[203] International Union of Railways, 'High Speed Lines in the World', 11 January 2011. Available online at: http://www.uic.org/spip.php?article573.

[204] Only one Spanish high-speed rail line was already completed in 1992; the rest was built in the period 2003-2010. International Union of Railways, 'High Speed Lines in the World', 11 January 2011. Available online at: http://www.uic.org/spip.php?article573.

[205] Apart from Kawasaki and Hitachi, the consortium consisted of Nippon Sharyo, Kinki Sharyo and Tokyu Car Corp. Infrastructurist, 'Meet the Train Makers, Part 4: The Japanese', 10 November 2009. Available online at: http://www.infrastructurist.com/2009/11/10/meet-the-train-makers-part-4-the-japanese/.

[206] Infrastructurist, 'Meet the Train Makers, Part 1: Alstom', 26 October 2009. Available online at: http://www.infrastructurist.com/2009/10/26/meet-the-train-makers-part-1-alstom/. Infrastructurist, 'Meet the Train Makers, Part 5: Siemens', 16 November 2009. Available online at: http://www.infrastructurist.com/2009/11/16/meet-the-train-makers-part-5-siemens/.

[207] Infrastructurist, 'Meet the Train Makers, Part 3: Talgo', 4 November 2009. Available online at: http://www.infrastructurist.com/2009/11/04/meet-the-train-makers-part-3-talgo/.

New global competition is now emerging from China, where in less than 7 years China already built a network which surpasses the combined length of the networks in Japan and Germany that were constructed over several decades (Figure 11).[208]

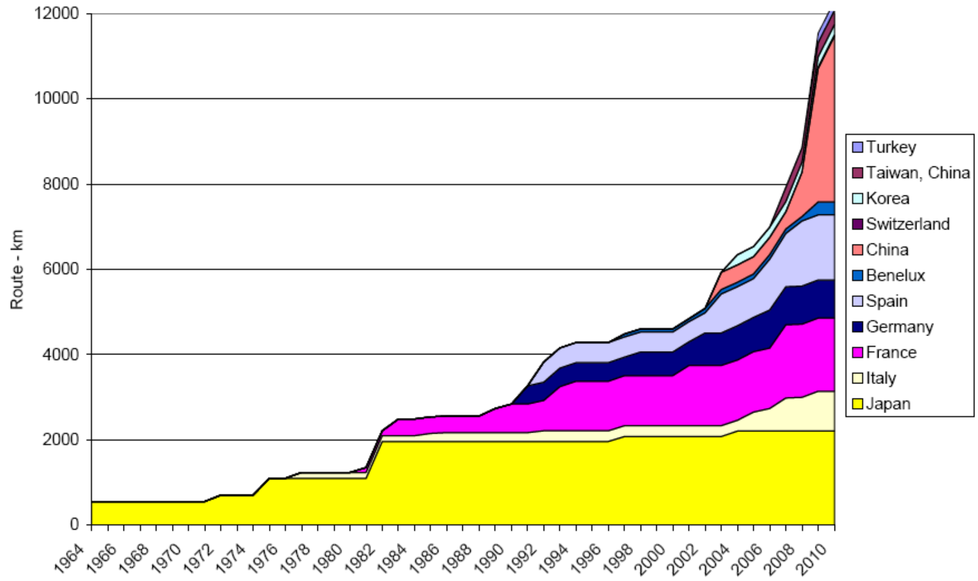


**Figure 11. Evolution of the world's high-speed rail network.**
Source: World Bank, *High-Speed Rail: The Fast Track to Economic Development?*, July 2010.

China's rapid expansion programme is the main factor driving the explosive growth of high-speed railways being constructed around the world. According to projections by the International Union of Railways, which monitors railways under construction and planned, the total global length of high-speed rail which stood at nearly 15,000 km at the end of 2009 will double to 30,000 km by 2016.[209]

As with earlier growth markets, this development is being accompanied by the emergence of a domestic high-speed rail industry.

## Chinese Market and Industry Developments

Railway has traditionally been an import means of transport in China and is intensively used to cover the enormous distances within the country. After a series of expansion projects for the passenger and freight railway network, the Chinese Ministry of Railways started implementing policies to allow the speed of passenger trains to increase in the mid-1990s.[210]

During this time, interest emerged in high-speed rail technology and several pilot projects were initiated. After an extensive effort to learn about high-speed rail technologies available

[208] *Wall Street Journal,* 'China Bullet Trains Trip on Technology', 3 October 2011. Available online at: http://online.wsj.com/article/SB10001424053111904353504576568983658561372.html.

[209] International Union of Railways, 'Expected Evolution of the World HS Network', 20 September 2010. Available online at: http://www.uic.org/IMG/pdf/20100000_c_high_speed_world_network_evolution.pdf.
[210] World Bank, 'High-Speed Rail: The Fast Track to Economic Development?', July 2010, p.6. Available online at: http://www.worldbank.org/research/2010/07/12582340/high-speed-rail-fast-track-economic-development.

internationally, China's Ministry of Railways (MORC) published a *Mid to Long-Range Network Plan* in 2003, which included for the first time detailed plans for dedicated high-speed routes.

The original plan targeted 12,000 km of high-speed passenger network by 2020, with top speeds between 250 and 350 km/h depending on the route. Yet as part of the stimulus package that was launched in the wake of the economic and financial crisis in 2008, additional investment was directed at railway construction, nearly doubling the available funds for the period 2008-2010. Construction was accelerated and in the revised plans the total length should already reach 13,000 km by 2012. Furthermore, all provincial-level capitals and major cities should be connected by 2020 with 16,000 km of high-speed railway tracks (see Figure 12).[211]

Due to its enormous expansion plans, China is by far the largest growth market worldwide and consequently it has recently been in a position to make strong demands on technology transfer. To be able to make use of the most advanced technology, China has negotiated deals with the largest international firms dealing with high-speed rail technology: Alstom, Kawasaki Heavy Industries, Siemens and Bombardier.

From the Chinese side, two main railway firms were created from the old state-led monopoly firm China National Railway Locomotive & Rolling Stock Industry Corporation (LORIC) in 2001:[212] China South Locomotive & Rolling Stock Corporation Ltd ("CSR") and China North Locomotive & Rolling Stock Corporation Ltd ("CNR").[213] These two firms were then coupled to foreign partners in order to benefit from technology transfer.

For instance, Qingdao Sifang, a subsidiary of CSR, teamed up with Bombardier to produce the CRH-1 (CRH denoting "China Railway High-Speed"), which is based upon Bombardier's Regina design. Sifang also cooperated with Kawasaki Heavy Industries, which allowed the import of Japanese technology for the CRH-2, a model similar to the E2 Shinkansen that is no longer in production on the Japanese market. Kawasaki was the only firm from Japan that took part in the bidding procedure, as other Japanese firms were withheld by fears over loss of technology.[214]

China North (CNR) partnered with Alstom and Siemens to develop the CRH-3. This train is based on the Siemens Velaro ICE-3 design and produced by Tangshan Railway Vehicle, a subsidiary of CNR. Alstom has provided its Pendolino technology for the CRH-5, which is produced at CNR's Changchun factory.[215]

For all these orders, the first couple of units were manufactured abroad in the international firm's home production base. Later in the process, more component manufacturing content was localized. In May 2010, CSR Sifang claimed that they successfully achieved indigenous innovation by means of the development of the CRH-380A: a model based on the Japanese E2-1000 model

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[211] World Bank, 'High-Speed Rail: The Fast Track to Economic Development?', July 2010, pp.7-8. Available online at: http://www.worldbank.org/research/2010/07/12582340/high-speed-rail-fast-track-economic-development.

[212] Michael Renner and Gary Gardner, Global Competitiveness in the Rail and Transit Industry, September 2010, p. 14. Available online at: http://www.worldwatch.org/system/files/GlobalCompetitiveness-Rail.pdf.

[213] This strategy to create at least two competing national firms from one state-led monopoly is in fact very similar to the way in which CNPC, Sinopec and CNOOC were created out of the old Chinese Ministry of Petroleum.

[214] Infrastructurist, 'Meet the Train Makers, Part 6: China', 20 November 2009. Available online at: http://www.infrastructurist.com/2009/11/20/meet-the-train-makers-part-6-china/.

[215] Infrastructurist, 'Meet the Train Makers, Part 6: China', 20 November 2009. Available online at: http://www.infrastructurist.com/2009/11/20/meet-the-train-makers-part-6-china/.

but with improved technology and able to reach speeds of 380 km/h. The President of CSR proudly commented that China had moved from ‘made-in-China’ to ‘created-in-China’.[216]


**Figure 12. Map of High-Speed Rail Network Map in China (Existing and Under Construction as of December 2010).**

Source: International Union of Railways, ‘High Speed Lines in the World’, 11 January 2011. Available online at: http://www.uic.org/spip.php?article573.

For international firms, China’s strong push for its own domestic technology development in some cases led to tension within the partnerships; Kawasaki, for instance, pulled out of its partnership with Sifang.[217] Other firms were alarmed by the speed with which China ‘digested’ their technology and began to fear the prospect of having China as a lower-cost competitor in other international projects, such the US or Middle East.[218]

Yet some unforeseen events severely impacted China’s ambitious plans for high-speed rail development, both domestically and abroad. First of all, a corruption scandal emerged and the Minister of Railways who had overseen the major high speed rail expansion project, Liu Zhijun, was sacked in February 2011.[219] It turned out that the Ministry was severely in debt because of corruption practices and the costly construction projects.

[216] China Pictorial, ‘Era of “Created in China” – An interview with CSR President Zheng Changhong’, 26 September 2010. Available online at: http://www.chinapictorial.com.cn/en/industry/txt/2010-09/26/content_300367_3.htm.
[217] Financial Times, ‘Japan Inc Shoots Itself in Foot on Bullet Train’, 8 July 2010.
[218] Norihiko Shirouzu, ‘Train Makers Rail Against China's High-Speed Designs’, Wall Street Journal, 17 November 2010. Available online at: http://online.wsj.com/article/SB10001424052748704814204575507353221141616.html#ixzz1iYMYoVSQ.
[219] The Economist, ‘Off the Rails? High-speed Trains Might be Forced to Go a Little More Slowly’, 31 March 2011.

Second, in a severe storm on 23 July 2011, one high-speed train crashed into another one that was standing still. The accident happened near Wenzhou, Zhejiang province. At least 40 people lost their lives and around 200 people were injured.

After investigations the accident was blamed on faulty signalling equipment. In response to the accident, the Chinese train manufacturer CNR temporarily stopped production of the trains and the government decided to implement several measures:[220]

- A reduction of the maximum travel speed by 40 to 50 kph for trains on the high-speed rail network, normally operating between the 200 to 350 kilometers per hour:
- Overall inspection of high-speed railways, including projects still under construction; and
- Renewed safety appraisals.

The crash had wider repercussions than the high-speed rail expansion strategy itself: the perceived disregard for safety standards and the insistence on pursuing an ambitious and costly showcase project led to strong domestic criticism.[221]

Observers naturally also questioned whether the extremely rapid push to develop the domestic high-speed rail industry might have led to mistakes when adopting the technology.[222] Already prior to the accident some of the train services on the newly opened line between Beijing and Shanghai suffered from delays and technical failures.[223]

It seems unlikely, however, that that the Wenzhou accident will stop the development of high-speed rail within China, even though the massive and rapid expansion has been slowed down. In November 2011 the government announced that new funding was being provided to continue with planned construction projects.[224]

## Future Outlook

Without a doubt the Wenzhou accident has hampered China's prospects on exporting high-speed rail technology in the near future. It also illustrates how important it is for companies to gain a reputation for safety and reliability and shows that China will need more time in order to gain such a strong track record as Japanese and European firms.

For the moment, the accident has alleviated the pressure of global competition coming from China, but in the longer term such competition will nonetheless be inevitable. Chinese companies have made it clear that they will make reliability and safety a priority following this disaster.

Given all high-speed rail tracks that are under construction, projections show that the global cumulative length of high-speed rail network will surpass 25,000 km before 2014 and will have

[220] *Caixin Magazine*, 'China Slows High-Speed Trains', 11 August 2011. Available online at: http://english.caixin.cn/2011-08-11/100289910.html. *Caixin Magazine*, 'CNR Halts Production of Bullet Train', 10 August 2011. Available online at: http://english.caixin.cn/2011-08-10/100289507.html.
[221] Caixin Magainze, 'For Post-Crash Railways, Next Stop Is Reform', 5 August 2011. Available online at: http://english.caixin.cn/2011-08-05/100288077.html; Li Yong, 'Corruption at High Velocity', *Caixin Blog*, 27 July 2011. Available online at: http://blog.english.caixin.cn/article/365/.
[222] *Caixin Magazine*, 'All the Wrong Signals for China's Fast Trains', 1 September 2011. Available online at: http://english.caixin.com/2011-09-01/100297517.html. *Wall Street Journal,* 'China's Bullet Trains Trip on Technology', 3 October 2011. Available online at: http://online.wsj.com/article/SB10001424053111904353504576568983658561372.html.
[223] Reuters, 'Flagship China Rail Line Hit by Power Outages', 13 July 2011.
[224] China Daily, '$31b Govt Stimulus to Revive Railway Projects', 2 November 2011. Available online at: http://europe.chinadaily.com.cn/china/2011-11/02/content_14021320.htm.

exceeded 40,000 km by 2024.[225] Apart from further Chinese expansion, there are also quite a number of countries that have announced expansion plans but which lack experience with high-speed rail development as of yet, including Turkey, Morocco, Brazil, Iran and India.

These projects will be interesting to follow in terms of global competition, as China is certainly interested in exporting its technology. Several other emerging markets will likely be the location where such competition will play out. Already China has achieved its first export success in the Middle East: several Chinese companies (under the name of China Railway Engineering) partnered with Alstom and Saudi companies in a consortium and were selected to build Phase 1 of the Haramain project: a 450 km high-speed rail link between Mecca and Medina.[226] It also succeeded in obtaining an order for a high-speed rail project in Turkey.[227]

China is also very much interested to participate in the US plans for high-speed rail development, and has signed a preliminary partnership agreement with General Electric (GE) to bid for a major 695 km project in California linking San Francisco and Los Angeles. The fact that the Chinese side can assist in financing the project, as well as their reputation for speed of construction and cost-effectiveness have been points in their favour. In fact, in an interesting case of role reversal, GE would be interested in licensing the Chinese high-speed rail technology, as it lacks such technology knowledge to date.[228] Furthermore, 80 percent of all components would need to be manufactured locally in the US following American provisions, according to GE.

