

UK-China Collaborative Study on Low Carbon Technology Transfer

Final report

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Table of Contents

Executive Summary	2
Acknowledgements	3
1. Introduction, context and approach.....	4
1.1. The Chinese context	5
1.2. Study rationale and objectives.....	9
1.3. Research methods	10
2. Defining technology transfer	14
3. Low carbon technology transfer to China: research results	19
3.1. Building technological capabilities in China	19
3.2. Domestic finance and policy in China.....	37
3.3. International Finance and Policy	44
4. Conclusions and implications.....	51
Appendices	56
Appendix A: Energy efficiency in the cement industry.....	57
Overview of China's cement industry and advanced cement technologies	57
Energy efficiency technologies in the cement industry in China	58
China's domestic providers of major technologies in the cement industry.....	62
The international cement technology providers and the cement technology transfer situation in China	65
Appendix B: Electric vehicles	66
Current state of China's automotive industry, and energy and CO ₂ issues	66
Key EV technology categories.....	67
Overview of the market situation of EVs in China.....	69
Discussion of Chinese capabilities in EVs	73
EV development paths in China	76
Appendix C: Offshore wind power	78
Overview of China's offshore wind energy.....	78
Overview of the market situation for China's offshore wind power.....	79
Existing policies related to the development of offshore wind power	81
Capabilities of China's offshore wind power manufacturers	83
Technology transfer in wind power development in China.....	84
Appendix D: More efficient coal fired power generation	86
Background of coal fired power generation in China	86
Overview of cleaner technologies in coal-fired power plants in China	88
Technologies in advanced countries.....	90
Technologies in China	92
Appendix E: Sample interview questionnaires	94
Interviews in China	94
International interviews	96
Appendix F: Individuals and organisations interviewed.....	98
References.....	100

Executive Summary

This report sets out the results of the UK-China collaborative project on low carbon technology transfer. The aim of the project was to identify new empirical evidence about the development, transfer and deployment of low carbon technologies in China, and to help inform national and international policy developments – particularly within the UN Framework Convention on Climate Change (UNFCCC).

The report analyses technology transfer from international sources in the context of broader processes of low carbon innovation in China. It does so by focusing on four empirical case studies of low carbon innovation in China: energy efficiency in the cement industry, electric vehicles, offshore wind power and more efficient coal-fired power generation. The report reaches six main conclusions:

1. There are important differences between low carbon technologies in China. Therefore a 'one size fits all' approach to supporting low carbon innovation is inappropriate. Chinese technological capabilities are stronger in more near-market technologies than they are in more early stage technologies
2. The case of China is unique, and should not be used as a proxy for developing countries in general. Whilst China still faces many development challenges, China has significant resources and a large potential market for foreign suppliers. The Chinese government has played a central role in supporting low carbon innovation and technology deployment.
3. A range of policy mechanisms are used to promote low carbon innovation in China, with an emphasis on regulations and targets. Appropriate policies differ between technologies. We support the Chinese government's intention to increase the use of market based instruments alongside regulatory approaches.
4. Chinese firms and institutions are developing their capabilities rapidly, but significant gaps remain. These capabilities have been acquired through indigenous innovation and international technology transfer. Limitations include access to advanced component technologies and knowledge, and some weaknesses in engineering and design skills.
5. Access to intellectual property rights (IPRs) is not a fundamental barrier to the development of low carbon innovation capabilities in China. This does not mean that IPR issues are unimportant since Chinese firms do not yet have independent capabilities in some technologies. IPR issues, and the need for policy intervention, should be evaluated on case by case basis.
6. International policy frameworks have played an important role in low carbon innovation. The Clean Development Mechanism has been used strategically by the Chinese government to provide significant finance for technology deployment.

The report considers implications for the Climate Technology Centre (CTC) and Network that are being established under the UNFCCC. The role of the Network will be particularly important, and it should work with existing institutions in developing countries. The experience of China suggests that a full range of functions should fall within the remit of the CTC and Network. These could include investment support, policy advice, collaborative R,D&D and knowledge development. Within these activities, it will be important to take account of national, sectoral and market differences. Implementation should be informed by learning from programmes with similar aims such as the GEF and the World Bank Climate Investment Funds.

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1. Introduction, context and approach

The United Kingdom (UK) government has clearly signalled that it will continue its predecessor's commitment to both domestic and global action to tackle climate change. During the United Nations Framework Convention on Climate Change (UNFCCC) 16th Conference of the Parties (COP16) in Cancun, Mexico in December 2010, the Energy and Climate Change Secretary Chris Huhne MP reaffirmed the UK's support for mitigation and adaptation within developing countries:

We have committed £2.9 billion of climate finance over the next four years to help developing countries tackle climate change. We have fulfilled our Fast Start pledge and are fully committed to the long term goal of \$100 billion a year in climate finance by 2020¹

The rationale for assistance to developing countries remains strong. Least developed countries are expected to be exposed to some of the most serious impacts of climate change but, in most cases, these countries lack the resources to adapt to these impacts. At the same time, some of the larger developing countries are growing rapidly, and are making significant contributions to global emissions from fossil fuel based energy systems. In the case of these countries too, international collaboration and assistance has a role to play – perhaps most importantly in accelerating the development and deployment of low carbon technologies. Despite the high economic growth rates of many emerging economies, leadership in low carbon technologies remains dominated by firms from OECD countries (Lee, Iliev et al. 2009).

To some extent, the outcomes of COP16 in Cancun have made up for the disappointments of Copenhagen. The Cancun Agreements² are more detailed, building on the Copenhagen Accord and are supported by both developing and industrialised countries³. They confirm specific commitments to significant financial assistance to developing countries for mitigation, adaptation and avoided deforestation. These include fast start finance 'approaching \$30bn for the period 2010-2012' (UNFCCC 2010), and a commitment by developed countries to 'a goal of mobilizing jointly USD 100 billion dollars a year by 2020' (UNFCCC 2010). The Green Climate Fund was established, with the World Bank invited to act as interim trustee for an initial three year period. A Technology Executive Committee (TEC), and Climate Technology Centre and Network were also established to support technology development and transfer⁴.

This is the final report from a UK-China collaborative research project by the Sussex Energy Group (University of Sussex, UK) and the Laboratory of Low Carbon Energy (Tsinghua University, China) on low carbon technology transfer to China. The report builds on an earlier interim report (Watson, Byrne et al. 2010b), and on two previous phases of research for a UK-India collaboration on low carbon technology transfer to

¹ COP 16 Plenary Statement by Chris Huhne, COP16, Cancun, Mexico, 8th December 2010.

² See http://unfccc.int/meetings/cop_16/items/5571.php for full text of the Cancun Agreements.

³ See <http://www.wri.org/stories/2010/12/qa-legal-character-and-legitimacy-cancun-agreements> for further information.

⁴ See <http://www.climaticoanalysis.org/post/cancun-agreements-on-technology-transfer/>

India. The UK-India research was conducted by the Sussex Energy Group (SPRU, University of Sussex, UK) with The Energy and Resources Institute (New Delhi, India).

The need for a separate China project was announced by former Prime Minister Gordon Brown during his visit to Beijing in late 2007, and its scope was developed through a workshop funded by the UK government and held at Tsinghua University in November 2008. As with the UK-India collaborative study, the key focus for this report is on the provision of new empirical evidence. This evidence primarily derives from four technological case studies: energy efficiency in the cement industry, electric vehicles, offshore wind power, and efficient coal fired power generation. The case studies focus on technologies at different stages of development. They are designed to provide examples of low carbon innovation and technology transfer in order to inform international policy development. In section 1.3, we give a more detailed rationale for why these case studies were selected.

Whilst low carbon technology transfer provides a useful focus for the project, it is important to recognise at the outset that technology transfer needs to be analysed within the context of broader processes of low carbon innovation in China. Technology transfer from international firms and other organisations is only one source of such innovation. This cannot be analysed in isolation from other, indigenous sources of innovation – or from the wider national and international policy contexts that will affect rates of low carbon technology development and deployment.

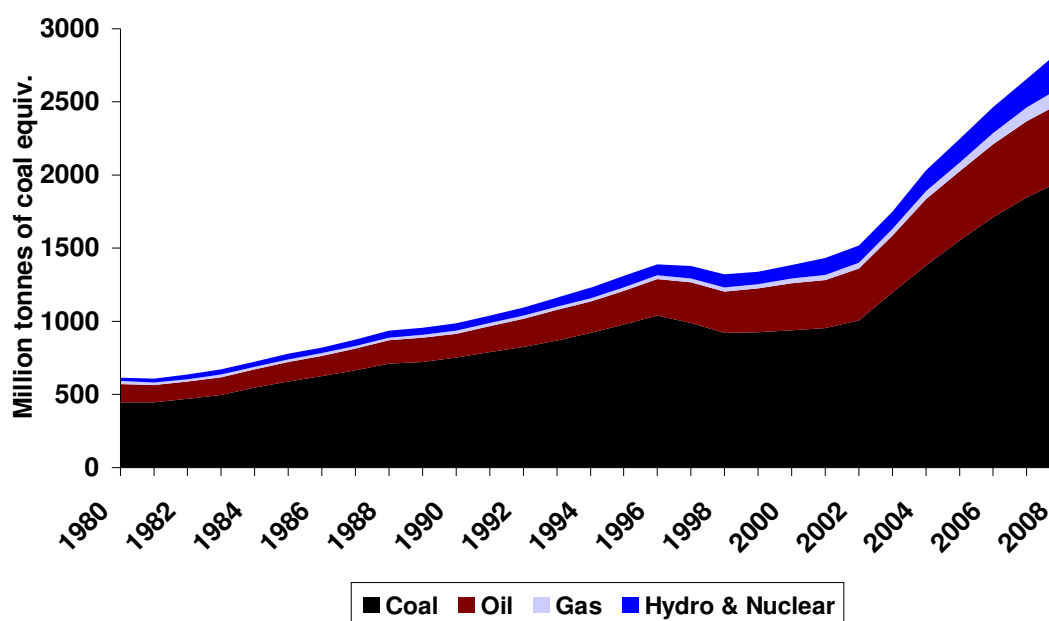
This report comprises 4 sections. The remainder of section 1 sets out the Chinese context for low carbon innovation, the rationale for this study and the methods that were used. Section 2 discusses the difficulty of defining technology transfer. It sets out our working definition, and links this to factors that influence innovation processes such as policy frameworks. Section 3 then discusses the evidence from our project case study technologies and focuses on a number of key issues including the development of technological capabilities, and the roles of national (Chinese) and international policy frameworks. Section 4 summarises the main conclusions and suggests some implications for policy. Detailed write ups of each project case study are provided in Appendices A to D to this report.

1.1. The Chinese context

During the past two decades, China's economy has continued to grow rapidly, at an average rate of around 10% per year (Wang and Watson 2009). At the same time, this economic expansion has led to large increases in energy demand and carbon emissions (see Figures 1 and 2). These increases have continued through the recent financial crisis which has led to falling emissions in many of the Organization for Economic Cooperation and Development (OECD) countries. China is now the world's largest emitter of carbon dioxide (CO₂), the most important greenhouse gas. However, on a per capita basis, China's CO₂ emissions are lower than those of most industrialised countries. Per capita emissions reached the global average level of about 4.5 tonnes in 2006 (UNDP China 2010:29). China is particularly vulnerable to the expected impacts of climate change which are projected to have serious effects on water availability, agriculture and coastal vulnerability (NDRRC 2007).

Whilst the energy and carbon intensity of China's economy has generally fallen over time during the past few decades, there have been shorter periods in which the energy intensity has increased. Between 2003 and 2005, intensity rose due to a particularly rapid period of expansion of heavy industries such as iron and steel, driven by a boom in infrastructure development. More recently, energy intensity rose again by 3.2% in the first quarter of 2010, making it more difficult for the energy intensity target in place at that time to be met. The target, established under the 11th Five Year Plan, called for a 20% reduction in energy intensity between 2005 and 2010. A report to the 2011 National People's Congress from the Chinese government's National Development and Reform Commission (NDRC) stated that a 19% reduction was achieved by the end of 2010 (NDRC, 2011).