One crucial remaining question is whether Europe and the United States will allow China to compete in their markets or not. Some of the international firms that have been working with Chinese companies have asserted that they will take legal steps if Chinese firms compete for projects using technology that has previous been transferred by them.[229] In fact, there are several disputes going on regarding the intellectual property rights ownership of high speed-rail technology that might be exported by China.[230] When CSR has announced that it was searching to file a US patent for its CRH380A bullet train, this aroused opposition of Japanese Kawasaki Heavy Industries: Kawasaki claims that the design is based upon its model.[231] Given the background of China's high-speed rail industry, we can expect that such controversies over technology and IPR will still play a role for future projects in which the companies will compete against each other.

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[225] International Union of Railways (UIC), *High Speed Rail: Fast Track to Sustainable Mobility*, November 2010, p.6. Available online at: http://www.uic.org/IMG/pdf/20101124_uic_brochure_high_speed.pdf.
[226] Railway Technology, 'Haramain High Speed Rail Project', 2011. Available online at: http://www.railway-technology.com/projects/haramain-high-speed/.
[227] China Daily, 'High-speed Rail Will Set the Pace in Turkey', 13 July 2011. Available online at: http://www.chinadaily.com.cn/cndy/2011-07/13/content_12888952.htm.
[228] New York Times, 'China Is Eager to Bring High-Speed Rail Expertise to the U.S.', 7 April 2010. Available online at: http://www.nytimes.com/2010/04/08/business/global/08rail.html.
[229] Financial Times, 'Alstom Attacks Chinese Train Exports', 1 January 2009.
[230] Financial Times, 'Alstom in Spat with Siemens over China Leaks', 31 October 2011. Available online at: http://www.ft.com/intl/cms/s/0/8fa2e080-0192-11e1-b177-00144feabdc0.html#axzz1iURETep5.
[231] *Caixin Magazine*, 'CSR Mulls U.S. Patent for High-Speed Trains', 24 June 2011. Available online at: http://english.caixin.cn/2011-06-24/100272914.html. China.org, 'China Denies Japan's Rail Patent-infringement Claims', 8 July 2011. Available online at: http://www.china.org.cn/business/2011-07/08/content_22945196.htm.

# 7

## Case Study VI: Hybrid and Electric Vehicles

Regarding the development of electric vehicles, plug-in hybrid electric vehicles and 'conventional' gas-electric hybrids, it is important to separate the hype surrounding this topic from reality. In the course of history, there have been quite a number of attempts to develop cost-competitive automotive transport not based on oil products, yet they have almost all proven to be unsuccessful or at best very limited in terms of global impact. An instructive example is the development of flex-fuel vehicles in Brazil that could run on ethanol derived from sugar cane, in response to the oil crisis in the 1970s. Although initially very successful, the market for such vehicles ran aground in the 1990s as oil prices became very low and have only recently recovered. Not too long ago, hydrogen and fuel-cell vehicles caught most of the attention and were expected by some to overtake the conventional car market, whereas current attention goes out mainly to electric vehicles.[232]

The first thing that should be noted about hybrids and electric vehicles is that they are – despite the large amount of media attention – still a marginal phenomenon. The sales in 2009 of about 740,000 gas-electric hybrid vehicles accounted for slightly more than 1 percent of global car sales, despite a significant growth over 2008.[233] Sales of plug-in electric hybrids and fully battery-powered electric vehicles are even much smaller, amounting to several thousands of vehicles worldwide and negligible from a global car sales perspective.[234] Moreover, similar to the position of renewables in the power generation sector, these sales have to a large extent been dependent upon significant government support, making the further development of this market vulnerable to the withdrawal or scaling back of this support. Especially if larger volumes are being reached, support mechanisms will need to be evaluated for their financial sustainability.

Nonetheless, there are some signs indicating that more headway is being made this time around. First of all, semi-electric hybrid models are being introduced to the market in fairly large numbers – larger than hydrogen cars ever reached. The cumulative sales of hybrids by Toyota – the global market leader – reached more than 3 million in March 2011, after reaching the 1 million mark in 2007 and the 2 million mark in May 2009.[235] Despite having suffered from the economic and

[232] See for instance: Bakker, S., "The Car Industry and the Blow-out of the Hydrogen Hype", *Energy Policy*, vol. 38, no 11, pp. 6540-6544, 2010. Working paper version available online at: http://www.geo.uu.nl/isu/pdf/isu0914.pdf; Bakker, S., van Lente H. & Engels, R., forthcoming, "Competition in a Technological Niche: The Cars of the Future", Technology Analysis & Strategic Management. Working paper version available online at: http://www.geo.uu.nl/isu/pdf/isu1004.pdf.

[233] In 2009 almost 740,000 hybrids were sold worldwide, a growth of 44.3 percent compared to 2008, according to the automotive consultancy Polk. This would account for 1.28% of global car sales. Margaret Zewatsky, 'Asia Pacific Region Propels Growth of Hybrid Market', PolkView, March 2010. Available online at: https://www.polk.com/knowledge/polk_views/asia_pacific_region_propels_growth_of_hybrid_market.

[234] Production of fully electric vehicles was estimated to be in the order of a few thousands units per year in: International Energy Agency, *Electric and Plug-In Hybrid Electric Vehicles (EV/PHEV) Technology Roadmap*, June 2011 (updated), p. 8. Available online at: http://www.iea.org/papers/2011/EV_PHEV_Roadmap.pdf.

[235] Toyota has stated a goal of selling 1 million hybrids annually. 'Toyota Reaches 3 Million Global Hybrid Car Sales', *Reuters*, 10 March 2011. Available online at: http://www.reuters.com/article/2011/03/10/idUS409910782820110310.

financial crisis, hybrid sales took off again in 2010 and the beginning of 2011, outpacing the overall market by almost 2 to 1.[236] As a sign of the interest from industry, the major Frankfurt Auto Show in 2011 had a special hall dedicated to electric cars: many carmakers are developing both conventional hybrid, plug-in hybrid electric and fully electric vehicles and have announced plans to introduce them. Apart from Japanese carmakers such as Toyota, Honda and Nissan that have already developed (semi-) electric vehicles, this includes major carmakers such as Audi, BMW, Volkswagen and others.

A key difference with respect to the introduction of hydrogen cars is that the potential further development and deployment of electric vehicles can be done in more gradual steps, rather than requiring a very radical transition. Conventional hybrids and plug-in electric hybrids offer some combination between the driving characteristics of conventional cars and a fully electric car. The conventional gas-electric hybrids can be used in the same way as ordinary cars but provide major improvements in fuel efficiency. Since part of the technology used (such as the battery) is shared with fully electric vehicles, a growing adoption of hybrid vehicles can lead to economies of scale and cost reductions that might also benefit the development of fully electric vehicles. The need to introduce charging infrastructure of course remains an impeding factor, but relative to hydrogen, electricity-based transport has the advantage that the power grid is already ubiquitous. Finally, an advantage is that utilities are supportive of the development and deployment of (semi-) electric vehicles, as it would provide them with additional revenues from electricity sales.[237]

## Global Technology Developments

One of the most crucial elements for the successful development of electric vehicles is battery technology. The battery pack is one of the most expensive parts of an electric vehicle and the component influencing the most its performance by its weight and the driving range it allows. The main challenge lies in the exceedingly high requirements for batteries if they are to be successfully used in fully electric vehicles: they need to have a high energy storage density (in Watt-hours per kilogram, Wh/kg), high discharge rates, be able to recharge quickly and should maintain their capacity even after thousands of charge and discharge cycles. Moreover, like all other car components, they should be able to meet high safety requirements regarding crashes and flammability, be able to perform well despite vibrations and varying temperatures, and be environmentally safe. Lastly they should be practical to manufacture and cost effective.[238]

In fact, battery improvements have been driving a lot of the technological progress in this area. See Figure 13 for an illustration of different battery technologies and their energy densities. Early electric cars introduced in the '90s used lead-acid batteries, but later models experimented with sodium-sulphur, nickel-salt, and nickel-cadmium batteries. In the second half of the '90s nickel metal hybrid (NiMH) batteries became popular, illustrating how developments in battery technology were steadily improving the capabilities of (semi-) electric vehicles.[239] Almost all hybrids available today, including the most successful Toyota Prius, still use nickel metal hydride (NiMH) batteries. However, it is generally expected that within a decade lithium-ion batteries will overtake the market almost completely. Projections show that by 2020 lithium-ion batteries will

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[236] Mark Pauze, 'Hybrids are on a Growth Track – Again', Polk (automotive consultancy) Blogpost, 31 May 2011. Available online at: http://blog.polk.com/blog/blog-posts-by-mark-pauze/hybrids-are-on-a-growth-track-again.

[237] McKinsey Quarterly, 'Electrifying Cars: How Three Industries Will Evolve', June 2009. Available online at: https://www.mckinseyquarterly.com/Automotive/Strategy_Analysis/Electrifying_cars_How_three_industries_will_evolve_2370.

238 Radu Gogoana, 'Current Battery Technology and Fully Electric Vehicles: A Review', MIT Angles, 2008. Available online at: http://web.mit.edu/angles2008/angles_Radu_Gogoana.html.

239 Radu Gogoana, 'Current Battery Technology and Fully Electric Vehicles: A Review', MIT Angles, 2008. Available online at: http://web.mit.edu/angles2008/angles_Radu_Gogoana.html.

be used in 70 percent of all conventional hybrids, and 100 percent of all plug-in hybrids and all electric vehicles.[240] Already now, these batteries have more capacity and less than half the weight compared to the lead-acid batteries used in for electric vehicles in the 1990s.[241]

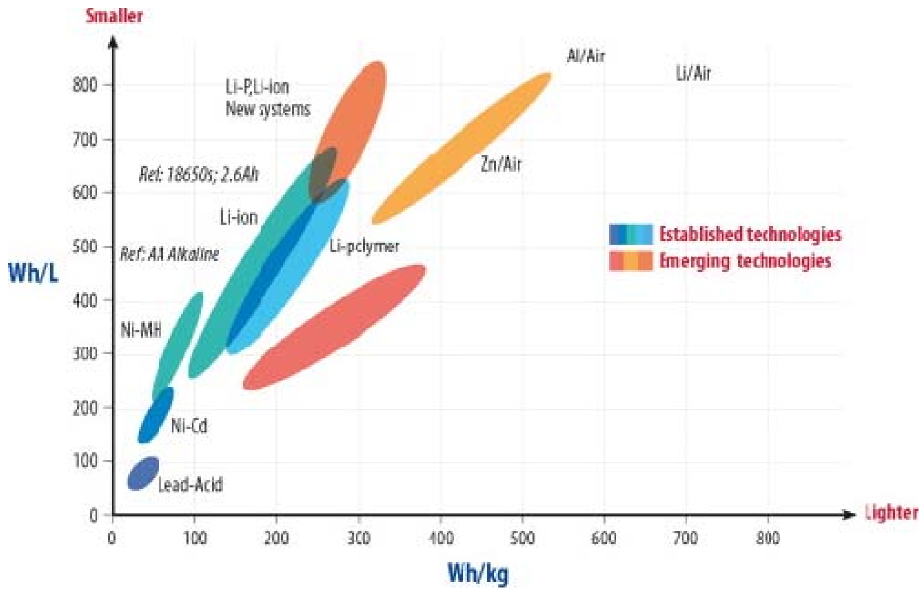


**Figure 13. Properties of Various Established and Emerging Battery Technologies.**
Source: Jon R Hickman, 'Advancements in the Clean Vehicle Industry', Renewable Energy Focus, 1 March 2009 (original chart provided by Nexergy). Available online at:

Some projections see battery costs, now between 1,000 and 1,200 US$ per kWh, declining by about 60-65 percent by 2020.[242] An enormous amount of research is being devoted to the development of new batteries. Part of this focuses on incremental improvements, such as the various lithium-ion based batteries.[243] Other firms are looking at more radical and potential 'breakthrough' technologies. In particular there are experiments with using different materials for the various components of a battery pack, namely the electrolyte, separator, cathode and anode.[244] Other innovative research focuses on ultracapacitors instead of conventional

[240] Deutsche Bank, *Electric Cars: Plugged In 2*, 3 November 2009.
[241] The Nissan Leaf has a lithium-ion battery of 24 kWh weighing 218 kg, compared to the Gen1 EV1 battery of 19 kWh and 595 kg. World Bank and PRTM, *The China New Energy Vehicles Program. Challenges and Opportunities*, April 2011, p.8. Available online at: http://siteresources.worldbank.org/EXTNEWSCHINESE/Resources/3196537-1202098669693/EV_Report_en.pdf.
[242] Boston Consulting Group (BCG), *Batteries for Electric Cars – Challenges, Opportunities, and the Outlook to 2020*, 2010, p.8. Available online at: http://www.bcg.com/documents/file36615.pdf.
[243] There are several different types of lithium-ion batteries, with each their own advantages and disadvantages. Lithium-cobalt oxide (LCO) batteries are used for consumer electronics but are not suited for automotive use. Some other lithium-based batteries that might be applicable are lithium-nickel-cobalt-aluminium (NCA), lithium nickel-manganese-cobalt (NMC), lithium-manganese spinel (LMO), lithium titanate (LTO) and lithium-iron-phosphate (LFP). Boston Consulting Group (BCG), *Batteries for Electric Cars – Challenges, Opportunities, and the Outlook to 2020*, 2010, p.3.
[244] Kevin Bullis, 'A Guide to Recent Battery Advances', *MIT Technology Review*, 29 June 2010. Available online at: http://www.technologyreview.com/energy/25660/.

batteries.[245] Furthermore, nanotechnology is also being used to improve the performance of batteries.

As of yet, Japan is still clearly the leader in this technology: not only in the development and deployment of hybrid and electric vehicles, which already received considerable government support in the '70s and '80s, but also in lithium-ion battery technology.[246] In terms of annual sales of hybrid vehicles, Japan's global market share was 45 percent in 2009.[247] Regarding the production of lithium-ion batteries designed for electric or hybrid vehicles, its global market share is estimated to be 57 percent, compared to 17 percent for South Korea and 13 percent for China. Also for components Japan is dominant producer: cathodes (73% Japanese market share), anodes (84%), electrolyte solutions (80%), and separators (71%). Finally, in terms of research Japan has a clear lead: of all international patents that were filed in the period 1998-2007 related to lithium-ion batteries, Japan accounted for 52%, compared to the United States 22%, South Korea 15%, Europe 6% and China 1%.[248]

## Chinese Policies to Build Up a "New Energy" Automotive Industry

There has been some speculation that China might actually take a leading role in developing and deploying (semi-) electric vehicles globally.[249] Given that the global market for electric and hybrid vehicles is very small and China's own automotive industry (both conventional and electric) is not playing a large role in its domestic market, let alone globally, this assertion seems rather premature. However, we will investigate the background behind China's push for "new energy vehicles" in this section.