Figure 1: Primary energy supply in China



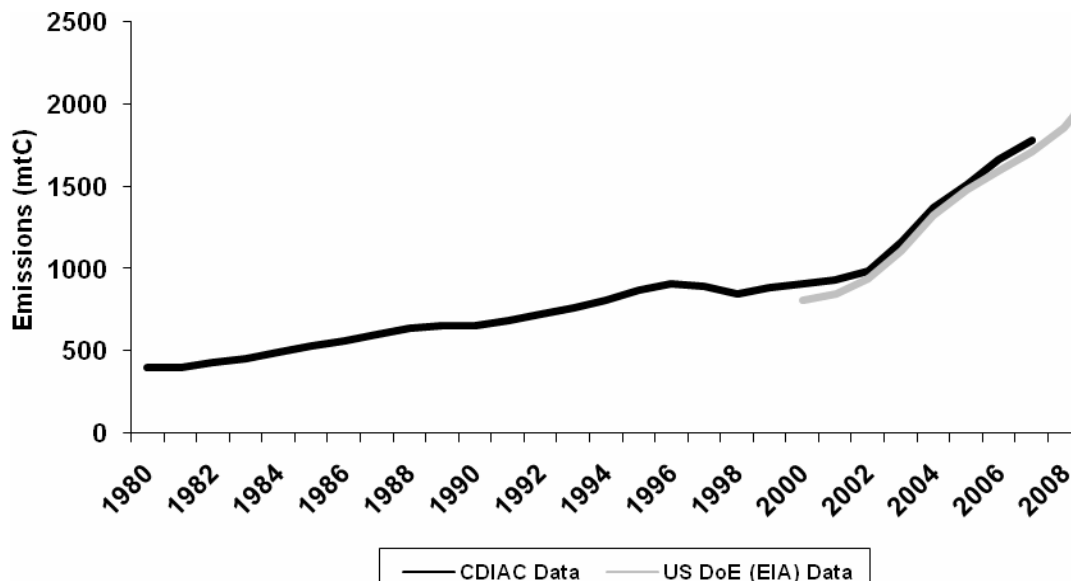
Source: National Bureau of Statistics of China⁵.

As Figure 1 shows, coal continues to dominate China's energy system despite a slowly declining share. It also continues to fuel the majority of power generation capacity. According to more recent statistics, total energy consumption rose to 3250 million tonnes of coal equivalent in 2010. According to the official Chinese news agency, China's power generation capacity reached approximately 960 GW by the end of 2010 – an increase of 85GW over the figure a year earlier. Around three quarters of this capacity is coal-fired. This is the second largest generation capacity in the world, and is now close to that of the United States (1010GW)⁶. Imported oil is also increasing sharply to over 50% of total oil consumption in 2009 – up from 29% in 2000 as domestic output has matured. Demand for natural gas keeps growing, but plays a small role in overall primary energy supply – it accounted for approximately 3.8% of primary energy consumption in 2008.

⁵ Data available from: <http://www.stats.gov.cn/tjsj/ndsj/2009/indexeh.htm>

⁶ Data from the US Energy Information Administration; www.eia.doe.gov/

Figure 2: Carbon emissions in China (1980-2008)



Source: Energy Information Administration (EIA), United States Department of Energy (US DoE); Carbon Dioxide Information Analysis Centre (CDAIC).

These trends lead to a number of pressing economic and environmental challenges. Securing enough energy to sustain economic growth is clearly an important priority for the Chinese government. The NDRC's report to the National People's Congress in March 2011 acknowledges these challenges, and states that 'total energy and resource consumption is too large and is growing too quickly, and emissions of major pollutants are high ... energy-intensive and highly polluting industries are still growing too fast. Consequently, we face mounting pressure to save energy, reduce emissions, and respond to climate change, and great challenges in sustainable development' (NDRC 2011: 18).

A new target for carbon intensity reduction was announced in the run up to the Copenhagen COP in 2010, and requires that carbon intensity should fall by 40-45% by 2020 from 2005 levels. Related to this, the State Council ratified a target that 15% of China's overall energy supply should come from non-fossil sources by 2020. Such targets are taken seriously in China, and are not announced lightly. During the efforts to meet the energy intensity target for the 11th Five Year Plan, and the evidence of increasing intensity in early 2010, Premier Wen Jiabao pledged that government would pursue the target with an 'iron hand'. This pledge was followed by stories that some Provincial governments were ordering power rationing in an effort to play their part in meeting the target (Watts 2010).

Significant attention is now being paid by government and research institutes to the implementation of the 12th Five Year Plan and the new carbon intensity target. The 12th Five Year Plan, which runs from 2011 to 2015, includes both energy and carbon emissions intensity targets. Premier Wen Jiabao's report to the National People's Congress on 5th March 2011 proposes targets for a 16% reduction in energy intensity and a 17% reduction in carbon emissions intensity during the period 2011-2015 (Wen Jiabao 2011). It also states that non fossil sources should account for 11.4% of primary energy by 2015, up from 9% in 2008 (Zhang 2010). As a first step

towards these targets, the NDRC has set goals for a 3.5% reduction in both energy and carbon emissions intensity of the Chinese economy during 2011.(NDRC 2011)

To achieve carbon and energy intensity goals, there will be a central role for the development and deployment of low carbon technologies, including technologies and measures to improve energy efficiency and low carbon energy supply. Energy efficiency technologies are particularly important for China due to the high energy intensity of its economy and the still dominant contribution of industry to energy demand and emissions. Over 80% of China's emissions come from the electricity, heat, manufacturing and construction sectors (UNDP China 2010). There are significant gaps between energy intensities in these sectors within China – and the average performance in OECD countries. There are also gaps between the best performing plants in China and the worst performers.

The Chinese government has consistently argued that developing countries (including China itself) should be provided with financial and other assistance in low carbon technologies by developed countries. Chinese leaders are also vocal in their disappointment that past promises to provide such assistance – including technology transfer⁷ – have not in their view been honoured. In the lead up to COP15 in Copenhagen for example, the Chinese government proposed that industrialised countries should provide funding of 0.5-1% of their GDP to various funds including a Multilateral Technology Acquisition Fund⁸.

Calls for assistance from industrialised countries have been tempered in recent years by a recognition that China's own capabilities are getting stronger. This has led to a modified tone in speeches by senior officials which tend to emphasise the need to protect intellectual property rights – and not to simply provide access to these rights for developing countries. For example, Zeng Peiyan, an influential former Vice Premier of China, summarised the Chinese government's views in May 2010⁹:

Regrettably, we haven't seen substantive progress in the sharing of these [low carbon] technologies. ... There is a need to develop institutions and finance ... to transfer technologies on concessional terms whilst safeguarding intellectual property rights.

There is, therefore, an increasing recognition that China can help foster low carbon innovation by its own domestic policy actions. Recent examples include research and development (R&D) support, incentives for technology deployment (e.g. renewables) and demonstration trials (e.g. of electric vehicles). Significant Chinese government funding has been devoted to R&D in low carbon technologies, and to energy efficiency and clean technology within the 4 trillion Yuan (approximately £400bn) stimulus package in response to the global financial crisis. There is also acknowledgement that international agreements on technology transfer need to take into account the legitimate concerns, including respect for intellectual property, of leading international firms that are developing low carbon technologies. Furthermore,

⁷ Also see Ockwell, Haum et al. (2010)

⁸ Implementation of the Bali roadmap: China's Position on the Copenhagen Climate Change Conference, 20th May 2009; http://en.ndrc.gov.cn/newsrelease/t20090521_280382.htm

⁹ Speech to International Cooperative Conference on Green Economy and Climate Change, Beijing, China, 9th May 2010.

the rapid development of Chinese capabilities in some low carbon technologies (e.g. wind and solar power) means that in some sectors, at least, there are valuable lessons to be learned by other countries, sectors and regions across the globe about how barriers to low carbon innovation have been overcome.

1.2. Study rationale and objectives

As noted earlier in this section, the key rationale for this study is need to provide new empirical evidence of low carbon innovation in developing countries – and the contribution to this of technology transfer. One headline conclusion from the preceding UK-India studies of low carbon technology transfer is that there is no ‘one size fits all’ prescription for policy in this field (Ockwell, Watson et al. 2006). Whilst United Nations (UN) negotiations on technology transfer necessarily deal in generalities, these negotiations need to take into account the empirical evidence on low carbon innovation which reveals a more complex, nuanced picture (Ockwell, Haum et al. 2010). The capabilities of firms and other organisations in specific low carbon technologies differ markedly between countries and regions – as do the capabilities within a given country with respect to different low carbon technologies.

Given this background, it was thought to be particularly important to conduct a further phase of research focusing on low carbon technology transfer to China. This basic rationale was accompanied by a number of objectives as set out in the original UK-China project proposal (Ockwell, MacKerron et al. 2008). The five research objectives are:

1. To add value to the rapidly growing literature on low carbon innovation in China, and the role of technology transfer;
2. To focus on a range of low carbon technologies that includes both early stage and near market technologies;
3. To examine the full range of factors that influence innovation and technology transfer including technological capacity, access to intellectual property rights (IPRs) and the role of national and international policy frameworks;
4. To look in particular at the role of the Clean Development Mechanism in supporting low carbon innovation in China; and
5. To suggest policy implications, particularly for the international UNFCCC negotiations

The first objective is particularly important. As China has emerged as one of the world’s largest economies (in 2010 overtaking Japan to become number two in the world)¹⁰, it has become more of a focus for international debate and discussion. The volume of research focusing on its energy, climate and innovation policies has also grown. The research published in this report builds on a growing number of existing studies, many of which are recent. These studies include research on China’s overall development pathway, and the extent to which it could be compatible with global limits on GHG emissions (e.g. Wang and Watson 2009; e.g. UNDP China 2010). They also include more detailed research on innovation in specific regions (e.g. Chatham House, Chinese Academy of Social Sciences et al. 2010), and specific

¹⁰ See <http://www.bbc.co.uk/news/business-12427321>

lower carbon technologies such as wind power, energy efficient methods of steel production, and supercritical coal-fired power (e.g. Lewis 2007; Tan, Seligsohn et al. 2010).

By bringing together complementary capabilities from Tsinghua University and the University of Sussex, the research published in this report adds value to these existing studies. To address the second research objective, we have focused on a set of case studies designed to capture the diversity of low carbon innovation in China. They encompass different stages of technological development, different markets (capital and consumer goods) and different parts of the energy system (electricity generation, industry and transport). The case studies include near market technologies (improvements in efficiency in the cement industry and more efficient technologies for coal-fired power) but also focus on future technologies that are still in the process of being commercialised in China (electric vehicles and offshore wind). Some of these cases (e.g. offshore wind) have not been examined in depth within previous studies of low carbon innovation.

To address the third research objective, our analytical framework focuses on a fuller range of key issues for low carbon technology transfer than previous studies. The importance of familiar issues such as intellectual property rights, finance and policy incentives have been investigated alongside an examination of the role of technological capabilities. By grounding the analysis in the innovation and development literature – an area in which the Sussex Energy Group has particular expertise (e.g. Ockwell, Ely et al. 2009) – this project has added to an understanding of how technological capacity is developed in China. In the context of international discussions, it is important to gain a better insight into how such capacity contributes to both industrial development and low carbon technology deployment.

With respect to the fourth research objective, the role of the Clean Development Mechanism has been investigated – particularly with respect to the case of energy efficiency in the cement industry and with respect to offshore wind. Whilst the latter technology has not been a significant beneficiary of CDM funding, the development of onshore wind in China has included a large number of CDM projects.