As was mentioned in Chapter 1, the Chinese government has designated "new energy vehicles" as a strategic emerging industry and has indicated it will offer strong support for its development. The reasoning behind this is that, if successful, the development and deployment of electric vehicles would achieve multiple objectives of the Chinese government at once. It would:

- **Improve its energy security with regard to oil.** Development of non-oil-based transport would reduce oil demand and thus counter the rapidly growing oil import dependency, which is China's most pressing energy security concern. In the time span of only one and half decades, China has shifted from being a net exporter of oil to an import dependency of more than 50 percent. Business-as-usual projections see China's import dependency rise to more than 75% by 2030, becoming both the world's largest oil consumer and largest oil importer.[250] Earlier policy measures have already attempted to limit China's growing oil demand in the transportation sector by issuing strict fuel efficiency

[245] Ultracapacitors can hold only a very limited amount of energy compared to real batteries, yet they are able to make a powerful discharge and can be recharged quickly and many times without losing capacity. There are experiments with using ultracapacitors on electric buses, where each stop gives them the chance to recharge. Seventeen of such (41 seat) buses have been deployed in Shanghai. They have also been used at the World Expo 2010. *MIT Technology Review,* 'Next Stop: Ultracapacitor Buses', 19 October 2009. Available online at: http://www.technologyreview.com/energy/23754/.

[246] Craig Windram, 'Government Policy & the Development of Hybrid and Electric Vehicles in Japan', Think Carbon, 19 September 2009. Available online at: http://thinkcarbon.wordpress.com/2009/09/19/government-policy-the-development-of-hybrid-and-electric-vehicles-in-japan/.

[247] North America accounted for 41 percent and Europe for 10 percent. Margaret Zewatsky, 'Asia Pacific Region Propels Growth of Hybrid Market', PolkView, March 2010. Available online at: https://www.polk.com/knowledge/polk_views/asia_pacific_region_propels_growth_of_hybrid_market.

[248] M. Lowe, S. Tokuoka, T. Trigg and G. Gereffi, *Lithium-ion Batteries for Electric Vehicles: The U.S. Value Chain*, 5 October 2010, pp. 18, 20, 24. Available online at: http://www.cggc.duke.edu/pdfs/Lithium-Ion_Batteries_10-5-10.pdf.

[249] Keith Bradsher, 'China Vies to Be World's Leader in Electric Cars', *New York Times,* 1 April 2009. Available online at: http://www.nytimes.com/2009/04/02/business/global/02electric.html.

[250] BP, Energy Outlook 2030, January 2011.

requirements and encouraging the sales of smaller and more fuel-efficient vehicles by tax and fiscal measures.[251]

- **Build up a domestic car industry which can compete globally.** China has the clear ambition of building up a domestic car industry, which at the moment is still rather unsuccessful. At the moment, China's automotive market is still dominated by foreign brands, which have a market share of more than 70 percent. Chery and BYD, China's largest two domestic car manufacturers, hold market shares of 5.5 percent and 5.1 percent, respectively. In comparison: two joint ventures by Volkswagen hold 16 percent together, while Hyundai holds 10 percent and GM 9 percent.[252] Chinese policy-makers regard the development of electric (as well other non-gasoline based) vehicles as an opportunity to try and 'leapfrog' into a technology which is expected to become more important in coming decades in the global automotive industry.
- **Mitigate urban air pollution.** Air quality in Chinese cities is some of the world's worst, and transportation is a major contributing factor. For instance, in Beijing, transportation is estimated to cause more than 70 percent of CO and HC emissions.[253]

Moreover, there are several factors which might help China in gaining an important position in the market for (semi-) electric vehicles:

- **Existing experience in battery manufacturing.** China has an important position in the global market of manufacturing lithium-ion-based batteries for consumer electronics and appliances. Although this is still quite different from the very advanced battery technology which is used in hybrid or electric car batteries, it could still provide a basis from which China could improve its technological capabilities for batteries, which are a critical component for a potential future 'breakthrough' in electric vehicle technology.[254]
- **Strong support of the government that might facilitate adoption, infrastructure development and standardization.** The Chinese government has shown itself willing to offer strong and consistent support for industries that it deems essential for its long-term economic development. It has already indicated its willingness to offer significant financial support, as is currently being offered in the Chinese renewable energy sector, to provide an initial stimulus that is aimed at allowing the industry to reach economies of scale such that eventually production becomes cost-competitive. Moreover, the strong position of the government could facilitate issues such as standardization and legislative support for the introduction of electric vehicles. The potential impact of government measures is illustrated by the ban on gasoline scooters that has been issued as an air pollution reduction measure in major cities such as Shanghai and Beijing in the 1990s, which has led to a rapid and near-complete shift towards electric bicycles and

[251] The Chinese government has implemented fuel efficiency standards similar to the European Euro-III and IV standards: these are already stricter than in the United States. Furthermore tax differentiation is favouring smaller vehicles. Reuters, 'China's New Fuel Specs vs Euro Standards', 20 November 2009.

[252] This stands in contrast to Japan and Korea where domestic car manufacturers have market shares of 94 and 73 percent in their own market. Also in Germany, France and the United States, domestic manufacturers account for more than half of the market. The Chinese car market is also still very dispersed with the top five car manufacturers accounting for only 50 percent of the total market.Yu Dawei, 'Domestic Car Makers Eye More M&As', *Caixin Magazine*, 15 April 2010. Available online at: http://english.caixin.cn/2010-04-15/100135441.html.

[253] World Bank and PRTM, *The China New Energy Vehicles Program. Challenges and Opportunities*, April 2011, p.12. Available online at: http://siteresources.worldbank.org/EXTNEWSCHINESE/Resources/3196537-1202098669693/EV_Report_en.pdf.

[254] World Bank and PRTM, *The China New Energy Vehicles Program. Challenges and Opportunities*, April 2011, p.13. Available online at: http://siteresources.worldbank.org/EXTNEWSCHINESE/Resources/3196537-1202098669693/EV_Report_en.pdf.

scooters.[255] Finally, several public-private initiatives have been taken by local governments to provide a 'demand pull' to the emerging new energy vehicle industry.

- **China is an enormous growth market for cars with many first time buyers.** Chinese car ownership is extremely low from a global perspective: currently only 3 out of 100 Chinese own a car compared to about 50 and 75 out of 100 people in Europe and the United States, respectively. Chinese analysts expect car ownership to increase five-fold up to 15 car owners per 100 Chinese by 2020, indicating the huge potential for further growth in the car industry.[256] There is less of a technology-lock-in and many car buyers will be first-time buyers which might – but not necessarily – facilitate the adoption of a new type of car, such as electric vehicles. End 2009, China already had 170 million vehicles on the road, but even more – 220 million – are projected to be sold between now and 2020.[257]

Very ambitious targets have been formulated by the central government as well as individual provinces and municipalities: overall, China has set out a goal of introducing 500,000 new energy cars by 2015 (cumulatively) and to reach 5 million by 2020.[258] It furthermore aims to drive down battery costs and achieve a production capacity of 1 million new energy vehicles by 2015, with pure-electric and plug-in hybrid each accounting for 50 percent.[259]

To achieve this target, the government has launched the *10 Cities, 1,000 Vehicles* [十城千辆] programme which designates pilot cities that are to encourage electric transportation.[260] Since its introduction, the programme has been extended twice: first to include thirteen pilot cities, and later 25 cities including China's largest cities: Beijing, Shanghai and Chongqing.[261] Central government subsidies are also available: for a fully-electric vehicle these can amount to 60,000 RMB (approximately 6,000 EUR). The government has also indicated it will introduce other 'secondary' incentives for new energy vehicles such as free number plates and waivers for traffic restrictions.[262] Since number plates are only issued in limited numbers and auctioned for high prices in the major cities of China, this might provide a significant additional incentive.

[255] As a consequence, China is the largest producer and consumer of electric bicycles in the world: annual production in 2009 reached 23.7 million and the total population of electric bicycles has exceeded 120 million. They primarily use lead-acid batteries. Robert Earley, Liping Kang, Feng An, Lucia Green-Weiskel, *Electric Vehicles in the Context of Sustainable Development in China,* The Innovation Center for Energy and Transportation (iCET), UN Background Paper No. 9, 2011, p. 6.
[256] *Bloomberg,* 'China 2010 Auto Sales Reach 18 Million, Extend Lead', 10 January 2011. *China Daily*, 'China Car Boom Could Last a Few Years: Analysts', 9 July 2009. Available at: http://www.chinadaily.com.cn/china/2009-07/09/content_8401265.htm.
[257] Worldwatch Institute Blog, 'China Set to Add 220 Million Vehicles, Aims to Green Transportation Sector', April 2011. Available online at: http://blogs.worldwatch.org/revolt/china-aims-to-green-transportation-sector/.
[258] These targets are being reconsidered, as it is becoming clear they are too ambitious and unrealistic – we will discuss that further on. *The Economist*, 'Electric cars. Highly charged', 30 June 2011. Available online at: http://www.economist.com/blogs/schumpeter/2011/06/electric-cars.
[259] Specific targets for battery costs are to reduce the price to 2 RMB per Wh by 2015 and 1.5 RMB per Wh by 2020 (1 RMB is approximately 0.1 EUR). China Daily, 'China Plans to Take Lead in New-energy Vehicles', 8 April 2011. Available online at: http://usa.chinadaily.com.cn/business/2011-04/08/content_12291105.htm.
[260] The *10 Cities, 1,000 Vehicles* itself is part of the *863 National High-Tech Development Plan* launched by the Ministry of Science and Technology.
[261] The thirteen selected cities are: Beijing, Shanghai, Chongqing, Changchun, Dalian, Hangzhou, Jinan, Wuhan, Shenzhen, Hefei, Changsha, Kunming and Nanchang. After two years the pilot has been extended to 25 cities. Shanghai Securities News, 新能源汽车"十城千辆"实施两年初见成效 [Initial Success of the "10 Cities, 1000 Cars" New Energy Vehicles Program After Two Years of Implementation], 25 February 2011. Available online at: http://money.163.com/11/0225/02/6TN32VI500253B0H.html.
[262] Xinhua, 'China Mulls Free License Plates for New-energy Cars', 20 November 2011.

Furthermore, China is attempting to kick-start the deployment of electric vehicles through government purchasing programmes aimed especially at public buses and taxis: up to 1,000 buses for each of the pilot cities will receive a US$70,000 subsidy. For taxis subsidies of up to US$8,500 are available.[263] Concerning charging infrastructure, the state-owned power grid company State Grid has announced that it will construct charging stations in Shanghai, Beijing, Tianjin and other large cities.

Of all municipal governments, Shenzhen can be considered the frontrunner of EV deployment in China. Not coincidentally, it is also the hometown of the automotive manufacturer BYD. Like Beijing, Shenzhen is part of the *10 Cities, 1000 Vehicles* demonstration programme. It has set the goal of having 24,000 electrified vehicles by 2015, including: 3,000 hybrid-electric buses and 1,000 all-electric buses; 2,500 all-electric taxis; 2,500 all-electric government fleet cars and incentives for 15,000 consumer EVs.[264] Since December 2008, Shenzhen has introduced 50 electric taxis of BYD's E6 model as part of the pilot project. Fast charging stations of 380 V can charge these taxis in 60-90 minutes and the number of battery chargers should be expanded to 12,750 by 2015.[265]

A number of other demonstration projects have been started because of the 2008 Olympics in Beijing and the World Expo in Shanghai. In Beijing 50 domestically manufactured fully electric buses were introduced that used a battery switching system to be able to recharge quickly. At the Shanghai Expo site 14 buses were deployed that used super-capacitors for electric power storage (these can fast-charge while passenger get on and off at specially constructed bus stops).[266]

## Challenges Facing A Chinese Hybrid and Electric Vehicle Industry

Despite the ambitious plans and strong government support, the development of the hybrid and electric vehicle industry in China is facing severe challenges:

- From current sales patterns the Chinese car buyers seem distinctly uninterested in energy-efficient or low-carbon vehicle options such as hybrids, let alone electric vehicles. In fact, sales levels of early producers of electric vehicles (such as BYD) have been negligible.
- From a technological perspective, China's car industry is far behind its Western, Japanese and Korean global competitors. Regarding advanced hybrid and electric vehicle technology, this might be even more the case, making it even more difficult for China to leapfrog into the successful commercialization of electric vehicles.
- All the same challenges and impediments which hold back the development of electric vehicles in developed countries, such as cost levels, driving range issues, comfort level, safety concerns, battery problems, lack of recharging infrastructure, hold also for China and often even more strongly. Especially since China still has a lower average income level, it would be rather contradictory to assume that Chinese consumers would rapidly adopt expensive electric vehicles and be even quicker to do so than OECD countries.

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[263] Deutsche Bank, *Electric Cars: Plugged In 2*, 3 November 2009, p.31.

[264] In comparison: Beijing has proposed it would introduce 23,000 electric and 7,000 hybrid cars by 2012, including 100 recharging stations and 36,000 rechargers. Subsidies are offered of RMB 3,000 per kWh of battery capacity, with a limit of RMB 60,000 for an EV and RMB 50,000 for a hybrid car.

[265] Robert Earley, Liping Kang, Feng An, Lucia Green-Weiskel, *Electric Vehicles in the Context of Sustainable Development in China,* The Innovation Center for Energy and Transportation (iCET), UN Background Paper No. 9, 2011, p. 25. Available online at: http://www.un.org/esa/dsd/resources/res_pdfs/csd-19/Background-Paper-9-China.pdf.

[266] Robert Earley, Liping Kang, Feng An, Lucia Green-Weiskel, *Electric Vehicles in the Context of Sustainable Development in China,* The Innovation Center for Energy and Transportation (iCET), UN Background Paper No. 9, 2011, p. 5. Available online at: http://www.un.org/esa/dsd/resources/res_pdfs/csd-19/Background-Paper-9-China.pdf.

We will elaborate on these points in the following.

First of all, deployment has been limited almost completely to the government purchasing programmes and public-private initiatives in the public transport sector that were indicated in the previous section. Private sector sales have been extremely limited: it has been reported that in 2010, only 2,000 electric cars were sold despite large government incentives.[267] Although at least 10 EV models have been introduced by Chinese domestic car manufacturers, it has been reported that many car dealers simply do not put them in the showroom because of a lack of interest of consumers.[268] Some domestic models have even been pulled back from the market, after registering almost no sales.[269]

Sales patterns and surveys show that Chinese car buyers prefer traditional gasoline-fuelled cars and that – in China certainly no less than the West – owning a car is a status symbol: for many, the car should be large and impressive. This is also part of the reason why German luxury car brands such as Audi, BMW and Mercedes, as well as American brands, are extremely popular in China, while domestic Chinese car manufacturers are still lagging.[270] Particularly for new energy vehicles, Chinese consumers are deterred by the higher costs, safety concerns and lack of convenience and driving comfort.

The story of BYD is in a way exemplary. Even though it has been heralded the company of the future that illustrated how China would dominate the electric vehicle industry, it has seen abysmal sales figures for its hybrid and fully electric models in China, and more recently it has been plagued by financial troubles and disputes with its domestic dealer network.[271]

Second, in terms of technology, China still suffers from a very significant R&D lag relative to its global competitors. It took Japan several decades to develop the technological knowledge of hybrids and electric vehicles from which it is now benefiting. Since China does not have a conventional car industry that is globally competitive, it would require a major technological leapfrog to successfully introduce electric vehicles on a global scale.