Finally, the fifth research objective has been addressed through close liaison with the Department of Energy and Climate Change, and through interaction with international institutions working on similar agendas, and through the participation of the research team as observers to the UN negotiations in Copenhagen and Cancun. The main focus has therefore been on international policy – but the research has also considered implications for Chinese and UK policies.

1.3. Research methods

The research was carried out between February 2010 and March 2011, and has comprised four main activities.

1. Development of analytical framework. During the first few months, the analytical framework for the project was developed in order to structure the case study research. This activity was led by the University of Sussex team. The final framework

identified several key issues for low carbon technology transfer, and conducted an updated literature review on these issues (both in general, and with respect to China). The issues identified were i) the development of technological capacity within China; ii) intellectual property rights; iii) finance and policy within China; and iv) international financial and policy frameworks. The updated literature review with respect to these four issues was published in this project's interim report (Watson, Byrne et al. 2010b) and was subsequently used to inform the case study interview questions (see below).

With respect to intellectual property rights, a separate project was funded by the UK Foreign and Commonwealth Office in Beijing. The project was led by Professor Wang Can at Tsinghua University, who is a member of the UN Expert Working Group on Technology Transfer. This project also focused on several specific technology case studies, with some significant overlap with our study¹¹.

2. Case study selection. In parallel with the development of the analytical framework, a case study selection process was carried out. The original project proposal listed four proposed case study technologies which were identified through a scoping workshop at Tsinghua University in November 2010. These were felt by participants to be priorities for China, and at a relatively early stage of development. They were: i) Integrated Gasification Combined Cycle (IGCC) technology for coal fired power generation in combination with carbon capture and storage (CCS); ii) second and third generation biofuels for transport; iii) coal mine methane production; and iv) fuel cells for vehicles and stationary applications. This list was revised in consultation with our research partners at Tsinghua University and staff at the UK Embassy in Beijing. A number of considerations informed the process of revision. The main aim is to ensure that the case study results will enable the project to provide well grounded policy recommendations. These considerations included:

- The need for a broader spread of technologies that are at different stages of development;
- The need to include both low carbon supply and energy efficiency technologies, particularly given China's recent commitment to a reduced carbon intensity target;
- The need to include cases in which Chinese firms have recently been 'catching up' with the international technology frontier (with respect to development and production), and cases in which there remains a significant gap between the average technology in use in China and international 'best practice';
- The need to prioritise technologies that fit with China's national priorities as outlined in official government communications;
- The desirability of including some geographical diversity to reflect different levels of income, technological capabilities and natural resources within different Chinese provinces and localities; and
- The need to choose cases in which the research team has some prior knowledge and means of access to relevant information and interviewees.

With these considerations in mind, four case studies were agreed. Brief rationales for each are as follows:

¹¹ At the time of writing the final report from Prof Wang's study was not available.

- Energy efficiency in the cement industry. China's carbon intensity target and the high share of China's carbon emissions from energy intensive industries means a continued focus on the efficiency of these industries (UNDP China 2010). Many of the technologies to improve energy efficiency are already available yet there remains a significant 'efficiency gap' between technologies in place in many Chinese firms and the best available technologies. Since the Tsinghua team have recently focused on the steel industry within a UK Foreign and Commonwealth Office funded study led by the World Resources Institute (Tan, Seligsohn et al. 2010), this study has chosen to focus on the cement industry.
- Electric vehicles. Whilst fuel cell vehicles were in the original technology list, and may be very important in helping to decarbonise the transport sector, there has recently been more of an emphasis on electric vehicles in many countries. China is no exception. There are now public programmes such as electric vehicle charging trials and company strategies. However, market diffusion remains at an early stage. Including electric vehicles as a case will balance the case study portfolio so that it is not too dominated by electricity supply options. There is considerable knowledge within the Tsinghua team of developments in Chinese electric vehicle technologies and associated policies and strategies.
- Offshore wind power. Renewable energy technologies are important for the project since there is the potential to learn from success as well as asking what further policy action might be needed. The specific focus on offshore wind was agreed for a number of reasons. Chinese firms have developed their capabilities rapidly in recent years in onshore wind technology, and are now applying these to offshore projects. In addition, there has been a clear influence from both international policy (e.g. through CDM projects) and national policy incentives in promoting the diffusion of wind power in China. Furthermore, offshore wind is a particular priority for the UK – and its inclusion may be attractive to UK audiences for this project's findings.
- Efficient coal fired power generation. One option for more efficient coal fired power generation (IGCC technology) was included in the original technology list. IGCC is a complex technology at an early stage of development, with some active interest from Chinese companies and government. It uses coal, which is an important fuel to include in at least one of the case studies given its important role in the Chinese energy system. With respect to more established supercritical technologies for coal fired power, there is also a good rationale for inclusion within the study. It is a technology in which Chinese firms have increasingly good capabilities – and is more commercially mature than IGCC technology. For this reason, this case focuses on both of these options for improving the efficiency of coal-fired plants. It was decided not to include carbon capture and storage (CCS) technologies within the case study because it would make the scope of the case too large. There was also a view from some Chinese experts we consulted that CCS technologies are not yet an sufficiently important priority for China.

3. *Case study research.* Having agreed the selection of case studies, the University of Sussex and Tsinghua University teams worked together to carry out the empirical research. This involved both primary and secondary sources including literature searches, as well as semi structured interviews with experts from industry, government and research institutions.

A clear division of labour was agreed. The Tsinghua team have the best knowledge about developments in China in the case study technologies. For example, it includes members with specialist knowledge of renewable energy technologies and policies, electric vehicle developments and IGCC technology. Therefore, they carried out the bulk of the case study interviews in Chinese, and provided notes of key points in English. The final case study reports from the Tsinghua team are included in this report as Appendices A to D, with some editing by the Sussex team for clarity and style. The notes of specific interviews have not been included for confidentiality reasons, but these notes have been used to inform both the case study reports and this final project report.

The Sussex University team used their knowledge to structure the approach to the cases (see above), including the theoretical framework, and the questions for the semi-structured interviews. To help embed this approach, Michele Stua of the University of Sussex team spent two periods in China working alongside the Tsinghua University team: from June to August 2010 and in October 2010. The Sussex team also searched the English-language literature on the case study technologies in China in order to 'triangulate' the findings of the Chinese team. In addition they conducted a small number of interviews with representatives of national and international organisations that have worked with Chinese firms and research institutes on low carbon technologies. A list of interviews is included in Appendix F of this report.

4. Synthesis and writing up. Following the completion of the empirical research, the results of the case studies were synthesised with insights from the literature. During this process, a number of revisions were made to the case study reports to improve comparability. The main results are reflected in section 3 of this report. At the same time, interim insights from the UK-China research were summarised alongside the results from the previous UK-India studies in a policy briefing (Watson, Byrne et al. 2010a). The briefing was launched at a side event at UNFCCC COP16 in Cancun, Mexico. University of Sussex team members also played a role in several other side events, a process that helped them to develop the policy implications outlined in section 4 of this report. A draft final report was subject to internal peer review within the University of Sussex. A full draft was discussed at a workshop at Tsinghua University attended by policy makers from several Ministries, academic experts and other stakeholders. Extensive comments were made on the findings and possible avenues for further research. Where possible, some of these comments have been incorporated in this final report text.

2. Defining technology transfer

This section discusses the concept and practice of ‘technology transfer’ in general terms, as a way to provide a context for the research results presented in section 3 of this report. We begin the discussion by referring to the definition of technology transfer used by the Intergovernmental Panel on Climate Change (IPCC) and then unpack that definition and what it means, making use of the literature on the topic. In the process, we will touch on a few aspects of technology transfer that we discuss more fully in other sections of the paper. These include the role of intellectual property rights (IPRs), and recognition that private sector firms are the main suppliers and importers of technology. The role of private firms in technology transfer is an important point that is often overlooked in policy debates and UN negotiations about transfer processes and access to technological knowledge.

The process of ‘technology transfer’ has been the subject of debate for many decades and depends for its definition on how the nature of technology itself is understood. In relation to climate change mitigation and adaptation, perhaps one of the more important definitions of ‘technology transfer’ is that provided by the IPCC (2000:3):

... a broad set of processes covering the flows of know-how, experience and equipment for mitigating and adapting to climate change amongst different stakeholders such as governments, private sector entities, financial institutions, non-governmental organizations ... and research/education institutions.

This is, the IPCC report asserts, a broader understanding than that used by the UNFCCC¹² (United Nations Framework Convention on Climate Change). The report then further defines the notion of ‘transfer’ as encompassing (IPCC 2000:3):

... diffusion of technologies and technology cooperation across and within countries. ... It comprises the process of learning to understand, utilize and replicate the technology, including the capacity to choose it and adapt it to local conditions and integrate it with indigenous technologies.

The report does not, however, provide an explicit definition of technology. That may be inferred from the list of elements the report identifies as ‘flowing’ and the actors who benefit from the process. So, technology can be interpreted as ‘know-how, experience and equipment’ flowing to and between ‘stakeholders such as governments, private sector entities, financial institutions, non-governmental organizations ... and research/education institutions’. The implication here is that technology incorporates what many describe as both ‘hardware’ (e.g. physical equipment) and additional components such as the know-how and experience mentioned in the IPCC report. Indeed, some refer exclusively to this knowledge dimension of technology when defining technology transfer (Schnepp et al. 1990 cited in Ockwell et al. 2008). Others observe that knowledge is embedded in

¹² However, the IPCC report does not elaborate on its assertion that the understanding of technology transfer within the UNFCCC is narrower than the IPCC version. Indeed, it is not clear whether the UNFCCC actually has an explicit definition of technology transfer.

hardware (Bell and Pavitt 1993). In addition, as the extract above from the IPCC report states, learning, choosing, adapting and integrating are all parts of the *process* of transfer. That is, each is time-dependent and often time and resource-intensive (Bell and Pavitt 1993).

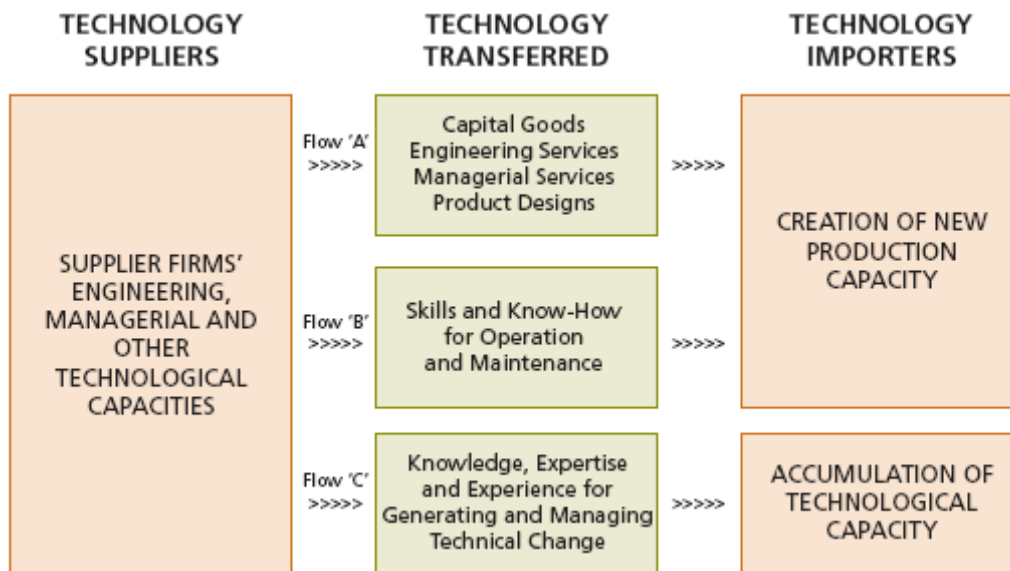
An important idea that helps us to understand why these processes are time and resource-intensive is tacit knowledge (Polanyi 1966). Polanyi and others, such as Tsoukas (2002), argue that all knowledge is tacit because it is embodied in human beings as cognitive structures and abilities for skilful performance; any ‘knowledge’ that is not human-embodied is at best ‘information’ or a representation of knowledge. From this perspective, the process of learning is one in which people working in organisations attempt to assimilate, accommodate or integrate new information with their existing knowledge and experience, and this results in new or enhanced knowledge and skills. Depending on the complexity of the new information or skills to be learned, and the prior knowledge and skills of the individual and/or organisation, there may be a need for prolonged training and practice in order to cultivate – to embody – the requisite knowledge. The processes of choosing, adapting and integrating technologies can all be understood as kinds of learning or, at least, dependent on learning. Whether the notion of tacit knowledge as argued by Polanyi, Tsoukas and others is robust, many recognise that there is some quality of knowledge that is tacit and that this has economic implications¹³ for processes of ‘technology transfer’. Notable among such analysts is Stern, who devotes some discussion in *The Economics of Climate Change* to the notion and implications of tacit knowledge (Stern 2006).