The main weakness of Chinese firms lies in the manufacturing of advanced batteries that are required for electric vehicles.[272] Illustrating this is an accident in which the battery pack of an electric taxi in Hangzhou caught fire (the car was produced by the Chinese firm Zotye).[273]

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[267] *China Daily*, 'Green is a Popular Choice for Car Buyers', 30 June 2011. Available online at: http://www.chinadaily.com.cn/usa/2011-06/30/content_12807751.htm.

[268] Xinhua News, 'China's New Energy Vehicle Sector Faces Growing Pains', 16 July 2011. Available online at: http://news.xinhuanet.com/english2010/china/2011-07/16/c_13989691.htm.

[269] 'Changan Auto has pulled the plug on its hybrid Jiexun. According to the company, not a single Jiexun was sold during the last year. BYD faces similar struggles, reporting that it has sold only 54 E6 electric vehicles and just 290 F3DM plug-in hybrids between January and October of this year.' Eric Loveday, 'Dismal Hybrid, Electric Vehicle Sales in China Concern Automakers', 12 December 2010. Available online at: http://green.autoblog.com/2010/12/12/dismal-hybrid-electric-vehicle-sales-in-china-concern-automaker/.

[270] Financial Times, 'Chinese Car Buyers Show Off with a "Baoma"', 15 August 2011. Available online at: http://www.ft.com/intl/cms/s/0/29fd0c30-c275-11e0-9ede-00144feabdc0.html#axzz1iURETep5 .

[271] *Caixin Magazine*, 'China's Plug-In Carmaker BYD Checks the Wires', 25 August 2011. Available online at: http://english.caixin.com/2011-08-25/100294672.html. *Caixin Magazine*, 'Carmaker BYD Wakes Up from a "New Energy" Dream', 3 November 2011. Available online at: http://english.caixin.com/2011-11-03/100321883.html. *Caixin Magazine*, 'Slow Sales, Job Woes as BYD's Engine Sputters', 13 September 2011. Available online at: http://english.caixin.com/2011-09-13/100304779.html.

[272] Alysha Webb, 'Technology Questions Loom Large for China's Plug-in Vehicle Battery Industry', 14 July 2011. Available online at: http://www.plugincars.com/chinas-electric-vehicle-battery-industry-faces-technology-quality-questions-107374.html.

[273] Alysha Webb, 'Flaming China Taxi Problem Revealed. It Was the Battery Pack. Making an EV is tough…', 12 June 2011. Available online at: http://chinaev.wordpress.com/2011/06/12/flaming-china-taxi-problem-revealed-it-was-the-battery-pack-making-an-ev-is-tough/.

Although China aims to catch up in terms of technology development, government R&D spending on batteries still falls short relative to that of Japan, South Korea and the United States.[274] A stronger point has been China's development of cost innovation processes that can reduce costs without requiring breakthrough technologies. BYD, for instance, replaced some EV battery materials with cheaper materials while maintaining high performance properties and re-engineered the production process such that expensive "dry rooms" were not required – thus reducing the battery cost by 45 percent.[275]

China is teaming up with foreign producers, which offers it a means to increase its technological capabilities. One of the oldest car manufacturers in China, state-owned FAW, has partnered with Toyota and produces the Prius for the Chinese market. BYD has signed a cooperation agreement with Daimler AG to develop electric cars for the Chinese market, as well as with Volkswagen to work on hybrid and fully electric vehicles with lithium batteries. Volvo has been working together in a joint venture with Shanghai-based Sunwin that has developed and deployed the supercapacitor buses for the Shanghai Expo as well as hybrid and fully electric buses. Better Place, the US company that has launched an ambitious electric vehicle scheme in Israel, has signed a partnership agreement with China's leading producer Chery.[276]

Also in the field of battery technology development, joint ventures are taking place with foreign manufacturers. US-based Ener1 has formed a joint venture with Wanxiang Electric Vehicle Co. of Hangzhou to produce batteries, and A123 – one of the most advanced and successful battery manufacturers in the US – has partnered with the major Chinese automotive firm SAIC.[277]

Although not many disputes have surfaced yet, lately there has been some criticism that foreign automotive companies that are active in China by means of joint ventures are facing increasingly strong demands for technology transfer.[278] Foreign brands are primarily excluded from the special subsidy schemes for new energy vehicles, and it has been reported that the Chinese government demanded extra conditions for technology transfer in order to allow the GM Chevrolet Volt to qualify for the subsidies when it was to be introduced the Chinese market.[279]

## Future Outlook

There are few certainties regarding the future development of hybrid and electric vehicles from a global perspective, as important impediments to their development remain. The IEA has estimated that announced targets for electric vehicle deployment by major economies would result in 7 million vehicle sales per year in 2020, but whether these plans will be successfully implemented remains quite uncertain.[280] In particular, the volatility of global oil prices is a crucial

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[274] Robert Earley, Liping Kang, Feng An, Lucia Green-Weiskel, *Electric Vehicles in the Context of Sustainable Development in China,* The Innovation Center for Energy and Transportation (iCET), UN Background Paper No. 9, 2011, p. 4. Available online at: http://www.un.org/esa/dsd/resources/res_pdfs/csd-19/Background-Paper-9-China.pdf.

[275] Eden Yin and Peter Williamson, 'Rethinking Innovation for a Recovery', Ivey Business Journal, May/June 2011. Available online at: http://www.iveybusinessjournal.com/topics/global-business/rethinking-innovation-for-a-recovery.

[276] Katie Fehrenbacher, 'A Chery On Top for Better Place & China', 25 April 2010.

[277] Alysha Webb, 'Technology Questions Loom Large for China's Plug-in Vehicle Battery Industry', 14 July 2011. Available online at: http://www.plugincars.com/chinas-electric-vehicle-battery-industry-faces-technology-quality-questions-107374.html.

[278] *The Economist*, 'Electric Cars. Highly Charged', 30 June 2011. Available online at: http://www.economist.com/blogs/schumpeter/2011/06/electric-cars.

[279] Keith Bradsher, 'Hybrid in a Trade Squeeze', New York Times, 5 September 2011. Available online at: http://www.nytimes.com/2011/09/06/business/global/gm-aims-the-volt-at-china-but-chinese-want-its-secrets.html?pagewanted=all.

[280] International Energy Agency, *Clean Energy Progress Report*, 2011, p. 9.

factor: if oil prices were to drop to lower levels for a prolonged period, much of the urgency and strong government support for the development of 'alternative' vehicles would likely disappear.

However, a more important role of gas-electric hybrids in global car markets seems reasonably assured, given their consumer acceptance and very high fuel efficiency levels. Technological progress in the field of batteries and (semi-) electric vehicles is another certainty, as major R&D efforts have been started in recent years which will likely yield results over time. Such advances in technology could increase the cost-competitiveness relative to conventional vehicles and improve driving characteristics, but other factors, such as consumer acceptance and infrastructure development, will remain important issues to address.

As for China's domestic market, it has certainly emerged as the world's most dynamic and rapidly evolving car market. In the wake of the global economic and financial crisis, China overtook the United States as the largest car market in early 2009. Car sales have exceeded 1 million per month, totalling 13.6 million in 2009 and 18 million in 2010, for a large part in response to the government stimulus programme which included tax cuts on vehicle sales.[281]

Although building up a domestic car industry is a clear government priority, the automotive market in China is still dominated by foreign brands and the Chinese domestic car industry is still some time off from becoming truly competitive at a global level.[282] For the moment, China's automotive industry is gradually trying to strengthen its global position, focusing mostly on exports to emerging markets that are cost-conscious and less brand-focused, such Latin America, the Middle East and Russia.[283] Concerning "new energy vehicles" such as hybrids and electric vehicles, China is still a very minor player, both in terms of a sales market, manufacturing capacity and global competitiveness. Japan, the US and Europe accounted for 96% of the global hybrid car market in 2009 and are likely to remain dominant for some time to come.[284]

In fact, the difficulty in achieving the official targets and making such a large technological leap regarding the development "new energy vehicles" seems to have led to a reconsideration within the Chinese government. In an article in *Qiushi*, the official Chinese Communist Party journal, published in July 2011, Chinese Premier Wen Jiabao pointed out that many challenges still remain to be addressed concerning the development of "new energy vehicles" – a statement which has been interpreted as a sign that the massive government support for the sector might be re-evaluated in the light of its effectiveness.[285]

Nonetheless, the elements that underlie the governmental support of "new energy vehicles" – the wish to address its growing oil import dependency and to build up a domestic automotive industry – will not change. It seems likely that China will at least attempt to develop its "new energy vehicle" industry further despite all setbacks, as long as it has the chance and interest to become globally competitive in this field.

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[281] 'China Ends U.S.'s Reign as Largest Auto Market', *Bloomberg,* 11 January 2010; 'China 2010 Auto Sales Reach 18 Million, Extend Lead', *Bloomberg,* 10 January 2011.

[282] William Russo, 'The Path to Globalization of China's Automotive Industry', 18 May 2009. Available online at: https://www.gplus.com/Transportation/Insight/The-Path-to-Globalization-of-Chinas-Automotive-Industry-39128.

[283] Stuart Burns, 'Chinese Carmakers Pushing for Exports', 3 November 2011. Available online at: http://agmetalminer.com/2011/11/03/chinese-carmakers-pushing-for-exports/.

[284] Margaret Zewatsky, 'Asia Pacific Region Propels Growth of Hybrid Market', PolkView, March 2010. Available online at: https://www.polk.com/knowledge/polk_views/asia_pacific_region_propels_growth_of_hybrid_market.

[285] Financial Times, 'China Debates Electric Car Policy', 22 August 2011; Eric Loveday, 'Moving forward? China rethinking plug-in vehicle policy', Green Autoblog, 29 August 2011. Available online at: http://green.autoblog.com/2011/08/29/moving-forward-china-rethinking-plug-in-vehicle-policy/.

# 8

## Taking The Next Step: Towards Innovation?

China's economic model has been based upon export-led growth, and its success has gained it the reputation for being the 'factory of the world'. In a typical latecomer strategy it has used existing technology and production processes to secure a place in global value chains by means of its ability to produce at low costs – mainly because of the availability of enormous amounts of low-cost labour.[286] Yet China is intent on moving up the value chain, leaving behind its status as a low-cost, low-quality producer and exchanging its reliance on the export of cheap products for a more innovative economy based upon the development and production of high-technology and high-quality products.

For the Chinese government, this strategy is a clear necessity.[287] Even though China has a massive rural population – roughly half of the total – that can provide a steady inflow of cheap labour, wages and production costs are rising. The most extreme low-cost manufacturing industries are already relocating from China to other countries in Southeast Asia and elsewhere.[288] This makes it imperative for China to gradually shift its economy towards a more value-added economy.[289] Such a strategy also follows from a natural desire to gain a larger share of profits in the total production value chain – following the example of Japan and other East Asian Tiger economies before it.

This trend has global implications. Since Western countries are often unable to compete with China on costs, their main asset is to have a technological edge and higher-quality products. This advantage seems likely to erode over time, however. China is rapidly moving towards the technology frontier in several industrial sectors, improving both quality and reliability.

Yet there are still large discrepancies in China's domestic technological capabilities in different industrial sectors, making it difficult to generalize. Our analysis of several industries related to low-carbon energy and transportation has shown that in some sectors, such as solar photovoltaics, hydropower and possibly in the near future wind power equipment, the quality of Chinese export products is already quite high compared to that of international competitors. Combined with relatively low costs, the value proposition of Chinese firms is very strong. For other sectors, such as nuclear power and high-speed rail, China is evidently quickly building up its domestic industry skills even though a technology gap remains and global competitiveness might

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286 Mei-Chih Hua, John A. Mathews, 'China's National Innovative Capacity', *Research Policy,* Vol. 37, 2008, pp. 1465–1479.

287 For an excellent account describing China's situation and motivation, see: Philip Levy, 'China's Indigenous Innovation Policy and U.S. Interests', Written Testimony before the US House Committee on Foreign Affairs, Subcommittee on Terrorism, Nonproliferation, and Trade, 9 March 2011. Available online at: http://foreignaffairs.house.gov/112/lev030911.pdf.

288 *New York Times,* 'China Shifts Away From Low-Cost Factories', 15 September 2010.

289 *China Daily,* 'Innovate or slip down value chain', 31 December 2010. Available online: http://europe.chinadaily.com.cn/china/2010-12/31/content_11781705.htm.

be still some time off. In the case of hybrid and electric vehicles, Chinese domestic technological capacities are still quite far behind when viewed from a global perspective.

Nonetheless, for all different sectors that have been analyzed in previous chapters, it is clear that technological skills in China are rapidly improving and that there is a clear intention to build up domestic industries that can be globally competitive.

In this chapter we will analyze how the Chinese government is supporting its move towards a more innovation-centred economy in a general sense, incorporating a focus on 'indigenous innovation', an increase in R&D efforts and an advancement in the technological level of its industries and economy. This active push for domestic technology development coincides with policies that facilitate technology transfer from foreign technology leaders.

The status of innovation in China is being assessed, leading into a broader discussion about innovation: first, how does innovation compare to commercialization in terms of economic value? And second, in what sense might innovation in China be different from familiar processes in the West?

## Chinese Policies on R&D, Technology Development and Innovation

China is actively pushing for domestic technology development: by means of developing its domestic technology development and 'indigenous innovation' but also by gaining as much as possible through technology transfer from international knowledge leaders.

As of yet, Chinese R&D spending as a percentage of its GDP still lags behind many of its Western peers. However, in absolute terms it is already a world power: it has already overtaken Japan as the second largest spender on R&D, after the United States (Figure 14). Also in terms of university education, particularly for engineering studies, China is pressing ahead, and huge numbers of graduates leave Chinese universities each year.[290] In fact, China aims to create its own system of top universities comparable to the United States' Ivy League and has initiated a special *985 Program* and funding to create its "C9 League" of nine designated top universities.[291] In terms of human capital, another important factor is that many Chinese who have studied or worked abroad, return to work in China and bring with them their international experience. This has led to the expectation that China will also be able to increase its innovative capacity over time.[292]

[290] China's focus on engineering and R&D is also increasing the perception of its technical strength relative to other countries: according to a survey taken in 2010, China currently ranks fourth behind the US, Japan and Germany, but respondents expected China to take the top spot by 2015. Batelle, *2011 Global R&D Funding Forecast*, December 2010, p. 30. Available online at: http://www.battelle.org/aboutus/rd/2011.pdf.

[291] Batelle, *2011 Global R&D Funding Forecast*, December 2010, p. 28. Available online at: http://www.battelle.org/aboutus/rd/2011.pdf.