Further reflection on the IPCC definition of technology transfer suggests that some technologies involve significant non-hardware components. The focus of our study is low carbon technologies for which hardware is clearly significant in many cases. However, energy efficiency is an area in which knowledge may play a particularly important role alongside hardware. For example, energy efficiency can be improved in some cases through changes to behaviour (such as turning off unnecessary power loads), something that could be achieved with appropriate knowledge or by implementing suitable procedures. In principle, such knowledge could be ‘transferred’ just as much as equipment, and this underlines the potential for the term ‘technology’ to be somewhat misleading unless carefully defined. Likewise, the term technology transfer could be misleading by implying that the process is simply one in which hardware is moved un-problematically from one place to another. This neglects the importance of context and the knowledge and skills needed locally with which to adopt, adapt, etc. new technologies in that context (see below and the next section, where this is discussed in terms of absorptive capacity). A more general – perhaps neutral – term could be innovation, which can encompass both hardware and knowledge dimensions of technology, whether they are sourced from within the local context or from elsewhere. Consequently, it may be more helpful to refer to ‘innovations’ than technologies, where the word innovation does not necessarily imply radically new or disruptive hardware or knowledge (see below for further discussion on innovations). Furthermore, bearing in mind our present focus on

¹³ It is interesting to note that the UK intellectual property regime recognises tacit knowledge as having economic value. However, as stated in its corporate plan in 2009, the UK IPO (Intellectual Property Office) identifies that there is a lack of ‘understanding of the economic connection between formal and informal IP systems and the value’ so derived (UKIPO 2009:11).

technologies for mitigating and adapting to climate change, it may be more helpful to use terms such as low carbon innovations, low carbon innovation capacity or capability, and so on.

Figure 3: The technological content of international technology transfer

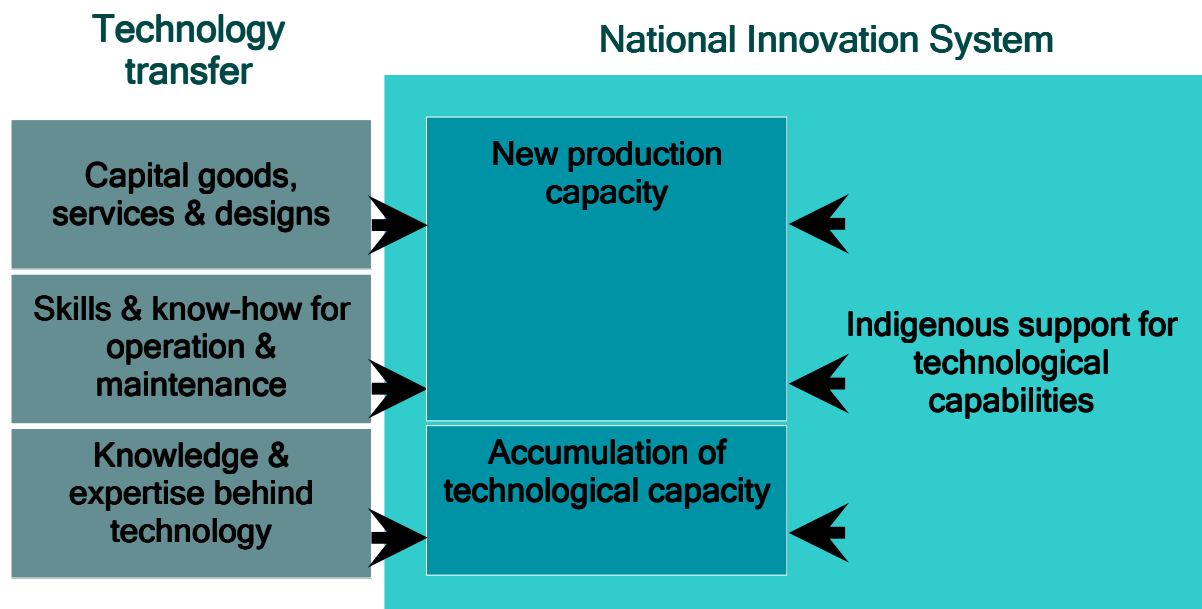


Source: Bell (1990:76 cited in Ockwell et al. 2006).

A useful way to think about the transfer of hardware and knowledge is given in Bell (1990). This separates technology transfer processes into three kinds of flows, as shown in Figure 3. Flow 'A' includes hardware (capital goods), as well as the engineering and managerial services that are required for implementing such transfer projects. These flows could also include product designs in the form, for example, of specifications for equipment. Flows of type 'B' consist of information about production equipment – operating procedures, routines, etc. – and training in how to operate and maintain such hardware. Bell (1990:77) describes these flows as 'paper-embodied technology' and 'people-embodied knowledge and expertise'. These kinds of flows are predominantly of the 'soft' variety. Both flows 'A' and 'B' add to or improve the production capacity of a firm or economy, but do little or nothing for developing the skills needed for generating new technology. Flows of type 'C', however, are those that help to create the capability to generate new technology; what Bell calls 'technological capacity', or what we could also call innovation capacity or capability, as Bell (2009) does in an updated discussion. What is not clear in this diagram of 'technology' flows is the role played by indigenous knowledge and skills. As the IPCC (2000) report states, these are also important for successful transfer of technologies, particularly where they may need to be adjusted to local conditions but also because the presence of existing knowledge and skills tends to make transfer easier. The extent to which such knowledge and skills are already present in a firm or economy is often called absorptive capacity, which we will discuss more fully in section 3. This capacity, and the way in which it also stems from indigenous support within a developing country's 'National Innovation System' is reflected in a modified version of Bell's diagram (see Figure 4). This National Innovation system is defined

by Freeman as ‘the network of institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies’ (Freeman 1987).

Figure 4: Technology transfer and National Innovation Systems



Source: Authors, based on Bell (1990)

When we refer to the creation of new technologies we do not always mean those that mark a radical departure from ‘old’ technologies. New technologies – or, more generally, innovations – can be characterised according to their position along a continuum that ranges from incremental to radical. New technologies can also be new to the world, the market or the firm (OECD 2005 cited in Bell 2009). Innovations new to the world or market¹⁴ might be described as involving ‘vertical’ transfer in the sense that they move from R&D to commercialisation; those that are new to the world, the market or the firm could be described as involving ‘horizontal’ transfer in the sense that they move from one geographical location to another (Ockwell et al. 2008). Of course, not all innovations involve both, but the distinction is a useful one when identifying the key barriers or constraints to innovation in a particular context such as China.

It can be argued that horizontal technology transfer that results in new adoption in a developing country market or firm is particularly important in the context of low carbon development. Ockwell et al. (2010:15-16) elaborate this argument at some length. In essence, developing country firms are more likely to put existing technologies into use than they are to create new-to-the-world technologies but they may have to adapt them to the local context and incrementally develop them over time. As such, technology flows of type A and B remain important (see the next section for more discussion of the capabilities associated with these types of flow). Nevertheless, there is an important mutually beneficial relationship between

¹⁴ Following Bell (2009:12, note 14): ‘The market may be defined (a) as firms’ competitors anywhere, or (b) in terms of a geographical region.’

adaptive/incremental innovation capabilities and those for R&D. Involvement in R&D tends to increase absorptive capacity (see the next section for more discussion of absorptive capacity) and so facilitates more efficient 'transfer' of all three flows of technology. In selecting the case studies for this research, one of the criteria is the desire for a spread of technologies ranging from near market or commercial to those in R&D or at the demonstration stage (see section 3 of this report for more details on the case studies). In practice, no innovation is likely to be entirely new or thoroughly radical: each innovation will depend to some extent on existing knowledge, other technologies and an institutional¹⁵ environment. Taken together, these broad processes of social and technological change occur through combinations of continuous incremental – and occasionally radical – innovations (Freeman 1992).

As the IPCC definition of technology transfer implies when it mentions a wide range of stakeholders, the context into which a technology is transferred consists of many actors connected through market and other kinds of relationships, operating in particular institutional environments, and providing a wide range of goods and services. Bearing this in mind, we can expect that processes of 'technology transfer' will also be affected in important ways by policy and economics. Policy frameworks in the recipient country and international frameworks (whether bilateral or multilateral) therefore have important impacts. In many cases, low carbon technology transfer is unlikely to lead to successful low carbon technology diffusion in the absence of incentives to create demand for the technologies in question.

One of the more contentious issues in technology transfer processes is that of IPRs. We will discuss the issue of IPRs more fully as part of our analysis of technological capabilities in section 3. Here, we will simply state that there are two principal levels at which these tensions arise. One is at the firm or organization level and the other is at the national level. At the firm level, where technologies are usually owned, the transferring firm will aim to maximise price and minimise leakage of proprietary knowledge. The recipient firm will want to minimise cost and maximise knowledge 'transfer'. At the national level, the 'transferring' country will want to maximise exports and minimise leakage of jobs / technologies to competitors. By contrast, the recipient country will want to maximise competitiveness and minimise imports.

So, to summarise, 'technology transfer' can be described as a complex process involving learning within and between firms and other organisations drawing on the human resources available from training institutions. All this occurs in a context of policies, laws, regulations, technical practices and cultural norms, and is influenced by political and economic interests. However, the use of the word 'technology' can mislead us into thinking only of hardware when, in fact, equipment cannot function without appropriate knowledge and skills, and many 'technologies' do not even include equipment. It may be more helpful, therefore, to redefine 'technology transfer' to reflect this broader understanding and to include recognition of our particular interest here in technologies to mitigate and adapt to climate change. On this basis, terms such as low-carbon innovation may be more suitable than technology transfer.

¹⁵ Institutions here refer to the range of policies, regulations and laws as well as technical practices and cultural norms (Scott 1995; Hodgson 2006).

3. Low carbon technology transfer to China: research results

3.1. Building technological capabilities in China

The discussion in the section 2 unpacked the concept of ‘technology transfer’ and, in doing so, referred to the notions tacit knowledge, absorptive capacity and innovation capacity or capability. In this section, we will use these linked concepts to analyse how capabilities have been developed within China in each of the four technological case studies. To aid this analysis, it is important to define two further concepts. The first is production capacity, which Bell and Pavitt describe as:

... the resources used to produce industrial goods at given levels of efficiency and given input combinations: equipment (capital-embodied technology), labour skills (operating and managerial know-how and experience), product and input specifications, and the organizational methods and systems used. (Bell and Pavitt, 1993:163)

The second definition refers to technological capabilities:

... the resources needed to generate and manage technical change, including skills, knowledge and experience, and institutional structures and linkages. (Bell and Pavitt, 1993:163)

As we discussed in Figure 3 in section 2, these two forms of capacity/capability can be illustrated as flows of type A, B and C from suppliers to importers. Flows A and B contribute to building production capacity, while flow C (in conjunction with A and B) contributes to the accumulation of technological capabilities. Figure 4 complemented this by emphasising that both production capacity and technological capabilities are also developed through indigenous innovation within developing countries.