[292] Dirk Jan van den Berg, 'EU Must Act Fast and Share Knowledge With China', *Wall Street Journal*, 8 October 2010. Available online at: http://online.wsj.com/article/SB10001424052748704696304575538072642688764.html.

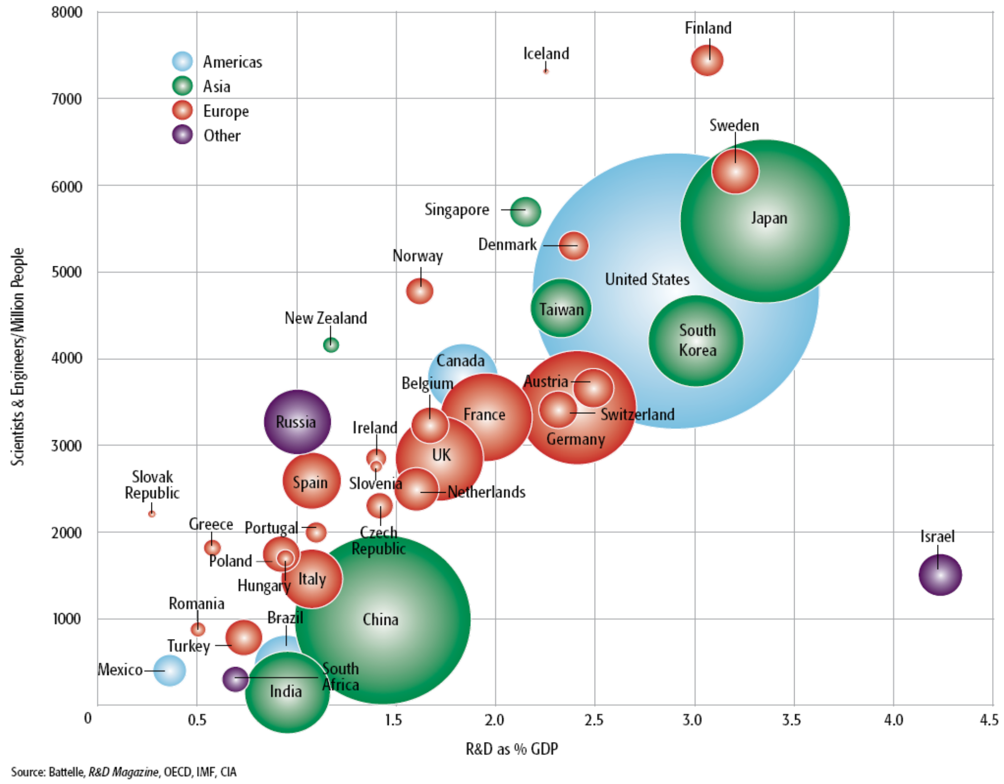


**Figure 14. Overview of Worldwide R&D in 2010.** Showing R&D as percentage of GDP and the number of scientists & engineers per million people for selected countries. Size of circle reflects the relative amount of annual R&D spending by the country noted. Source: Batelle, *2011 Global R&D Funding Forecast*, December 2010, p. 4.

Promoting domestic innovation has been elevated to a major policy goal with the latest (12th) Five-Year Plan. Several targets are aimed especially at stimulating scientific development and innovation:[293]

- There is a target for R&D spending measured as a percentage of GDP. This percentage stood at 1.75 in 2010, but the target is to increase this to 2.2 percent of GDP by the end of the 12th Five-Year Plan in 2015.
- For the first time in any Chinese Five-Year Plan, there is a specific target on the number of patents: 3.3 patents per 10,000 Chinese citizens by 2015. This would imply nearly doubling the amount of patents filed in 2010.

A set of new policies has also been introduced around the concept of *indigenous innovation* [自主创新]. As was mentioned in Chapter 1, several industry-specific plans (such as on renewable energy or nuclear power) mentioned the goal to develop national industries and domestic innovative capacities. In a more general context, the *Medium to Long-Term Plan for the*

[293] US-China Economic and Security Review Commission, *Backgrounder: China's 12th Five-Year Plan*, 24 June 2011, p. 8. Available online at: http://www.uscc.gov/researchpapers/2011/12th-FiveYearPlan_062811.pdf.

*Development of Science and Technology* issued in January 2006 states the following objectives for 2020:[294]

- Raising the contribution made by technological advances to economic growth to more than 60 percent;
- Limiting dependence on imported technology to no more than 30 percent (from an estimated 60 percent in 2006);
- Becoming one of the top five countries in terms of invention patents granted to its citizens; and
- Ensuring that Chinese-authored scientific papers are among the most-cited in the world.

One aspect in the development of domestic technological capacities is the creation of government-supported R&D programmes.

The case studies have provided examples how national R&D programmes have in some cases supported domestic technology development in low-carbon sectors. Since the start of China's economic reforms and the 'opening up' policies of the late 1970s, China has launched a series of national R&D programmes such as the *National High-Tech R&D Program (863 Program)*[295] that aimed to develop high technology industries and commercialize them. The *Torch Program* included the establishment of 53 high- and new-tech industrial development zones at a national level. Another large project is the *National Basic Research Program (973 Program)* that was launched in March 1997 and which for instance includes research into low-cost high-density energy storage systems for electric vehicles.[296] A significant part of both national research programmes focuses on the development of clean energy technology.[297]

Yet possibly even more important than the direct investment in R&D as a means to increase domestic technological capabilities is the knowledge that is being gained by means of technology transfer from foreign companies. In China, about 60 percent of the investment in R&D is being done by industry rather than the government. Moreover, in many sectors of the economy large state-owned enterprises play a major role, often enjoying the benefits of government support and advantageous financing.[298]

China has been particularly successful in creating circumstances that could enhance direct or indirect technology transfer. In the case of major national projects such as its hydropower and nuclear power expansion programmes or the construction of its high-speed rail infrastructure, it has played a decisive role in organizing international tenders and requesting technology transfer in exchange for market access. In these cases, state-owned Chinese companies have been appointed as the recipients of foreign technology and have been coupled with the international firms that have won the bidding contests.

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[294] This list is taken from: United States International Trade Commission (USITC), *China: Intellectual Property Infringement, Indigenous Innovation Policies, and Frameworks for Measuring the Effects on the U.S. Economy*, USITC Publication 4199, November 2010. Section 5, p. 3. Available online at: http://www.usitc.gov/publications/332/pub4226.pdf.

295 Named after the year and month in which it was approved: March 1986 [863计划] See: http://www.863.gov.cn/ [Chinese-only].

296 Chinese Ministry of Science and Technology (MOST), National Basic Research Program of China, 2011. Available online at: http://www.973.gov.cn/English/ReadItem.aspx?itemid=522.

[297] For a detailed analysis of the clean energy-related programmes included in the *863 Program* see: Evan Osnos, 'Green Giant: Beijing's Crash Program for Clean Energy', The New Yorker, 21 December, 2009. Available online at: http://www.newyorker.com/reporting/2009/12/21/091221fa_fact_osnos?currentPage=all.

[298] US Council on Foreign Relations, *Energy Innovation*, November 2010 , pp. xiv, 32.

Also in a more general sense, the Chinese government is encouraging joint ventures between local firms and foreign partners – examples within our case studies can be found in the automotive industry as well as the nuclear industry and wind energy industry. For these joint ventures, control over technology is also often a critical issue.[299]

More indirectly, domestic capacity for research and innovation is strengthened by foreign companies that are active in China. The Chinese government is encouraging foreign companies to invest in local R&D facilities, for instance by creating science parks with preferential treatment policies for foreign firms regarding taxes and fiscal matters: a pragmatic approach which shows similarities to the first Special Economic Zones that China initiated in the 1980s. China has been creating science parks such as Zhongguancun in Beijing (officially recognized as a national science park in 1988) and the Zhangjiang Hi-Tech Park in Shanghai (1992). By 2002, China had 44 national-level and 124 local university science parks, while plans have been announced to build another 100 national-level science parks.[300] Some analysts have questioned the effectiveness of Chinese science parks, yet the clear government support for specific sectors such as the 7 key sectors indicated in the 12th Five-Year Plan is certainly attracting foreign companies. The Chinese government has been particularly keen on attracting major R&D centres of multinationals and has been quite successful in this pursuit.[301]

Furthermore, China appears to use government regulation to support Chinese firms, such as by using localization requirements in the wind energy sector and by introducing government procurement preferences for domestic firms within its indigenous innovation policies.[302]

Not unlike in Europe or the United States, government procurement and policy measures are used in some sectors to create a 'demand pull' for emerging industries with the hope of creating sufficient economies of scale to stimulate further independent growth. In this respect, examples that spring to mind are the wind and solar PV sectors, as well as the hybrid and electric vehicle industry.

Naturally, the strong government push regarding 'indigenous innovation' that favours domestic companies is leading to tensions in the trade sector.[303] Yet it should also be recognized that the policies deployed by China are not unique and are in fact in many ways reminiscent of how other countries have tried to climb up the value chain and guide economic development. We will discuss this issue in some more detail in later sections.

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[299] For more on joint venture strategies in China for international firms, see: *McKinsey Quarterly*, 'Past Lessons for China's New Joint Ventures', December 2010. Some of the key strategies to safeguard intellectual property are discussed in the article, such as: bringing only older technology to China; leaving the blueprints at home; keeping critical intellectual property completely out of a joint venture or charging for intellectual property upfront.

[300] *China Daily,* 'China to Build 100 University Science Parks', 17 October 2003. Available online at: http://english.peopledaily.com.cn/200310/17/eng20031017_126234.shtml.

[301] 'Business leaders identify China as the top destination for future overseas R&D spending, followed by the USA, India, the UK and Germany - a result that marks the growing attractiveness of key emerging markets as locations for technology innovation.' *Economist Intelligence Unit*, 'Scattering The Seeds of Invention: The Globalisation of Research and Development', 2004. Available online at: http://graphics.eiu.com/files/ad_pdfs/RnD_GLOBILISATION_WHITEPAPER.pdf.

[302] James McGregor, 'China's Drive for Indigenous Innovation: A Web of Industrial Policies', APCO Consulting, July 2010. Available online at: http://www.apcoworldwide.com/content/PDFs/Chinas_Drive_for_Indigenous_Innovation.pdf.

[303] Adam Segal, 'China's Innovation Wall. Beijing's Push for Homegrown Technology', *Foreign Affairs*, 28 September, 2010. Available online at: http://www.foreignaffairs.com/articles/66753/adam-segal/chinas-innovation-wall; American Chamber of Commerce in China (AmCham), *2011 White Paper*, 2011. Section on Innovation Policy, Industrial Policy and Market Access. Available online at: http://web.resource.amchamchina.org/cmsfile/2011/04/25/531a4229bf929d61e0963dfdac96f1e0.pdf.

## Status of Innovation and IPR Development in China

Among Western observers, there exists quite some anxiety about the possibility that China will successfully gain an advanced position in the field of science, technology and innovation.[304] Depending on how long its (labour) cost advantage will last, success in the innovation and R&D field would make China a formidable global competitor.

The current status and prospects of innovation in China, however, are strongly debated. Those negative about these prospects point at the educational system and 'culture of conformism', and argue that this is hampering the development of critical innovative thinking and a free and open innovation system. Also the heavy-handed way in which the Chinese government is 'appointing' state-owned enterprises as industry leaders and 'picking winners' is seen as stifling rather than promoting innovation.[305] While these arguments might hold truth, the relevant question is how the current situation might evolve in the future, given the policies that have been described in the previous section.

The extent of innovation in a country is often measured by using patent filing data as a proxy.[306] In this regard, China has shown a strong growth which has been further accentuated by the economic and financial crisis.[307] Yet given that very few real, global 'breakthrough' innovations have emerged from China up to now, this growth has also attracted criticism as consisting for a large part of junk patents filed to meet the government targets.[308]

If we consider the energy sector and several low-carbon technologies, the current degree of Chinese innovation is still very limited, as confirmed by our case studies.[309]

In almost all sectors that we have analyzed in this paper, the technologies being used in China stem from foreign sources and little 'real' innovation has been added up to this point for most sectors – although Chinese reports are more optimistic about this. Also in sectors such as solar

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304 *New York Times,* 'Will China Achieve Science Supremacy?', 18 January, 2010. Available online at: http://roomfordebate.blogs.nytimes.com/2010/01/18/will-china-achieve-science-supremacy/; Christopher J. Forster, *China's Secret Weapon? Science Policy and Global Power*, U.K. Foreign Policy Center, April 2006. Available online at: http://fpc.org.uk/fsblob/753.pdf; *New York Times,* 'When Innovation, Too, Is Made in China', 1 January, 2010. Available online at: http://www.nytimes.com/2011/01/02/business/02unboxed.html?_r=1.

305 George J. Gilboy, 'The Myth Behind China's Miracle', *Foreign Affairs*, July/August 2004. Available online at: http://www.foreignaffairs.com/articles/59918/george-j-gilboy/the-myth-behind-chinas-miracle; BusinessWeek, 'Obstacles to Innovation In China and India', 25 September 2006. Available online at: http://www.businessweek.com/magazine/content/06_39/b4002421.htm.

306 Mei-Chih Hua, John A. Mathews, 'China's National Innovative Capacity', *Research Policy,* Vol. 37, 2008, pp. 1465–1479.

307 *Wall Street Journal,* 'China Issued Record Number of Patents in 2009', 4 February 2010. Available online at: http://online.wsj.com/article/SB10001424052748703575004575042691331624302.html. 'In 2008, the total number of patent applications filed across the world grew by 2.6%, compared to 2007. This is the lowest growth rate since the dot-com crisis in the early 2000s. The slowdown is largely due to zero growth in applications filed in the United States of America (US), and a drop in applications in Japan (-1.3%) and the Republic of Korea (-1.1%). The substantial growth of applications in China (+18.2%) prevented the worldwide total from reaching zero growth in 2008.' Citation from: World Intellectual Property Right Organization (WIPO), 'Signs of Recovery Emerge after Economic Crisis Hits Innovation & IP Filings', Available online at: http://www.wipo.int/pressroom/en/articles/2010/article_0029.html.

308 *Wall Street Journal,* 'China as an Innovation Center? Not So Fast', 28 July 2011.

309 Linda Jakobson, *Innovation with Chinese Characteristics: High-Tech Research in China,* Finnish Institute of International Affairs, 2007; Watson, J. et al, *UK-China Collaborative Study on Low-carbon Technology Transfer: Final Report*, Report to the UK Department of Energy and Climate Change, Sussex Energy Group, April 2011. Available online at: http://www.sussex.ac.uk/sussexenergygroup/research/ukchina.

PV, in which Chinese manufacturers have gained a dominant global market share, the underlying manufacturing technology still originates mostly from Europe or other OECD countries.