The first report of this present study discussed the role of technological capabilities in some detail (Watson, Byrne et al. 2010b) and so we will not repeat that discussion here. Instead, we will refer to the most relevant aspects of that discussion since these are applied in our analysis of the case study evidence.

Our picture of technology flows can be enhanced by recognising the importance of local absorptive capacity, defined as the ability to ‘recognize the value of new information, assimilate it, and apply it to commercial ends’ (Cohen and Levinthal 1990:128). Absorptive capacity is an important element of the technological capabilities defined by Bell and Pavitt (1993). In turn, technological capabilities broadly characterise an innovation system, hence the addition of the national system of innovation to Bell’s (1990) diagram of technology flows, as given in Figure 4.

Implied in this description is a positive interdependent relationship between the building of technological capabilities and the particular state of absorptive capacity. In crude terms, the higher the absorptive capacity of firms and organisations, the easier it is to build technological capabilities in a particular country or sector. Similarly, the building of technological capabilities raises the level of absorptive capacity. In practical terms, this building process can be achieved by focusing on

'simpler' production capabilities initially and moving to more 'complex' innovation capabilities later (Bell 1997:75). Given that these two properties of firms, organisations and innovation systems have a large degree of overlap, this report refers mainly to capabilities for the sake of simplicity.

We can see the process of building capabilities as one of 'catching up' with the 'technological frontier', although we should recognise that there are important criticisms of these notions that caution us not to ignore the possibility of multiple 'directions' of innovation (Stirling 2009) and that not all innovation is necessarily at the world 'frontier' (see e.g. Kaplinsky 2011 on 'below the radar' innovation). Nevertheless, as we see in the case studies, firms and other actors do hold conceptions of what constitutes the 'cutting edge' or 'frontier' of a particular technological area and so, from an analytical perspective, the notions of catching up and frontier provide some useful purchase. This was also the case in our previous case study research in India.

This discussion also brings us to the issue of intellectual property rights (IPRs), which often arises around access to technologies – particularly those at the frontier. In the area of low carbon technology transfer, it tends to provoke particularly thorny debate between industrialised and developing countries. IPRs are legal rights over ideas, creative processes and products. They include copyrights, trademarks, and patents¹⁶ – where holders can prevent the use of these technologies; thus patents are likely the most important type of IPRs within the context of low carbon technology transfer (Harvey 2008:5). There are often two sides to this debate. Some commentators and Parties to UN negotiations (particularly developing country Parties) assert that low carbon technologies are public goods¹⁷, contributing as they do to the mitigation of future carbon emissions, and that the IPRs to these technologies should therefore be bought up by an international fund and made freely available to developing countries, similar to agreements made over certain anti-retroviral drugs for treating HIV/AIDS. Current IPR regimes, they argue, are inappropriate and restrict access to low carbon technologies by developing country firms and organisations. On the other side of the debate some (particularly in developed countries) argue that low carbon technology transfer will be better facilitated if developing countries tighten up their legal frameworks for IPR protection, and the enforcement thereof.

Empirical evidence available to date on IPRs in the context of low carbon technology transfer is limited. Nevertheless, there are recent substantial pieces of research on this issue, some of which are based on case studies. For example, Barton (2007) reviews the markets for three renewable technologies (solar PV, wind and biofuels). Similarly, Lewis (2007) presents an in-depth analysis of the wind power industry in China and India and is drawn on extensively in Barton's analysis. Harvey (2008) addresses the issue by examining IPRs more generally among developing countries, and considers the potential role of China and international institutions, such as the World Trade Organization (WTO). The International Centre for Trade and

¹⁶ Copyrights, trademarks and patents are considered formal parts of the UK intellectual property regime. However, as noted in section 2, the UK system also recognises informal types of intellectual property such as tacit knowledge.

¹⁷ However, as noted in Mallett, Ockwell et al. (2009:29), low carbon technologies are rival and excludable, so are not 'pure' public goods.

Sustainable Development (ICTSD) carried out two studies examining the role of intellectual property for climate technologies. The first (ICTSD 2008) dedicates a chapter to the potential role of IPRs. The second (Oliva 2008) provides an overview of the issues, drawing on evidence from studies of technology (not necessarily low carbon) transfer to developing countries and discusses how IP might be dealt with under the UNFCCC process. In addition, a study by Chatham House (Lee et al. 2009) focuses on the ownership of intellectual property in a range of low carbon technologies, and also analyses the speed at which these technologies are brought to market.

Empirical research for the UK-India collaboration on low carbon technology transfer, led by the Sussex Energy Group (SEG), was conducted in parallel with these studies. Two phases of research were completed. The first phase (Ockwell et al. 2006) used technology case studies¹⁸ in India to look more generally at low carbon technology transfer but was able to draw only tentative insights on IPRs. The second phase (Mallett, Ockwell et al. 2009) focused explicitly on IPRs, examining five case studies¹⁹, also in India. The emphasis throughout the studies was on a consultative approach that engaged directly with industry, government and researchers. Across the two studies over 300 people were consulted, most based in India but discussions were also held with stakeholders from the industrialised world.

Whilst these studies are inconclusive on the overall impact of IPR regimes on technology transfer (e.g. Oliva 2008), almost all found that developing country firms had access in principle to the technologies they examined. There is usually a cost associated with such access – but in many cases, costs are not so high as to prohibit access to a generic technology (such as wind power or solar power). However, the inconclusive nature of the studies lies in the fact that IPR issues depend on a set of factors that are difficult to generalise.

For instance, Harvey (2008) found that companies often do not file patents in the Least Developed Countries (LDCs) because they do not see them as lucrative markets. Alternatively, they may be willing to sell their IP at a lower price if they feel confident that the lower-cost technologies produced in the LDCs will not be re-exported to their ‘home’ markets where they could be more competitive. But the status of the firm may be important here. A publicly funded intervention by the Global Environment Facility (GEF) tried to subsidise licenses for Chinese firms to gain access to efficient boilers. It was only ‘second tier’ suppliers²⁰ who were willing to sell (Birner and Martinot 2005). These firms believed they would gain more from selling licenses than they would by operating in the Chinese market, whereas leading firms held the opposite view.

¹⁸ The case studies analysed by Ockwell et al. (2007) were integrated gasification combined cycle (IGCC) technology for coal-fired power generation, light-emitting diode (LED) lighting, hybrid vehicles, biomass generation and improving the combustion efficiency of existing power stations.

¹⁹ The case studies in Mallett, Ockwell et al. (2009) were hybrid vehicles, solar photovoltaics (PV), energy efficient technologies in small and medium-sized enterprises, wind energy and IGCC for power generation.

²⁰ So-called ‘second tier’ companies are smaller firms than the market leaders, although this does not imply that they sell inferior technology (Lewis 2007).

Similar to our findings, both Barton and Lewis demonstrated that Indian and Chinese firms achieved access to technologies by buying licenses, entering into joint ventures, buying majority shares in firms or acquiring them outright. Of course, these options may not be possible for all firms, particularly if the company with the IP is large and the 'buyer' relatively small. Indeed, firm size, the structure of the market (highly concentrated or not), and the degree of competitiveness in supply of a technology can all play a role in determining how easy it is to get access (Barton 2007; Lee, Iliiev et al. 2009; Ockwell et al. 2006). And, where a firm cannot get access to the most recent variant of a technology, they may face difficulties securing finance. This is particularly likely in the case of venture capital funds, which tend to favour start-ups with strong proprietary positions with regard to patented technologies (Barton 2007).

More recent studies of patenting activity have confirmed that the majority of patents in clean or low carbon energy technologies are held by developed country firms (e.g. UNEP et al 2010). However, they also show significant and growing patenting activity within China and other rapidly developing economies. One recent report states that a third of the patent applications within developing countries in a four year period to 2008 were made in China (Maskus and Okediji 2010). This growth is part of a broader trend in which patenting activity has increased in China across the economy - a trend that has continued as a result of China's accession to the World Trade Organisation (Yueh 2009). Chinese patenting laws were revised for the third time in 2009 in recognition of the growing importance of protecting the property rights of domestic firms²¹.

The case study analysis in the remainder of section 3.1 concentrates on some key themes. In each case, we give a brief rationale to underline the significance of the technology to low carbon technology transfer. We then provide a summary of the status of the technology in China, as expressed by interviewees and as discussed in the literature. More extensive information is given in the case study reports in Appendices A to D. Following this, we examine the current state of technological capabilities and discuss the local innovation system around that technology. This is to provide a basis from which we can critically analyse the extent to which Chinese firms have 'caught up' through the accumulation of technological capabilities. Within this analysis, we have also identified related IPR issues, particularly where they have been highlighted by interviewees. Of course, an important aspect of the Chinese innovation system is the role played by policy frameworks. We include reference to policy in the analyses below but provide more extensive discussions of the role of Chinese and international policy and finance frameworks in sections 3.2 and 3.3.

Energy efficiency in the cement industry

Globally, the production of cement contributes around 8% of anthropogenic CO₂ emissions²² (Müller and Harnisch 2008:1). China has been the world leader in cement production for many years, reaching 1.65 billion tonnes in 2009 or more than 50% of world production (CCA 2010). The process of cement production generates

²¹ According to one of our final report workshop participants, this third set of reforms were different to the first and second revisions (in 1992 and 2001 respectively) since they were not implemented in response to international pressure.

²² The figure of 8% is for 2006: see Müller and Harnisch (2008: endnote 4).

CO₂ emissions in two important ways. Currently, the conversion of limestone into lime accounts for about 55% of these emissions, and the combustion of energy carriers needed to drive this conversion process accounts for another 40% (Müller and Harnisch 2008:2). There are many measures that can reduce primary energy consumption in the production of cement and so could be characterised as energy efficiency improvements. These range from behavioural changes amongst staff to using the most efficient technological hardware and optimised processes (Worrell and Galitsky 2008). In addition, the use of fossil energy carriers as the source of heat can be substituted with waste material or biomass, and waste heat itself can be recycled and/or recovered for power generation (Müller and Harnisch 2008).

Technology status

As stated above, there are numerous energy efficiency improvements possible in cement production. Apart from using the most efficient equipment that drives the production process (motors, pumps, compressors, etc.), and using such equipment in the most efficient ways, there are opportunities to optimise the process itself and to make further savings through fine-tuning of the many concurrent processes across a cement plant (Worrell and Galitsky 2008).

Kiln technology. The commercial state-of-the-art equipment for the process itself includes the New Suspension Pre-Heater kiln (NSP). The most efficient NSP-based kilns are generally large (5000 tpd – tonnes per day) and use a dry manufacturing process, which is less energy-intensive than a wet process (Müller and Harnisch 2008; Price and Galitsky 2006). China has moved rapidly to medium and large-sized NSP-based cement production in recent years. By the end of 2009, China had 1113 NSP-based production lines or almost 77% of total Chinese cement production (see Appendix A). This is reducing the average energy-intensity of the Chinese cement industry but it has some way to go, partly because there are still some small and inefficient kilns in operation (Müller and Harnisch 2008). By 2007, the energy-intensity of cement production in China had fallen to 158 kgce/t (kilograms coal equivalent per tonne) but was significantly higher than the international advanced level of 127 kgce/t (Ohshita and Price 2011:53). More recently, the Vice Minister of the NDRC, Xie Zhenhua stated that the energy intensity of cement production fell 16% during the 11th five year plan period (2005 to 2010), suggesting that this gap has been closed further since 2007²³.