A number of studies have also indicated that traditional industry leaders from Europe, Japan and the United States still have a clear lead in terms intellectual property rights and international patents.[310] Particularly the United States is known for groundbreaking research and for providing a very dynamic business environment for start-up firms with angel investors and venture capital funds that are keen on picking the most promising technologies to invest in.[311]

Although the above observations might prompt the conclusion that the leadership in terms of developing innovative technologies remains in Western countries, we wish to delve somewhat deeper into this subject and bring forward some additional observations.

## Innovation in China: Developing its Own Characteristics?

One important question is whether patenting is in fact a good proxy for measuring innovation. Although IPR development is an important element in the development of breakthrough technologies, there are certain aspects of the Chinese market and innovation processes which might not be captured by statistics on IPR development. We list two key issues here:

- **Fierce domestic competition ensures that Chinese companies are often extremely cost-competitive, which is having a global impact.** Faced with enormous pressure from their home market, Chinese companies need to be extremely cost-efficient, and one of the strong points of innovation in China is cost innovation.[312] Although China's international cost advantage derives in large part from its labour cost advantage, the cost-focused domestic economy also spurs cost innovation which goes beyond employing cheap labour.[313]

  Regarding the industries that we observed, a distinction should be made between the sectors which are dominated by large state-owned companies which essentially have a domestic monopoly and feel less competitive pressure (such as nuclear power and high-speed rail) and sectors where domestic competition is very fierce (e.g. solar and wind energy and the Chinese automotive industry). A multitude of Chinese companies have shown they are able to creatively employ cost-cutting methods: examples in the solar PV sector or BYD in the electric vehicle sector illustrate this point.

  Consequently, in some sectors Chinese companies have succeeded in turning high-priced, low-volume specialty products into mass consumer products that sell high volumes due to the decreased costs.[314] This will be particularly valuable in the low-

[310] United Nations Environment Programme (UNEP), European Patent Office (EPO) and International Centre for Trade and Sustainable Development (ICTSD), *Patents and Clean Energy: Bridging the Gap Between Evidence and Policy*, 2010.

[311] According to Bloomberg New Energy Finance (BNEF), North America accounted for 67 percent of the global total invested venture capital and private equity in the renewable energy sector. Bloomberg New Energy Finance, *Global Trends in Renewable Energy Investment 2011*, 2011, p. 34; United Nations Environment Programme (UNEP), European Patent Office (EPO) and International Centre for Trade and Sustainable Development (ICTSD), *Patents and Clean Energy: Bridging the Gap Between Evidence and Policy*, 2010.

[312] Peter Williamson and Ming Zeng, 'How to Meet China's Cost Innovation Challenge', Ivey Business Journal, May/June 2008. Available online at: http://chinaanalysis.com/cat1_innovation/media/users/williamson/Ivey%20Business%20Journal%20-%20FEATURE%20ARTICLE.pdf.

[313] Lenny T. Mendonca, 'Innovation from Asia', *McKinsey Quarterly*, February 2005.

[314] Peter Williamson and Ming Zeng, 'How to Meet China's Cost Innovation Challenge', Ivey Business Journal, May/June 2008. Available online at:

carbon energy sector, where a major constraint on broader deployment is the high cost. The developments in solar PV, and possibly in the near to medium future also for wind energy, high-speed rail and nuclear power all illustrate that Chinese cost-competitiveness can have a global impact if combined with a sufficient degree of quality.

- **Chinese innovation might look different from what we are used to.** There exists a certain stereotypical image about innovation in the Western world: from R&D efforts there emerges some breakthrough innovation, which is subsequently patented. If it can be commercialized into a competitive product successfully, it will be introduced to the market by its parent company.

  However, there are signs that Chinese 'innovation' works in a slightly different way. First of all, conditions are different: Chinese companies often have very little R&D budgets and the pressure to cut costs is enormous due to the multitude of domestic competitors and price-sensitivity of the market. Also, the intellectual property rights (IPR) system is much less developed, so Chinese companies cannot expect to make a handsome profit from having a monopoly on some innovation or product like in European markets.[315] Yet this is not to say that there is no innovation going on in China. Although innovations in China are mostly incremental in nature, they can still have a large impact – something that is also illustrated by our case studies.[316] Scale and price have been identified by some observers as two key competences of China that can drive a different type of innovation.[317]

  The above factors might contribute to innovation in China developing some particular characteristics. According to Winter Nie, four separate aspects can be distinguished: on-site innovation, innovation to reduce costs, tailored innovation and rapid product innovation.[318]

  That China's particular economic growth model and circumstances can lead to alternative approaches to innovation also has historical precedents, and Japan can serve as an example. The Japanese growth model, which also included the 'digestion' of foreign technologies and building further upon that, has for instance delivered unique ways of managing companies. The success of just-in-time inventory management and 'lean management' made Toyota the world's largest car company, for instance.[319] Moreover, the Japanese approach also entailed growing beyond its reputation for being a 'copy-cat' and producing cheap, low-quality goods to being one of the industries most respected for high-quality and advanced technology products.

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http://chinaanalysis.com/cat1_innovation/media/users/williamson/Ivey%20Business%20Journal%20-%20FEATURE%20ARTICLE.pdf.

[315] For a discussion on the role of the IPR regime on technological innovation in China see: Richard P. Suttmeier and Xiangkui Yao, *China's IP Transition - Rethinking Intellectual Property Rights in a Rising China*, Special Report #29 of the National Bureau of Asian Research (NBR), July 2011, p. 15. Available online at: http://www.nbr.org/Publications/element.aspx?id=520.

[316] *Economist*, 'The World Turned Upside Down', 15 April 2010; Stefan Wagstyl, 'Innovation: Replicators No More', *Financial Times*, 5 January 2011. Available online at: http://www.ft.com/intl/cms/s/0/97a67340-1904-11e0-9c12-00144feab49a.html#axzz1cglzzabL.

[317] *Forbes*, 'China's Innovation Advantage', 7 August 2009. Available online at: http://www.forbes.com/2009/08/06/china-innovation-dcm-intelligent-technology-david-chao.html.

[318] Winter Nie, 'Chinese Innovation – Lessons from the East', *Innovation Management*, 5 September 2011.

[319] John Krafcik, 'Triumph of the Lean Production System' *Sloan Management Review, 30*(1), 1988, pp. 41-51.

## The Value of Innovating Versus Commercializing

A second question to be posed in relation to the observation that traditional industry leaders in Europe, Japan and the United States are still ahead in terms of developing IPR and patenting, is how much this actually matters when an important part of the economic benefit is about commercializing technology and bringing it to the market.

Leadership in basic research and innovation is not the same as economic leadership, since owning a patent and developing a profitable manufacturing business are two different steps. In order to truly capitalize on breakthrough innovations they need to be followed-up by successful upscaling, commercialization, market introduction and secondary innovations that will elaborate on a new technology.[320] It is in this aspect that China is competing strongly with Europe, Japan and the United States, as it has proven that it is very capable of scaling-up manufacturing and delivering on the domestic and export potential.

That China can offer a rapidly expanding domestic market and clear government support are critical elements to its success in this respect. As a concise overview shows, the existence of a strong domestic market and government support has been instrumental in the developing of some of the global industry leaders. Putting it differently: it is no coincidence that Vestas is Danish, Areva is French and Toyota and Honda are Japanese (see Box 2).

The thesis that "scientific pre-eminence does not necessarily lead to economic success" is borne out by a host of examples.[321] Studies have shown that quite often other companies than the 'lead innovator' actually get the chance to make a profit from the development and deployment of the product.[322]

Within our analysis, Japan and its role in developing solar PV technology is a case in point. Japan has historically played a very important role in developing solar PV technology, which it defined as a focus area in the 1970s in response to the oil crises of that decade. In the early 2000s, Japan was still by far the most dominant market, both in installed capacity – accounting for 44 percent of the world's total – as well as in technology and solar PV production capacity.[323] As recently as 2005, Japan still dominated the market, being home to the first four firms of the top-ten solar PV cell and module manufacturers.[324]

[320] James Manyika, Daniel Pacthod, and Michael Park, 'Translating Innovation into US Growth: An Advanced-industries Perspective', *McKinsey Quarterly*, May 2011. Available online at: https://www.mckinseyquarterly.com/Translating_innovation_into_US_growth_An_advanced-industries_perspective_2810.

[321] Quote taken from: Stefan Wagstyl, 'Innovation: Replicators No More', *Financial Times*, 5 January 2011.

[322] 'The power of innovation to create economic value and reward pioneers with exceptional profits is a deeply-held belief of inventors, entrepreneurs, investors and the public. Innovation can enrich companies and individuals and sometimes disrupt entire industries. Yet many studies have shown that the value from innovation is often captured by someone other than the original innovator, whether by imitators, suppliers of key components, intellectual property owners, or providers of related products and services.' Although this particular paper focuses on consumer electronics, there are strong signals that this observation also holds for energy technologies. Jason Dedrick, Kenneth Kraemer, Greg Linden, 'Who Profits from Innovation in Global Value Chains? A Study of the iPod and notebook PCs', MIT Sloan Industry Studies Annual Conference, May 2008. Available online at: http://web.mit.edu/is08/pdf/Dedrick_Kraemer_Linden.pdf.

[323] IEA, *Technology Roadmap – Solar Photovoltaic Energy*, 2010, p. 6. Available at: http://www.iea.org/papers/2010/pv_roadmap.pdf.

[324] The global top four firms were Sharp Electronics, Kyocera Solar, Sanyo Electric and Mitsubishi Electric. Boston Consulting Group (BCG), *Sunrise in the East .China's Advance in Solar PV—and the Competitive Implications for the Industry*, December 2010, p. 2.

### Box 2: The Importance of a Home Market for Creating Industry Leaders

A quick overview of major industry leaders in the low-carbon sectors that we evaluated shows the importance of the home country providing a major expansion opportunity for the industry to grow and mature:

Sinohydro is now a global market leader in dam construction worldwide since it benefited from the major hydropower expansion projects in China in which it took a major share.

The French nuclear industry took off after France embarked on its nuclear power expansion programme in response to the oil crises of the 1970s. Other global players such as Atomstroyexport (Russian), GE-Hitachi (US-Japanese), Toshiba-Westinghouse (US-Japanese) all come from countries with strong markets for nuclear power. South Korea is the most recent global player that has emerged, also illustrating the point.

Concerning wind energy, leading companies come from countries that strongly pushed for the development of wind power: Vestas from Denmark; Enercon, Siemens and REpower from Germany; GE Wind from the US; Gamesa from Spain and Suzlon from India.

Japan has a dominant position in hybrids and electric vehicles and in the relevant battery technology as well – as was analyzed in our earlier chapter. In 2009, Japan accounted for 45% of the global market for hybrid vehicles due to its strong incentive schemes and consumer preferences for Japanese cars such as the Toyota Prius and Honda Insight.

For high-speed rail, most leading firms come from Japan (Kawasaki Heavy Industries) and Europe (Siemens, Alstom). Bombardier is the exception, being originally Canadian but having a very strong European presence. More recently, Spain gave rise to its own high-speed rail firm in the form of Talgo, which benefited from the domestic expansion projects.

Vice versa, even though industries have become more globalized, markets are often localized to a large extent. We can take wind energy and automotive markets as an example.

Concerning the German wind turbine market, German firms account for 74 percent of the market. When counting all European brands the share reaches 94.5 percent. In Spain, Spanish firms account for 51 percent – when including all European brands it's 91 percent. The US is slightly more international, with American brands, such as GE and Clipper, together accounting for almost 45 percent. In India, domestic firms have a market share of nearly 60 percent.

Regarding automotive markets, Japan and Korea have very strong domestic car manufacturers that have market shares of 94 and 73 percent in their own markets, respectively. Also in Germany, France and the United States, domestic manufacturers account for more than half of the market.

Sources: Margaret Zewatsky, 'Asia Pacific Region Propels Growth of Hybrid Market', PolkView, March 2010; Infrastructurist, 'Meet the Train Makers', November 2009; CREIA, GWEC and Greenpeace, *China Wind Power Outlook 2010,* October 2010, p. 5; Yu Dawei, 'Domestic Car Makers Eye More M&As', *Caixin Magazine*, 15 April 2010.

This edge in the global market has now been lost to China and, to a lesser extent, other countries that have begun to develop their own solar PV industries. Although Japanese firms still have a very strong position in terms of technology patenting (accounting for 13 of the 19 top patent holders in the solar PV industry[325]) it still appears to have difficulties in reaping the benefits from its investment in R&D in this sector.

When considering possible future economic benefits, it is important to realize that the development of new technologies may have important spin-off effects. In the case of wind energy, one can think of the related composite material technology which is being used for the wind turbine blades. Through the rapid demand growth this has been going through an enormous development which could have much wider impact than the energy sector alone.[326] In the hybrid and electric vehicle sector, technological progress will be strongly linked to advances in battery technology, which offers a much wider functionality. Nanotechnology is another key field that interacts with these sectors and which plays a major role in technological advances in batteries, composite materials, and solar photovoltaics.

Taking Denmark as an example, its leading role in developing wind energy domestically did not only give rise to Vestas as a global market leader, but also led to the success of several other related Danish firms along the value chain: the Danish firm LM Glasfiber, for instance, started with wind turbine blade manufacturing in 1978 and had gained a 40 percent global market share by 2001.[327] Another successful Danish wind turbine firm, Bonus, was acquired in 2004 by Siemens and has formed the basis for Siemens' Wind Power division.[328]

## Conclusions

Although China might not have the capacity to become an innovation leader in the near future and upend the dominant position in terms of the energy technology IPR development of OECD countries, it nonetheless has some strong advantages that could allow it to take the lead in commercializing technology and creating incremental or cost innovations.

Although the case studies have shown that the technological level of Chinese low-carbon industries is still mixed, they also show how government support is strengthening their development and improving the technological and innovative capabilities of selected industries. In particular we can identify the following common themes:

- **Strong and consistent government support,** with ambitious targets and implementation measures.
- **A push for technology transfer,** in exchange for market access or by attracting foreign investment, including R&D.
- **Pragmatism and a willingness to experiment,** by means of pilot projects, best practices, learning-by-doing.
- **Creation of a demand 'pull' for domestic industries,** by regulation on local content, government procurement and using state-owned enterprises.

Overall, both industry trends within the case studies and our assessment of science and technology policy show that it is almost inevitable that China will increase its technological and innovative capacity in coming decades and become a stronger global competitor.

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[325] Chatham House, *Who Own Our Low-carbon Future?*, September 2009, p. 26.

[326] Joseph A. Grande, 'Wind Power Blades Energize Composites Manufacturing', *Plastics Technology*, October 2008. Available online at: http://www.ptonline.com/articles/wind-power-blades-energize-composites-manufacturing.

[327] Donna Dawson, 'Big Blades Cut Wind Energy Cost', *Composites World*, February 2003. Available online at: http://www.compositesworld.com/articles/big-blades-cut-wind-energy-cost.