Power generation from heat recovery. Using the best available kiln technology, cement production consumes about 100 kWh/t of clinker (80 kWh/t of cement), accounting for 25% to 30% of production cost (Müller and Harnisch 2008:22). With the large amount of waste heat generated by cement production there is clearly potential to make use of it to replace primary energy use for electricity supply by, for example, driving a steam turbine (Worrell and Galitsky 2008). Müller and Harnisch (2008:23) state that conversion of heat recovered can generate 20 to 45 kWh of electricity per tonne of cement, where larger plants are more efficient and so more cost-effective. By the end of 2009, there were 498 NSP cement lines of 2000 tpd (tonnes per day) capacity with residual heat power generation systems installed in

²³ Xie Zhenhua, Speech to 2011 International Conference on Low Carbon Energy and Climate Change, Tsinghua University, 24th March 2011.

China, providing a total of 3.3 GW of electricity generation capacity or 22.2 billion kWh (see Appendix A). This represents avoided CO₂ emissions of 20 Mt. Other system-sizes have been installed. For example, a 1350-tonne cement line was renovated beginning in May 2002 to generate electricity from heat recovery. Using local expertise to renovate the facility, this now generates more than 1.8 MW of electricity, or 11.34 GWh annually in excess of the needs of the plant (Price and Galitsky 2006:27). By 2006, Chinese domestic technology was reported to be able to produce in the range of 24 kWh/t to 32 kWh/t, foreign technology could produce 28 kWh/t to 36 kWh/t, and Japanese technology had reached 45 kWh/t of clinker (Price and Galitsky 2006:28).

Alternative fuels for heat generation. Alternative fuels for heat generation include waste streams and biomass. There is a wide range of potential waste products from both industrial and domestic sectors that can be successfully used in generating heat for cement production: tyres, oils, solvents, paper-industry residues, chemical wastes, plastics and many others (Müller and Harnisch 2008:27). The extent of carbon savings depends on the carbon content of the waste material used, and whether there is heat-recovery in the cement plant (Worrell and Galitsky 2008). But other benefits can be derived from waste-burning. For example, because the waste is burned at very high temperature and resides for long periods in the kiln, almost all organic compounds are destroyed and efficient scrubbing of the exhaust gases can result in much-reduced emissions besides carbon (Worrell and Galitsky 2008). The use of waste materials for burning in kilns has grown worldwide but China has not yet adopted this approach on any great scale. Our case study research suggests that about 10% of the approximately 5000 cement plants in China use waste for fuel, with annual emissions reductions of less than 50 ktce (kilotonne coal equivalent).

Other energy efficiency technologies. A range of other technologies and techniques are recommended for improving energy efficiency, although we only highlight three of them here (see e.g. Worrell and Galitsky 2008 for a detailed discussion of other options). Adjustable speed drives (ASDs) can result in significant electricity savings. For example, a plant in Mexico using ASDs reported reduced electricity consumption of 40% together with improved reliability (Price and Galitsky 2006). In China, savings of more than 30% electricity consumption were reported by one firm owning 10 plants (Price and Galitsky 2006). ASDs are being made in China but some of the parts and instrumentation may still be imported from elsewhere (Price and Galitsky 2006). Grate coolers lower the temperature of the clinker from about 1200 °C to 100 °C, and are the preferred option in modern kilns (Worrell, Galitsky and Price 2008). Heat recovery rates of grate coolers are reported to be in the range 65% to 72%; the latter achieved with a third generation grate cooler in a 2500 tpd precalciner kiln in China (Price and Galitsky 2008:23). Process control systems can help to optimise the kiln combustion process and conditions, as well as improve the quality of the cement produced (Worrell and Galitsky 2008). Some firms in China supply IT for optimising process control (Worrell et al. 2008).

Those we interviewed identified all the technologies discussed above; either as having already been adopted or as being planned for adoption. Technologies and techniques not discussed above but mentioned in our interviews include: the use of milling agents, roller presses, vertical mills, high-performance refractory materials, precision weighing equipment and x-ray diffraction examination equipment. Most of

the equipment can be sourced from within China but some still needs to be imported. In this respect, vertical mills, grate coolers, precision weighing machines and x-ray diffraction instruments were cited most often.

Technological capabilities

It is clear that the energy efficiency of cement production capacity has been improving over time, although there is still a significant gap between the international and Chinese averages and a much larger distance to the international frontier. And, in terms of manufacturing production equipment, the case study research suggests that Chinese firms are able to make most of the equipment locally. But, as we have just mentioned in the preceding paragraph, there are still important technologies that Chinese firms have not yet mastered the capabilities to manufacture and so these are still being imported.

There is certainly evidence that Chinese firms have been able to build cement production facilities in other countries, beginning as early as 1992, particularly in South Asia, West Asia and Africa, and that this capability has strengthened over time. The first plant exported was rated at 700 tpd but this had risen to 10,000 tpd plant by 2005. Moreover, there are now five firms able to construct 10,000 tpd production lines and more than 300 with the capability to construct 5000 tpd facilities. However, one of the interviewees noted that this does not assume Chinese firms are able to construct these plants to the same level of energy efficiency (and other quality measures) as the international advanced level.

It is difficult to assess the extent to which innovative capabilities have been developed. Indeed, comments from some of those interviewed suggest that Chinese firms have not yet developed such capabilities. For example, it seems that they are experiencing difficulties training staff in new and advanced energy efficiency technologies, and in integrating these technologies into production systems. Another example, less directly related to energy efficiency, suggests that they have yet to develop enough tacit knowledge of some of the more advanced processing technologies. Specifically, the limestone used in China is generally harder than elsewhere and this has implications for the alloys that can be used for grinding. At present, Chinese firms have not been able to develop alloys that can cope with this harder limestone, the consequence of which is that the grinding plant wears more quickly than in other cement facilities.

However, there is one area in which Chinese firms may have developed important innovative capabilities. It would appear that the renovation of the plant in 2002 to make use of waste heat for generating electricity was successful. Of course, it is possible that the efficiency gains were not as high as they could have been but the point is that the power generation adaptation worked. And the later figures for power generation from waste heat (24 to 32 kWh/t) compare favourably with the international level (28 to 36 kWh/t), if not with the highest achieved by Japanese firms (45 kWh/t). In any case, the number of NSP lines with similar power generation is now around 500, suggesting that Chinese firms are developing their innovative capabilities in this area of energy efficiency technologies.

Innovation system

While Chinese firms do appear to have developed their own technological capabilities – both production and innovation – to some extent, we should also look to the broader innovation system for indications of capability-building. The evidence is patchy but suggestive of some degree of a functioning innovation system in the area of cement production. First, a number of Chinese firms claim to collaborate with local research institutes and universities in joint R&D activities. Second, there are organisations that help to disseminate information about cement production technologies and build capacity to support the purchase of these (e.g. China Cement Association, China Strategy Institute of Building Materials). Third, our interviewees within the Chinese cement industry expressed their preference for interacting with local companies for at least four reasons: the technologies are cheaper than foreign-made equipment, it is faster and more convenient to get after-sales service, easier to pursue continuous improvement strategies, and there is a wish to support the development of the local industrial system. One interview summed up this preference by stating that ‘domestic techniques fit the Chinese cement development better’.

The idea that it is easier to pursue continuous improvement strategies, in particular, is suggestive of the functioning of an innovation system. Implicit in this is the requirement for collaborations between firms and other organisations, activities indeed claimed by the interviewees. The fact that it is faster and more convenient to get after-sales service is also suggestive of working relationships between firms. Still, we do not have strong evidence here on which to draw robust conclusions in regard to the nature of the innovation system around cement production in China.

Catching up strategies

In what is a familiar pattern across the case studies, Chinese firms have developed their technological capabilities through a sequence of increasingly sophisticated and larger-scale activities. In cement production, these larger-scale activities began in the late 1970s with the installation and subsequent operation of a 700 tpd NSP line supplied by a foreign firm, most probably Japanese. Later, a local firm was licensed to supply Japanese separator technology. By 1984, some Chinese firms were able to design and develop a 2000 tpd NSP kiln and source most of the equipment locally. In the early 1990s, the first joint ventures were established, beginning with a 4000 tpd NSP line in 1992 under Dalian Huaneng-Onoda Cement Company. Others followed, including Yantai Mitsubishi, Daewoo Sishui and Qinhuangdao Asano. In 2007, a Japanese firm set up a joint venture with a Chinese firm to manufacture waste heat power generation equipment. Izumi (2008) claims that the technology was shared with the local firm and that 61 plants in China subsequently installed the technology.

Chinese firms began to demonstrate their technological capabilities when they started exporting to other developing countries in 1992, although they may still not have achieved the international capability level. The next step in the sequence was to enter into joint R&D activities, with foreign firms and with local research institutes and universities. Despite this learning, and building of absorptive and innovative capacity, some of the interviewees commented that IPRs are something of a barrier

to the further development of their capabilities. None was specific about which IPRs and which equipment but we might speculate, given that some technologies are still being imported, that they are referring to x-ray diffraction and precision weighing hardware, grate coolers and vertical mills. Furthermore, the comments in regard to problems integrating energy efficiency and production processes suggest that there could be management systems that are difficult to develop without deeper involvement of those firms that have achieved the highest efficiencies, particularly Japanese firms. Nevertheless, there have been recent attempts to introduce energy efficiency benchmarking and other interventions in China. Ohshita and Price (2011: 63) list 15 cooperative energy efficiency programmes involving multilateral, regional, bilateral and non-governmental actors, although these are not all the measures of energy efficiency that have been active in China.

Electric vehicles

China was the third largest automobile producer and the second largest consumer in the world in 2008 (NBS 2009) but became number one on both counts for the first time recently, mainly due to two reasons. There are domestic subsidies for buyers in China, and the Japanese and US markets shrank because of the financial crisis (Xinhuanet 2010). Vehicle sales rose in China to a record of 9.35 million in 2008 and motorcycle sales reached 25.5 million in 2007 (CATARC 2008). However, vehicle ownership is still much lower than the world average, on a per capita basis, and so the potential for growth in vehicle ownership is high. In 1990, road vehicles accounted for 54% of transport energy demand in China, and grew to 65% in 2005 (IEA 2008). Under a business as usual scenario, this share is projected to become 77% by 2030. Consequently, the Chinese government is making great efforts to curb oil demand, which could also reduce CO₂ emissions. A number of initiatives have been taken to promote 'new-energy' vehicles, including hybrid and electric vehicles (HEVs) (Ouyang 2006; Wan 2008).

Technology status

Taking a broad definition, electric vehicles include pure electric vehicles (PEVs or EVs), hybrid electric vehicles (HEVs – often used to mean hybrid and electric), and fuel cell electric vehicles (FCEVs). In principle, they can all perform with lower carbon emissions, than the internal combustion engine (ICE), though this clearly depends on the fuel used to generate electricity. EVs achieve zero emissions during driving and possess a fuel economy considered to be 300% higher than an ICE-based vehicle (Zhang, Shen et al. 2008). If potential technology improvements are achieved (see Appendix B), it is estimated that EVs could save about 50% of primary energy demand and 35% of GHG emissions (based on 2012 emissions) (Ou, Qin et al. 2009). Here, we will consider electric motors, batteries, battery management systems, electronic control systems and the charging infrastructure.

Electric motors. An electric motor is obviously a key component of an EV. Electric motors are well suited to urban driving during which there are frequently low speeds, stop and go situations, and occasional reversing. A number of Chinese firms are active in motor manufacture and have recently made large investments to enhance production capacity. In 2009, capacity was estimated to be 73,000 sets with

investments of RMB 300 million. In 2010, capacity was estimated to be 272,000 sets and investments of RMB 520 million (Ouyang 2010).