[328] *Power Engineering International*, 'A wind Bonus for Siemens', 1 November 2004.

# 9

# Challenges for the Future

In this chapter we will evaluate some key issues regarding China's emergence as a global competitor and possible future role in terms of innovation and technology development.

We analyze two key determinants in more detail:

- Will the rapid development of clean energy sectors in China be sustained?
- Will protectionist tendencies in clean energy markets ('green protectionism') become more intense in future, influencing market developments?

In a concluding section we will present an analysis of the respective challenges that Chinese and Western companies will need to address in the face of growing global competition.

## Can and Will China Sustain its Push for Clean Energy Development?

In this paper we have discussed how China has a number of advantages in pushing for the development of clean energy technologies. We observed that the growth of its domestic market has been instrumental for it to build up its own industrial sectors in the clean energy field. This led us to the question of whether China can and will in fact continue its massive push for clean energy development domestically.

This is particularly relevant since China is experiencing the same problems as Western countries with regard to its clean energy technology deployment:

- Despite the massive investments in renewable energy capacity (especially wind) the actual contribution of renewable energy to the overall energy system in China is still only very limited.
- Grid companies have not been keen on integrating the intermittent and variable wind farm output, which has led to a massive number of Chinese wind farms not being connected to the grid. The massive support for industry growth has led to 'overheating' and quality problems, as is now acknowledged by the Chinese government.
- The most promising regions for wind and solar energy are far from electricity demand centres, requiring enormous investments in the electricity grid.
- Difficulties to influence customer preferences: Chinese car buyers often do not wish to buy hybrids or electric cars but rather opt for expensive large SUVs.

Apart from these issues, there is of course the question of costs and whether the results warrant the huge investments that China is making in this sector. Bringing down costs of clean energy technologies is as important in China as they are in Western countries. The current support for new energy technologies such as onshore and offshore wind power, solar PV and "new energy" vehicles are undertaken with the clear view that costs should be driven down in the coming period to make these energy sources economically competitive. Chinese policy makers realize very well that they are unable to support the deployment of renewable energy sources indefinitely and that also for China there will be limits to the financial means that can be made available. Although the current situation and system still leaves scope for further support (see Box 3 on China's Feed-In Tariff System), this question will need to be addressed in the longer run.

### Box 3: The Cost of Renewables: China's Feed-In Tariff System

To finance its renewable energy stimulus policy, China has adopted a system similar to Germany's. For wind farm development feed-in tariffs have been implemented, which guarantee a set price for the electricity produced for fixed period, usually 20 years or so. Since the set price is above conventional electricity production costs, the extra costs of this support mechanism are then spread out over all electricity users (with a few exceptions) by means of a 'renewable energy surcharge'.

The Chinese *Renewable Energy Law* introduced such a surcharge for almost all users, set at 0.001 RMB per kWh in 2006. It has been raised a few times since and will be 0.006 RMB/kWh in 2012. Compared to residential electricity prices of circa 0.7 RMB/kWh this is still less than 1 percent.

In comparison: in Germany the surcharge has been increased as well a few times since its introduction. It is now set to reach 3.592 eurocents/kWh in 2012, nearly 15 percent of the total retail consumer electricity price of about 25-26 eurocents/kWh.

While the renewable energy surcharge is increasing, overall electricity prices in China are also showing a clear upward trend (Figure 15). Although the inclusion of a solar energy feed-in tariff will accelerate the costs of renewable energy deployment support in China, the current surcharge is still relatively small, which leaves room for continuing the current support schemes as they are.

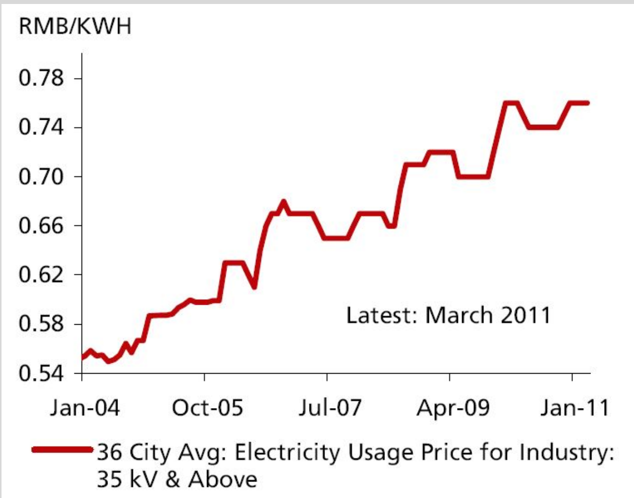


**Figure 15. Gradual price increase of Chinese Electricity Prices**. Source: DBS Group Research, 'China: A Case Study of Price Control on Electricity', 20 May 2011. Available online at: https://www.dbsvresearch.com/research%5Cdbs%5Cresearch.nsf/(vwAllDocs)/17F0CBCF95C2A3324825789600198A4F/$FILE/CN_110520.pdf.

## Will 'Green Protectionism' Impact Global Clean Energy Markets?

Given their relation to financial support from public funds, clean energy markets run the risk of becoming more politicized as global competition increases. This holds in particular for those technologies that are not yet cost-competitive in the current market, such as wind energy, solar energy and electric vehicles. The case studies have shown that some signals of this are already apparent.

Increasingly, climate policy is being framed as industrial or economic policy: targets are expressed in terms of green growth, a green economy and the creation of green jobs. However, this means that there are expectations that green energy investments will lead to 'green jobs' locally. To ensure that the public financial support that is available for clean energy policies will increase local welfare and create 'green jobs', many countries have included localization requirements with such policies. This does not always go undisputed, however; explicit preferential rules for domestic producers can violate WTO regulation.

We have seen how China has used local content rules within its wind energy sector, but the use of such regulation is not limited to China alone. For instance, Canada included regulation that required clean energy projects in the province of Ontario to use locally manufactured equipment. This policy was subsequently challenged in a WTO case by Japan, in which the US and EU later joined.[329] Also Brazil and India have issued localization requirements coupled to their renewable energy policies.[330] Another example is the US, where a local content clause for rail projects requires at least 60 percent of locally manufactured components.[331]

For large international firms in the clean energy field, such as the wind turbine manufacturer Vestas, these localization requirements are already making it more difficult to run an efficient global manufacturing chain.[332]

In the case of China, which is perceived as a major economic competitor, the notion that public funding from Western countries is contributing to the growth of the Chinese clean energy manufacturing sector has started to cause quite some political protectionist responses.

An early signal has been the rejection and subsequent discussion about the additionality of Chinese wind farm projects undertaken under the Clean Development Mechanism (CDM) of the United Nations Framework Convention on Climate Change (UNFCCC) in the run-up to the COP-15 Copenhagen meeting in December 2009. This mechanism is intended to encourage climate change mitigation actions such as renewable energy development in developing countries. A key criterion is that such projects would not have taken place without this additional support – an inherently difficult condition to prove.[333] The Clean Development Mechanism has indeed

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329 *Reuters,* 'Ontario's Green Energy Push Draws Fire From Japan, U.S. and E.U.', 12 October 2010. Available online at: http://www.reuters.com/article/2010/10/12/idUS84066630720101012.

330 See section on 'Local Content Rules' in: Bloomberg New Energy Finance, *Global Trends in Renewable Energy Investment 2011*, 2011, p. 29.

331 Marcy Lowe, Saori Tokuoka, Kristen Dubay and Gary Gereffi, *U.S. Manufacture of Rail Vehicles for Intercity Passenger Rail and Urban Transit. A Value Chain Analysis*, Center on Globalization, Governance & Competitiveness, Duke University, 22 June 2010, p. 4. Available at: http://www.cggc.duke.edu/pdfs/U.S._Manufacture_of_Rail_Vehicles_for_Intercity_Passenger_Rail_and_Urban_Transit.pdf

332 Vestas, 'Fighting the Rise of Green Protectionism', news item, 13 July 2010. Available online at: http://www.vestas.com/Default.aspx?ID=10332&NewsID=2342&action=3.

333 Gang He and Richard Morse, *Making Carbon Offsets Work in the Developing World: Lessons from the Chinese Wind Controversy*, Program on Energy and Sustainable Development Working Paper #90, March 2010 . Available online at:

contributed to the growth of Chinese wind energy capacity. Although in financial sense the support should not be overestimated, it has led to questions regarding whether or not China needed such support when it had already become one of the world's strongest global growth markets.[334]

A more general case was brought forward by the US Steelworkers Union (USW) that filed a complaint accusing China of unfair support for its clean energy industries in September 2010. Several aspects were identified that allegedly would be in violation of WTO rules, including: (1) restrictions of access to critical materials; (2) prohibited subsidies contingent on export performance or domestic content; (3) discrimination against imported goods and foreign firms; (4) technology transfer requirements for foreign investors; and (5) trade-distorting domestic subsidies.[335] The complaint was taken up by the US Trade Representative to the WTO, after which China agreed to cancel a special fund supporting its domestic wind industry.[336]

More recently, the large amounts that are being spent on subsidizing the deployment of solar photovoltaics has come under scrutiny since more than half of the manufacturing sector for solar panels is dominated by China. As some commentators put it, European feed-in tariff systems are now subsidizing China's green energy revolution.[337] Remarks in a similar vein have been made by the French Environment Minister Nathalie Kosciusko-Morizet who declared that '[n]inety percent of the solar panels installed in France come from China and our import criteria must be strengthened. (..) We are not here to subsidize the Chinese economy but to create green jobs in France.'[338]

In the United States, similar complaints have come up, especially now that the domestic solar energy industry is clearly suffering from low-cost Chinese competition. President Obama has been requested by a Democratic Senator to curb the imports of Chinese solar panels, and a ban on the import of Chinese solar panels has already been instigated by the Department of Defense.[339] The political sensitivity on this topic has only become stronger since several American solar energy firms went bankrupt (such as Solyndra) and remaining solar PV producers in the US have filed a case at the Department of Commerce accusing the Chinese of 'dumping' their panels below market prices and requesting extra import tariffs.

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http://pesd.stanford.edu/publications/making_carbon_offsets_work_in_the_developing_world_lessons_from_the_chinese_wind_controversy.

[334] For a thorough discussion on Chinese wind power development and the Clean Development Mechanism, see section 6.4 in: Li Junfeng, Shi Pengfei and Gao Hu, *China Wind Power Outlook 2010*, 2010, pp. 54-57.

[335] Office of the United States Trade Representative, 'United States Launches Section 301 Investigation into China's Policies Affecting Trade and Investment in Green Technologies', October 2010. Available online at: http://www.ustr.gov/node/6227. United Steelworkers, 'United Steelworkers' Section 301 Petition Demonstrates China's Green Technology Practices Violate WTO Rules', 9 September 2010. The original petition text is available at: http://assets.usw.org/releases/misc/section-301.pdf.

[336] Office of the United States Trade Representative, 'China Ends Wind Power Equipment Subsidies Challenged by the United States in WTO Dispute', June 2011. Available online at: http://www.ustr.gov/about-us/press-office/press-releases/2011/june/china-ends-wind-power-equipment-subsidies-challenged.

[337] Remarks by participant of the EU Joint Research Center conference, 'Politics & Economics of European Energy Security', Amsterdam, 19 November 2010.

[338] *Bloomberg*, 'France Calls for Curbing Chinese Solar-Panel Imports', 21 December 2010. Available online at: http://www.bloomberg.com/news/2010-12-21/france-should-curb-chinese-solar-panel-imports-minister-says.html.

[339] *Reuters*, 'Senator Asks Obama to Curb Chinese Solar Panels', 8 September 2011. Available online at: http://www.reuters.com/article/2011/09/08/us-usa-china-trade-solar-idUSTRE7875DW20110908. Keith Bradsher, 'Pentagon Must "Buy American," Barring Chinese Solar Panels', 9 January 2011. Available online at: http://www.nytimes.com/2011/01/10/business/global/10solar.html?pagewanted=all.

The Chinese Ministry of Commerce has responded by launching an investigation into US government support for clean energy.[340] The discussion about this trade dispute shows the complexity of these trade flows and global value chains, as China is actually importing the poly-silicon it needs for solar panel manufacturing from the United States. According to some reports, the value of the exported poly-silicon is greater than the solar panel imports, which would still make the United States a net beneficiary of its solar energy sector trade with China.[341] Moreover, approximately half of the total cost of solar PV systems is spent on the installation of panels, which is inherently local.[342] This nuance is lost, however, in the politics surrounding the issue, and the debate is threatening to hamper an open trade system for global clean energy deployment.

What these developments illustrate is that clean energy deployment runs the risk of becoming more of a politicized issue; something which is almost inevitable given that public funding is involved and considering the current economic and financial pressure. If such tensions about fair trade in clean energy were to escalate, this could have serious repercussions for the global market for clean energy products and to the reciprocity that is offered by China and OECD countries.

## Global Competition: Challenges for Chinese and Western Companies

In the above sections and previous chapters we have sketched a number of developments in terms of technology development, innovation, global competition and 'green protectionism'. Consequently, Chinese and OECD companies that are active in low-carbon industrial sectors face their own set of particular challenges in order to be successful.

For Chinese companies we can identify the following key issues:

- **Shedding the 'low-cost, low-quality' image and gaining a reputation for quality products.** There is no reason why China could not become a producer of high-tech, high-quality products. The historical example of Japan has shown that it is perfectly possible to make a transition from imitation and low-cost production to high-tech manufacturing. Progress in this direction is visible although there is still quite some work to be done before China can achieve this goal. Moreover, perception also plays an important role and a next challenge for China will be to earn worldwide recognition for its higher quality products.

  China might be particularly vulnerable to setbacks in this aspiration given the fact that there is a strong impression that the Chinese government and companies are so demanding in their push towards technological development and deployment that they sometimes sacrifice safety considerations in order to meet certain targets in time. The Wenzhou high-speed rail accident is a case in point.

  Doubts about the exact quality level might be willingly accepted in the case of solar panels or wind turbines, if the cost advantages are sufficiently attractive. Yet especially for technologies where safety and reliability are critical, such as nuclear power, high-speed rail, electric cars, and possibly offshore wind power, it is less likely that quality and safety requirements will be made subordinate to economic considerations.

[340] *Financial Times,* 'China to Probe US Clean Energy Subsidies', 25 November, 2011. Available online at: http://www.ft.com/intl/cms/s/0/22d9033e-174b-11e1-b20e-00144feabdc0.html#axzz1gG5u1YDX.
[341] ChinaFAQs (by World Resources Institute), 'Trade Case on Imports of Solar Cells from China', 7 December 2011. Available online at: http://www.chinafaqs.org/blog-posts/trade-case-imports-solar-cells-china.
[342] European Photovoltaic Industry Association, *Global Market Outlook for Photovoltaics until 2015,* May 2011, p.36.