Batteries. A battery stores the electrical energy that is needed to power an electric motor. It can be charged and discharged but different battery chemistries exist and each can be characterised according to a number of standard parameters: energy capacity, charge rate, self-discharge rate, efficiency, energy density (by mass or volume), and others. For electric vehicles, the values of most interest tend to be energy density, charge rate, efficiency, and cost. The battery type receiving most interest is Lithium-ion (Li-ion), as they have one of the most favourable combinations of parameters among current battery options. However, their cost is still very high and the charging process causes some 'wear and tear'. Also, the current level of battery technology does not allow distance driving. At present, while Chinese firms can manufacture batteries, there are parts of the process that they have not mastered. For example, there is a critical membrane in a Li-ion battery that must be imported. Without a satisfactory membrane, the battery can overheat and catch fire.

Battery management systems. Battery management systems are important for a number of reasons. First, there is a complicated set of charge and discharge needs in an electric vehicle but the battery needs to be able to service these reliably. Second, there can be need for thermal management to avoid the risk of fire. Third, and related to the first, a battery cannot be charged or discharged too quickly as doing so tends to lower its serviceable lifetime. These systems are already sophisticated but they are likely to be increasingly so. As batteries and their management systems become more sophisticated, it is more likely that access to new IPRs will be required to improve technological capabilities. Chinese firms are actively seeking the capabilities for battery management systems.

Electronic control systems. The integration of electrical, mechanical, chemical and software technologies is needed in EVs. An electronic control system is an advanced system integration technology to achieve this. Some of the key components for these systems have to be imported to China. Moreover, this is another area in which China is actively seeking capabilities.

Charging infrastructure. This is needed to ensure that vehicles can be charged conveniently wherever a driver happens to be. Without the infrastructure there is unlikely to be significant demand for EVs. The development of this infrastructure in China is patchy at present (UKTI and SMMT 2010). Some charging networks are beginning to appear in China's 'sustainable cities' but there is much uncertainty about how soon the charging network will be in place.

Technological capabilities

Chinese firms have developed a wide range of technological capabilities in internal combustion engine (ICE) based automotive manufacturing. And, alongside this manufacturing, there are research organisations and many firms supplying components. They are able to service a strong and growing local market and, with the state-level imperative to find ways of reducing the demand for imported oil, they are being encouraged to translate these capabilities into the building of an indigenous hybrid and electric vehicle industry. This has created opportunities for

those with capabilities in battery technology, such as BYD Auto, to play an important role in the development of the sector. However, there are many challenges for Chinese firms to meet before they can be said to have indigenised an HEV industry. Our interviews identified a number of areas of battery technology in which international firms have a clear advantage such as materials and battery management systems (see Appendix B).

While Chinese firms have built significant production capacity in traditional vehicle manufacture, they are not yet able to make cars for the local high-end market – a segment that is still dominated by firms from the West and Japan. Part of this appears to be because of inconsistent quality of production but there may also be an element of risk-aversion. The study by UKTI and SMMT (2010) reveals an automotive industry that *in general* is reluctant to move beyond vehicles that have been proven to sell. Instead, it appears that the bulk of effort has been focused on servicing a cost-conscious mass market where quality matters much less. In doing so, Chinese firms have been able to build production capacity in terms of large-scale plants and operation but have not necessarily developed much in the way of innovative capabilities. Indeed, the observation in the UKTI and SMMT study, that component suppliers in China may struggle to service the nascent HEV industry because of years of supplying to the same auto makers, may be an indication of this low level of innovativeness.

However, there are some firms that are attempting to make the development of HEVs a priority, encouraged by substantial government funds through the 863 programme (see section 3.2). Nevertheless, the design and manufacturing demands of HEVs appear to me much more complex – and costly – than those of traditional ICE vehicles and so Chinese auto makers find themselves with (currently) inadequate technological capabilities. Even for those firms that have entered with battery and electrical technology capabilities there appear to be many challenges in the shift from the needs of mobile phones and laptops.

There is certainly a considerable amount of R&D work being done by many Chinese firms – an important aspect of technological capabilities – but there are problems in achieving innovativeness in its fullest sense. That is, putting the research, design and development work – done largely away from the pressures of the market – into commercial use. In other words, innovation is happening, but this has not yet had commercial impacts. And these difficulties are present across a range of important technologies for the commercialisation of HEVs: in many aspects of batteries, advanced transmissions, the integration and management of vehicle systems, and meeting the various regulations necessary for exporting to European and US markets in particular. Where Chinese firms are enjoying more success in developing innovative capabilities appears to be in the domestic electric bicycle market. This may act as a platform from which they can build more complex capabilities over time that could see currently unexpected evolutions of HEVs.

Innovation system

Despite the success of the ICE-based vehicle industry, it would appear that the innovation system in China has some weaknesses. One aspect of the explanation for this may be that suggested by UKTI and SMMT (2010), mentioned above,

whereby component suppliers have been servicing too few firms and so have become 'rigid' in their own production processes. As a result, they have not become sufficiently practiced in R&D and other innovation activities. Considering these observations together with the fear that there is not enough expertise in newer vehicle technologies such as EVs within Chinese firms, there is a possibility that suppliers will find it difficult to respond to the high and perhaps rapidly changing demands of the HEV industry.

There is also a high degree of uncertainty generated from lack of policy clarity in the government on subsidies for private consumers, and its apparent reluctance to commit to building charging infrastructure for HEVs. Further concerns have been generated because of the slow pace in setting regulations and other codes. The subsidies for private customers are seen as necessary to help stimulate demand in a market that, as we have said, is deeply cost-conscious. Demand is also unlikely to materialise if there is insufficient charging infrastructure. The lack of standards, regulations, and other codes, makes it difficult to design products with any confidence, particularly in such a capital-intensive industry. Perhaps this is one reason for the interest in Chinese firms to penetrate foreign markets such as in Europe and the US.

It appears, then, that there are weaknesses in the innovation system around automotive manufacturing. Moreover, these weaknesses are apparent in different parts of the system. Supplier firms may not have established good links outside of just a few buyer firms, there may be a shortage of new-energy knowledge and skills, demand for HEVs is unproven, and the institutional environment is uncertain.

Catching up strategies

Part of the manufacturing base for the HEV industry was built through the development of production capacity for ICE-based vehicles. And part of it was built from the base for battery production for mobile phones and laptops. The building strategies have been similar in that Chinese firms began manufacturing under license from foreign firms in possession of the relevant technology. However, with the requirement for joint ventures, Chinese firms were able to accumulate their own knowledge of the technologies, enter into joint R&D activities and, eventually, to design and manufacture in their own right. Nevertheless, not all cases of joint ventures have necessarily resulted in Chinese firms accumulating significant knowledge. It appears that Toyota, in particular, have been careful not to lose their knowledge to competitors or partners.

For HEVs, the process of joint R&D has been encouraged via government funds, particularly under the 863 programme (see the policy discussion in section 3.2), and particularly with foreign firms. Those firms have been attracted by the prospect of access to China's rapidly growing market for private vehicles. One development from this mutual interest has been a deepening of links between Chinese and UK firms. Shanghai Automotive Industries Corporation (SAIC), for example, have now bought UK capabilities²⁴ and so have an R&D base in the UK. They have been using this

²⁴ For example, Shanghai Automotive Industries Corporation, who had worked with Ricardo in the past, now own MG Motor in the UK: <http://www.insideline.com/saic/mg-motor-opens-uk-design-studio.html>

over the past two years to help train Chinese engineers who then shuttle back and forth to China to pass the training onto SAIC's engineers there. Chang'An Automobile Company have also invested in an R&D base in the UK, recently entering into work with the University of Nottingham²⁵.

One of the significant results of this State-sponsored R&D drive has been China becoming the second most successful country for HEV patents. In such an R&D intensive industry, IPRs can be seen as particularly important. The issue of IPRs often generates tension in the UNFCCC negotiations but it came to the fore outside of that setting recently amid accusations of Chinese attempts to steal electric vehicle technology²⁶ from the French auto maker Renault. The accusations were withdrawn after French prosecutors found there was 'no case to answer'²⁷. Indeed, Chinese firms have clearly been highly successful in creating their own patents. But this patent success may have become a source of paralysis in the local market. One of the comments made by UKTI and SMMT (2010) is that Chinese firms are reluctant to release their HEVs into the local market because they are fearful that their competitors will imitate them. With demand low at present, it is straightforward to understand that the loss of any market share could be very costly. Still, the money continues to flow for R&D and a number of Chinese firms are investing heavily to get vehicles and components into the local market at scale. And foreign firms are continuing to invest in joint ventures and R&D. In any case, Chinese firms are building technological capabilities in the HEV industry but only a few are actively trying to commercialise the technologies.

Offshore wind power

Wind power is an important part of China's energy strategy as it looks to reduce fossil fuel imports. It already has a highly active onshore wind industry that has grown from almost nothing at the end of the 1990s to become, by 2009, second to the US in installed capacity totalling 25.9 GW (Lewis 2007; Levi, Economy et al. 2010). Having witnessed explosive growth for several years, China raised its 2020 target for installed capacity from 30 GW to 100 GW²⁸. It is now looking to exploit its offshore wind potential. However, unlike the onshore wind industry when China entered, the offshore wind industry worldwide is still in its early stages. This may have important implications for the ways in which Chinese firms develop their technological capabilities for the industry.

Technology status

At present, there are just over 2 GW of offshore wind turbines actually installed worldwide. Therefore, there is relatively little experience available from which to learn. This makes each project highly unique, although each will have its particular

²⁵ See <http://www.nottingham.ac.uk/news/pressreleases/2010/july/chinapartnerships.aspx>

²⁶ "China link to Renault car spy plot", The Scotsman, January 8th 2011. Available: <http://www.scotsman.com/news/China-link-to-Renault-car.6683661.jp>; "Renault spy scandal: China denies involvement", BBC online, January 11th 2011. Available: <http://www.bbc.co.uk/news/business-12160430>

²⁷ See <http://www.guardian.co.uk/world/2011/mar/14/renault-staff-spying-case-collapses>

²⁸ Speech by Zhang Guobao, chair of the National Energy Administration to the International Cooperative Conference on Green Economy and Climate Change, Beijing, China, 9th May 2010.

challenges in any case. While the most experimental technology is the floating turbine concept – a joint venture project between Siemens and Statoil – that could revolutionise the industry, every offshore farm presents a difficult challenge. The early attempts at offshore were essentially adjustments of the knowledge gained onshore. The effort has now moved to re-engineering the turbines and their supporting infrastructure while trying to achieve two objectives. The first is, obviously, designing for the marine environment. The second is to build in redundant systems in order to minimise the number of times a turbine needs to be accessed, and to avoid losing a turbine's output for the sake of a simple spare part. But this does not convey the complexity of the turbine design challenge. One of our interviewees described it as finding constant trade-offs between structural strength, flexibility, sophistication and cost. The blades will typically endure 20 to 50 times the duty cycle of an aircraft wing, while being longer and heavier, but be expected to cost one twentieth that of an aircraft wing. Moreover, this is not engineering that can be patented. Indeed, much of the engineering knowledge is publicly available. Instead, the skills needed for this balancing of performance demands are learned through experience, or what we described in the first report as tacit knowledge (Watson, Byrne et al. 2010b).

The first offshore wind farm in China became operational in 2010. A young Chinese firm, Sinovel (started in 2005/6), won the contract for the project, having designed the 3 MW turbines in collaboration with Wintec (an Austrian firm). The turbines were manufactured in China and so there is considerable interest in how they will perform.

Technological capabilities

China has become a world leader in production capacity for onshore wind power. With its long coastline, it is an obvious move to try to use these capabilities to exploit its offshore wind potential. However, the demands for offshore wind technology are significantly different from those for onshore operation. The marine environment, of course, is challenging everywhere but there are also specific issues to consider in China. For example, it experiences frequent typhoons and the base for turbines is harsher than in Europe, particularly the silt base of the intertidal zone. Furthermore, the management and operation of equipment that can be far off shore means there is a need for redundancy of systems to minimise downtime, and there are many engineering and economic parameters to optimise for any given site and conditions. For these reasons, and with only 2 GW deployed worldwide, the offshore wind industry is still in its infancy. Much like electric vehicles, therefore, the industry is in an intensive learning phase.