Following the bullet train crash, analysts have been quick to point out that consequent quality concerns might also impact upon potential future exports of nuclear technology by China, since also in this field safety requirements are of paramount importance.[343]

- **Realizing the export potential and gaining market acceptance in spite of protectionist signals.** Especially with tension emerging over restricted access to the Chinese market and China's 'indigenous innovation' policies, the reciprocity of market access to Western markets for Chinese products will be put to the test, as discussed in the previous section. Although the domestic Chinese market provides ample growth opportunities, it will be crucial for Chinese companies to deal with these political sensitivities if they wish to be successful globally.

- **Moving from 'absorbing' foreign technology to creating 'real' innovation.** The question of whether this is possible ties in to the debate on innovation in China discussed in the previous chapter. As of yet, technological progress by Chinese manufacturers has mostly consisted of incremental improvements upon imported technology. Examples are the development of larger (and offshore) wind turbines, and the goal of developing an indigenous CAP1400 reactor on the basis of Westinghouse's AP1000 nuclear reactor design. Being able to manufacture existing products at lower costs and being able to develop incrementally better products based on similar designs can offer a very effective way to become a major player in these respective global markets (as the solar PV market and hydropower cases illustrate), yet for long-term global success China will eventually also need to be able develop its own technologies, especially if it becomes more difficult to obtain state-of-the-art technology from abroad. However, it remains an open-ended question as to whether China will be able to match the technological innovation systems of Western countries.

On the other hand, leading Western firms will need to deal with a changing situation in terms of global competition and innovation, and with the emergence of China as a major growth market and competitor.[344] Specific challenges are the following:

- **Addressing the cost challenge coming from China.** For Western companies Chinese competition means even more distinctly then before that they will have to prove they are worth the extra cost. Given that Chinese firms come from a business environment which is enormously cost-focused, it will be hard to rival them on costs. However, in order for Western firms to get the right balance between quality, technology and price, cost-innovation will need to be a key component of their strategy, for instance by using methods similar to those of Chinese manufacturers or by seeking partnerships.[345]

- **Following through on innovations.** A common reaction of Western firms to the challenge posed by cost-efficient Chinese companies that are increasing both their quality and technological capabilities is to focus even more on R&D and technology

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[343] Kevin Jianjun Tu, David Livingston, 'Wenzhou Crash Shows the Dangers of China's Nuclear Power Ambitions', *Jamestown China Brief*, Vol. 11, no. 14, 29 July 2011. Available online at: http://www.jamestown.org/programs/chinabrief/single/?tx_ttnews%5Btt_news%5D=38239&tx_ttnews%5BbackPid%5D=25&cHash=7351300adad6334f2216f4a414a03003.

[344] A lot of reports address this issue in more detail, but a good overview is offered by: The Economist Intelligence Unit, *Multinational companies and China: What future?*, November 2011. Available online at: http://www.businessresearch.eiu.com/sites/default/files/downloads/Multinationals%20and%20China%20ENGLISH_0.pdf.

[345] Eden Yin and Peter Williamson, 'Rethinking Innovation for a Recovery', Ivey Business Journal, May/June 2011. Available online at: http://www.iveybusinessjournal.com/topics/global-business/rethinking-innovation-for-a-recovery.

development. There is certainly merit in this, yet just focusing on more innovation and R&D will not suffice if companies cannot benefit from the subsequent commercialization and deployment of newly developed technologies. It is imperative that firms ensure that they make the most out of deployment and further development.

- **Finding a sustainable China strategy.** Insofar as companies are active in China, a key issue will be to define a strategy that will allow them to do business in China without becoming superfluous. Especially for those sectors where China is a major growth market, the proposition of market access versus technology transfer is hard to resist, yet finding a sustainable course to deal with this issue is key to long-term survival.

- **Finding a way to deal with upcoming Chinese innovation.** When Chinese efforts at increasing its domestic innovative capacities start to be successful, Western companies will need to choose a strategy to deal with it: by collaboration, competition or otherwise. If retaining a technological edge becomes more difficult, this will require them to evaluate in what field they have a competitive advantage and what is the value proposition that they can offer.

Global competition in low-carbon energy and transportation sectors will play out at the global level, depending on exactly how trends in ‘green protectionism’ further develop. Yet given the localized nature of many markets, the competition between Western and Chinese firms might very well start to play out in other emerging markets, as is also illustrated by some evidence from our case studies, such as for wind energy, nuclear power and high-speed rail: it is in markets such as the Middle East, South-East Asia and Latin America that Chinese competition with its attractive cost advantage is beginning to make inroads.

# 10

## Conclusions

This paper has sought to analyze the role which China might play in several low-carbon industries in future and to what extent it is succeeding in its ambition to increase its technological and innovative capabilities in these fields.

Regarding renewable energy and other low-carbon technologies, Europe, Japan and the United States have traditionally been global leaders in terms of innovation, industrial capacity and actual implementation. However, their leadership position is coming under increasing pressure as China is emerging both as a global competitor and major growth market.

While the government support in Western countries that has driven much of the growth in the past decade has become more troubled in the wake of the economic and financial crisis, China is investing significantly in a more low-carbon energy future.

By leveraging its expanding domestic market and its skills in cost innovation, China has set out to develop several advanced energy technologies that it deems of key importance – both for its own development and because of the future export potential. Selected industries include wind energy, solar energy, third-generation nuclear power, advanced coal-fired power generation, high-speed rail and (semi-) electric transportation. Technology transfer requirements and a major push for more R&D and innovation are increasing the technological capabilities of Chinese firms – in some cases much faster than anticipated. Although the Chinese strategy is not without its challenges, market leaders in Europe, the United States and elsewhere are already feeling the effects of increasing global competition coming from China.

Our evaluation of the different industrial sectors related to China's energy and sustainability challenges shows some common themes and recurring trends. We first present our main findings which will be elaborated below:

- China's current technological capabilities are still mixed and real innovation in the field of low-carbon technologies is quite limited; however,
- China is extremely well-positioned to take a lead in advancing low-carbon technologies. It offers a major growth market and can leverage this in order to gain the technological know-how which it lacks. Furthermore, its push to promote low-carbon industries is very strong, as it is part of broader government policy objectives; and
- It can be expected that this push to build up low-carbon industries will have both a local and global impact, as China is deploying these technologies in its home market as well as seeking to export them at very competitive prices.

In the following pages we will discuss three aspects more in-depth.

**(1) China has emerged as a major growth market for many low-carbon technologies and has become the largest investor in renewable energy.**

Having a major expanding home market provides several benefits to China. First of all, the large growth market gives it an easier opportunity to deploy various technologies and there is less of a technology lock-in effect. Second, it can leverage its huge market to gain technology transfer agreements and speed up its technological development. Furthermore, we have seen how an expanding home market has been a decisive factor in the emergence of several global players in the various industries that we have considered.

- **As financial support for clean energy deployment in Europe and the United States has become more constrained, China is likely to increase its role as a major growth market for such technologies.** The potential for further growth in the transportation and power sectors is enormous. We have seen that China already is the largest global growth market for a number of industrial sectors, including wind energy, nuclear energy, hydropower, automotives and high-speed rail. For many international companies in the clean energy and low-carbon technology sector, China has grown into one of the most important sales markets. The construction of nuclear power plants is one example, but also for European solar PV equipment manufacturers, almost all sales are made in China. Moreover, the government has sufficient financial means to provide support to the development of clean energy technologies that are not yet cost-competitive, assuming that China succeeds in ensuring continuing economic growth.

- **China's support for the development of clean energy technologies is founded on strong principles.** Government policy illustrates that there is a strategic support for the clean energy sector and several other low-carbon industries. While renewable energy deployment in Western countries is mostly driven by climate change concerns, for China other aspects appear even more important. First, there is the long-term challenge of achieving a sustainable energy system that can provide sufficient energy to its enormous population and fuel economic growth. Second, there is a wish to avoid the negative effects on health and environment stemming from coal use. Third, it wishes to address energy security concerns, such as its increasing imports of oil and other energy resources. Fourth, it perceives a clear economic opportunity in the export potential of clean energy technologies.

Partly as a consequence of this strong support, we can conclude:

**(2) China is becoming a global competitor for many clean energy and low-carbon technologies.**

Our case studies have illustrated that in many sectors China is becoming a strong global competitor or has already done so. The maturity and global competitiveness of China's domestic industries vary per sector: its solar PV and hydropower industries are already very competitive globally, while wind energy, nuclear power and high-speed rail are expected to have a global impact in the near future. Both within the domestic Chinese market and the global market, competition from Chinese firms will almost inevitably become stronger. There are a number of key factors at work here:

- **China is showing a clear commitment to support industries which it deems strategic to its future, and public-private cooperation is helping the development of new industries.** A series of industries related to low-carbon energy use and transportation have been designated as strategic by the Chinese government. They tie in with the objective of achieving sustainable growth and the more general policy to shift the economy towards more value-added industrial sectors rather than low-cost manufacturing. Since the state has an important role in China's economy and some of the most important Chinese companies are state-owned enterprises, there is sometimes a degree of close collaboration which can facilitate the development of new industries. For instance, the municipal government of Shenzhen, home to the Chinese battery manufacturer and electric car building firm BYD, purchased a number of electric vehicles to function as taxis and the central government supported Sinovel with establishing an offshore wind R&D centre. Moreover, specific regulation or government policies, such as localization requirements, have helped to build up domestic industries. The example of state support for the Chinese solar PV industry when export markets collapsed in the wake of the economic and financial crisis is also illustrative.

- **China is very pragmatic in its approach to support and implement new technologies.** A preference for pragmatism and experimenting with pilot projects has been a consistent feature of Chinese policy: it can be traced back to the Special Economic Zones of the late 1970s that catalyzed China's economic growth. A degree of 'trial and error' in Chinese fashion also applies to new energy technologies. Examples include the pilot projects with electric vehicles that are used as taxis and buses in a number of selected cities and the first few offshore wind farms that were built using Chinese technology. Such projects are implemented even though such technologies have not been previously used: through 'learning-by-doing' experience is gained. Furthermore, China is using government policy, state-owned enterprises and government procurement in order to create demand and pull technologies out of their niche markets and to increase domestic technological skills.

- **For those sectors in which China represents the largest and most important growth market, conditions on technology transfer in return for market access are hard to decline.** This has been a common theme in many industrial sectors, also outside of the energy field. Of the sectors included in this report, we have seen this strategy at work for hydropower, nuclear energy, high-speed rail and, to a lesser extent, wind energy. In these cases, China has been a major market with a very significant growth potential, making it possible for Chinese parties to negotiate strong concessions on technology transfer. The exception here is solar energy, where China has gained a dominant global market share and gained technological knowledge without having much of a domestic market.

- **The advantage of having a lead in terms of quality and technology will gradually disappear for Western firms.** It is already apparent that quality, safety and reliability are becoming more important in China and there is no inherent reason why Chinese products should be of lower quality. Like Japan and other Asian Tiger economies before it, China is poised to climb up the value chain and gradually shed its reputation as a low-cost, low-quality producer. Moreover, also in terms of management practices and innovation, China benefits from both an influx of workforce that has been educated abroad and the experience from foreign companies active in China.

As we have seen by looking more closely at a few sectors, the development of clean energy and low-carbon technologies is still in an extremely dynamic phase. In many cases, it not yet clear which technologies will emerge as the most viable or cost-competitive. As for the role of China in becoming more innovative power, we should distinguish between making real 'breakthrough' innovations and making incremental innovations based upon existing technology:

(3) **It seems unlikely that China will be able to make the next step towards 'indigenous innovation' of breakthrough technologies in the short term. However, it may well be very successful in pursuing incremental 'process innovations' and 'cost innovations' that decrease the cost of production, thus making a key step towards the further global commercialization of low-carbon technologies.**

For a number of the industries we studied (wind energy, solar energy, hybrids and electric vehicles), high cost is the main factor that is still hampering their market deployment and that still makes them reliant on uncertain government support. This entails certain risks for the further development of low-carbon technologies and for global competition that is now playing out in these industrial sectors. Regarding the future challenges for both Chinese and Western companies, we have identified the following points:

- **There is a real risk that the growing competition in low-carbon technologies will lead to increasing 'green protectionism'.** Insofar as governments are providing financial support for deployment of low-carbon technologies, increasing competition from China will likely lead to political tension, as is already apparent in some cases. The import of Chinese solar panels is coming under increasing scrutiny, both in the US and Europe, since the deployment of solar energy still makes use of public subsidies. For wind energy, cost-competitive imports might not be too far in the future. In fact, to capture the benefits of support schemes for clean energy and translate these into local 'green jobs', some countries have been including localization requirements in their renewable energy and climate laws. Whether this trend will continue in future remains uncertain, but the risk of such an outcome might very well increase – especially since China is becoming a stronger competitor.

- **One of the main challenges for China in realizing its export potential is to build up a reputation and track record for safety, quality and reliability.** This is particularly true if it wishes to export some of the more safety-critical technologies to Western countries, such as nuclear power plants, high-speed rail and, possibly in the future, hybrids and electric vehicles. Although some other countries might be concerned more with price than quality, China will need to improve in this field in order to win consumer confidence in Western markets.

- **Another challenge for China will be to move towards more radical innovation, rather than incremental innovation.** As of yet, the technologies which China has been developing have originated from foreign countries, and China has been building further upon that. Despite all efforts and clear strategy to increase domestic Chinese R&D efforts the most innovative new technologies in the clean energy and low-carbon field are still developed outside of China. If China wishes to truly lead in the global market in the longer run it will also be important to gain a technological edge.

- **For Europe and other Western countries, the challenge remains to capitalize on innovation: being a technology leader does not immediately translate into being successful in the global market.** Success in the global market place is not determined just by those making the innovations. Whether any new technology is followed up by deployment and further enhancement will determine whether the full economic potential is realized. The case of Japan, which had a clear technological lead in solar PV technology but failed to develop that in terms of market deployment and global commercialization, shows how initial efforts are not always followed through. Although Europe has built up a strong clean energy industry and is still in many cases a technology leader, it will need to address the cost innovation challenge posed by China. Assuming that it will have difficulty in competing with China on costs, it will need to demonstrate that it can offer higher quality and better technology that is worth the extra cost. Second, our case studies show the importance of domestic deployment; and for this a clear government strategy in support of low-carbon technologies and targets on their deployment are required.

- **Competition might not only play out in Western markets, but is even more likely in other regions such as Southeast Asia, Latin America and the Middle East.** China, the US, Europe and Japan remain the most important markets for many of the technologies that we discussed. As we noted, competition in these markets is set to increase. However, given that each of them will have or will develop some kind of preference for domestic firms, the real field of competition will be in other emerging markets. In markets where the brand recognition and reputation of Western companies matters less, China stands a better chance. Especially regarding capital-intensive sectors, such as nuclear power, high-speed rail and perhaps the automotive sector, there could be export opportunities for China's very cost-competitive industries. The high-speed rail project in Turkey and nuclear power expansion plans in the Middle East could be early signals of this development.

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