By the end of 2009, there were about 80 wind turbine manufacturers in China, although only 30 of these had actually sold turbines²⁹. The top three manufacturers have a combined production capacity of about 8 GW/year, supplying to a domestic market of 13.8 GW/year. The top ten manufacturers could supply this market between them. Clearly, the market is highly competitive but there continue to be new entrants. However, for offshore wind, the government introduced an access standard, which means that only those manufacturers that can produce turbines of

²⁹ Levi, Economy et al. (2010:88, endnote 144) report the presence of about 100 turbine manufacturers and that the Chinese government intends to set guidelines for the industry that will see only 'twenty to thirty survivors'.

2.5 MW or greater will be eligible for selection for offshore wind projects. This has spurred the larger firms to develop prototype machines to meet this criterion. Sinovel, one of these large firms, designed and produced the 3 MW turbines for China's first offshore wind farm off the coast of Shanghai, which began operation in 2010. It is too soon to know whether Sinovel really has strong capabilities but reports by engineers who inspected the turbines suggest that Sinovel at least has potentially strong design and manufacturing capabilities for offshore wind.

In general, however, while the production capacity for wind turbines is high in China, there are problems in certain aspects. The manufacture of blades, gearboxes, converters and spindle bearings are not yet fully indigenised. Discussions with interviewees indicate that poor capabilities for materials processing seems to be the problem rather than design skills, and there are certainly firms manufacturing these components. With respect to offshore wind, some Chinese representatives of industry and government are cautious about Chinese capabilities – and stress that power companies have little knowledge so far, and that it will take time for the technology to mature (Prideaux and Qi 2010). Therefore, we can see that some innovation capabilities are present in Chinese firms but there is still a gap between them and the more experienced firms such as Siemens and Vestas.

Innovation system

It is not clear the extent to which turbine manufacturing firms in China's wind power industry cooperate with each other, or how much we can realistically assess the innovation system. Certainly, there are many players in the market so there may be many opportunities for interactions. But, given that the market is highly competitive, it is less likely that we would see cooperation between direct competitors. Indeed, Goldwind, for example, have been highly proactive in protecting their IPRs from domestic competitors (Lewis 2007). It is more likely that turbine manufacturers interact with their supply chain firms. The latter was encouraged with the local content rules that were imposed by the central government. These rules had a large impact on international suppliers, and have recently led to an inquiry by the Obama Administration about a possible legal challenge under the WTO³⁰. The record of rapidly delivered production capacity on a huge scale suggests that the innovation system around onshore wind functions quite well. We can also say that links to international innovation networks are now well established and of great importance to large Chinese manufacturing firms. For offshore wind, it is too early to make an assessment with respect to this issue.

We can be more certain about the institutional environment, at least for the onshore wind industry. Policy in China continues to be enabling of wind power development, and the Clean Development Mechanism (CDM) has been used to great advantage (see sections 3.2 and 3.3 for more discussion of the national and international policy contexts). However, one interviewee commented that there may be some difficulties for Chinese firms trying to develop their offshore wind capabilities because of Chinese sensitivity to foreign presence along the coastline – a security issue for the Chinese. If foreign expertise is prevented from operating offshore then it may be

³⁰ K Bradsher 'To Conquer Wind Power, China Writes the Rules' The New York Times 14th December 2010; <http://www.nytimes.com/2010/12/15/business/global/15chinawind.html?pagewanted=all>

more difficult to make use of this longer experience in offshore wind technologies that might be needed to speed the accumulation of Chinese capabilities.

Catching up strategies

The firm Goldwind (55% State-owned) serves as something of an exemplar of the catching up strategies in the Chinese wind power industry. Established in 1998, it grew to become one of the world's top five wind turbine manufacturers in 2009 (GWEC 2010:10). It started by purchasing a license to manufacture 600 kW turbines from a second-tier German manufacturer, Jacobs, and subsequently bought licenses for other turbines, increasing in size each time (Lewis 2007). Our case study (see Appendix C) shows that, by 2009, Goldwind were able to manufacture turbines of 2.5 MW with an annual production of 2.2 GW. This makes them eligible to manufacture for offshore wind although, as stated above, Sinovel won the first offshore project in China. Sinovel, themselves, began by licensing to manufacture turbines, purchasing from the Austrian firm Windtec. In time, Chinese firms such as these have sent their employees overseas to learn from experienced firms or to study (MBAs, for example). And they have entered into joint ventures with foreign firms. Sinovel, for instance, worked with Windtec to design the 3 MW turbines for the Shanghai offshore project, and Mingyang and Aerodyn co-designed the Super Compact Drive 3 MW turbine (see Appendix C). More recently, Chinese firms have acquired foreign capabilities by buying foreign firms. One example is Goldwind, which has bought Vensys in Germany in order to strengthen its R&D capabilities. But, as we mentioned before, the offshore wind industry is in its infancy and so there are different challenges to meet compared with onshore wind. It remains to be seen whether Chinese firms will be able to make the shift to this new area successfully.

More efficient coal fired power generation

China derived about 81% of its power from coal in 2008 (IEEPS 2009). With its abundance of coal reserves, and its desire to lessen dependence on imported energy carriers, China is unlikely to stop using coal over the next few decades. Furthermore, China's economy has maintained robust growth over an extended period of years and is likely to continue growing. Clearly, China's use of coal for power generation will also generate large emissions of CO₂ for some years to come. So, there is a strong need to ensure that China's use of coal is realised as cleanly as possible. Having said this, China has been steadily improving the efficiency of its coal-fired power generation stock over the past two decades, from 28.8% in 1990 to 35.6% in 2008 (IEEPS 2009). But even at these higher efficiencies, coal-combustion still poses an enormous environmental problem (WCI 2005; IEA 2005). The exhaust gases carry particulates and various other pollutants, besides CO₂ – sulphur dioxide, oxides of nitrogen and trace elements. The results can be acid rain, smog, respiratory disease, and many others including, of course, climate change.

Technology status

China has been moving rapidly over recent years to install cleaner coal-fired power station technologies. We will consider here three types: supercritical (SC), ultra-supercritical (USC), and integrated gasification combined cycle (IGCC).

Supercritical and ultra-supercritical coal-fired power generation. Pulverised coal (PC) can be used to fire a boiler to produce steam and drive a turbine for generating electricity. This is a well established technology, having been in use for more than 50 years. But it has been developed from this 'subcritical' technique to 'supercritical' and more recently to 'ultra-supercritical'. In each progression, both the temperature and pressure of the steam is increased. The result of these increases is to raise the efficiency of the electricity generation process. The supercritical PC process can achieve efficiencies from 37 to 42% at a temperature of 565 °C (pressure 24 MPa), while an ultra-supercritical process can achieve efficiencies of 42 to 45% at a temperature of 600 to 615 °C (pressure 32 MPa) (AEF 2009).

Integrated gasification combined cycle (IGCC). An IGCC system first converts coal into syngas by reacting it with oxygen and steam. The syngas comprises mainly hydrogen and carbon monoxide. Impurities are removed and the syngas is then burned in a gas turbine to generate electricity. Steam is also produced and this feeds a steam power cycle. The gas stream has no nitrogen, which allows smaller components than otherwise would be needed. The process efficiency is high (in the mid 40s) but future expectations are for this to reach over 50% if technological improvements are successfully realised. And the exhaust gases can be scrubbed to remove 95 to 99% of NO_x and SO₂ emissions (WCI 2005).

Carbon capture and storage (CCS). Both of these variants of more efficient coal-fired technology can, in principle, be combined with capture and storage (CCS). This has the potential to reduce CO₂ emissions by up to 90% when compared to a plant without CCS (IPCC 2005). There are a large number of pilot and demonstration projects for CCS world-wide that are either planned or in operation. Many of the component technologies for capture, transport and storage are well known. However, there remain key challenges in developing and deploying integrated CCS systems at full power plant scale (i.e. on a typical until of 600-900MW). This full scale deployment has not yet been achieved on a fossil fuel power plant anywhere in the world. Furthermore, strong policy support in the form of R,D&D support and incentives for deployment are required if power companies and other large industrial emitters are to be persuaded to invest in CCS (von Stechow, Watson et al. 2011). This is particularly true in countries such as China where electricity demand is growing rapidly. The high up-front costs and large efficiency loss associated with CCS means that China's electric utilities currently have a strong incentive not to invest in the technology. According to a recent study for the Global CCS Institute, efficiency losses of adding CCS to coal-fired power plants are expected to be between 9 and 12 percentage points (Worley Parsons 2011).

Technological capabilities

The interest from China in gaining supercritical (SC) and ultra-supercritical (USC) coal-fired power plant is long-standing and the desire to localise the technology was designated a Key National Programme in the 1990s (Tan 2010). As of 2008, there were 93 SC and USC units in operation, and by 2009 there were more than 100 USC units on order from Chinese power companies (see Appendix D). In 2010, the USC technologies R&D alliance of Chinese companies and research institutes was created. In the same year, it was expected that SC and USC power plants would account for over 40% of new thermal units in China (Chen and Xu 2010).

There are Chinese firms that can now build SC and USC plants but there is still a significant gap in their capabilities compared to the international advanced level. Our case study notes that manufacturing companies such as Shanghai, Harbin and Dongfang have not mastered the core design software. The normal practice is for these manufacturers to collaborate with regional design institutions within China on power plant designs. However, they often need to collaborate with leading foreign companies such as Siemens, Hitachi and Alstom when they design new plants. There are also difficulties in manufacturing the high temperature components locally. The special steel materials all need to be imported.

With respect to IGCC technology, the capabilities picture is different. Capabilities within China in coal gasification technology are now strong. Chinese firms have a long history in this technology, through its application for chemicals and fertiliser production rather than for power generation. More recently (since the 1990s), there has been a strategy of acquiring licenses from leading international firms such as Shell (Watson, Oldham et al. 1998). As explained in section 3.2, Chinese gasification technology has now developed to the stage where it has been specified for an IGCC plant in the United States. The Thermal Power Research Institute in Xian has developed a design which is being used in China's first full scale IGCC plant (Greengen). This plant eventually plans to fit carbon capture and storage. The gasification technology for the Greengen plant has been specified for the planned Good Spring IGCC in the United States.

The gasifier is, however, only one component of an IGCC plant. Another critical technology is the advanced industrial gas turbine which burns the syngas produced by the gasifier. With respect to this component of IGCC plants, Chinese capabilities are considerably weaker. There are only a handful of leading suppliers of advanced industrial gas turbines world-wide – with GE, Siemens and Mitsubishi as market leaders. Chinese turbine companies have formed collaborations with these suppliers, but there is a long way to go before the Chinese partners have independent capabilities (Liu, Ni et al. 2008). For example, Dongfang collaborates with Mitsubishi Heavy Industries under a license agreement signed in 2003³¹. They have a joint venture service company and collaboratively manufacture gas turbines (though some that are notionally supplied by Dongfang are actually manufactured in Japan). Similarly, Siemens and Shanghai electric have been collaborating since 2004. The manufacture of 'low tech' parts and final assembly are undertaken in Shanghai, whilst many 'high tech' parts such as turbine blades are still made in Berlin. The gas turbine for the Greengen plant has been supplied directly by Siemens.

Innovation system

The innovation system around SC and USC coal-fired power generation appears to be heavily policy-driven, even by Chinese standards (see section 3.2). This is perhaps unsurprising, given the size of plant involved. There are strong links between different sorts of actors in the system: manufacturing firms, research institutes and government. Indeed, although it was created only last year, the USC

³¹ Details from MHI website: <http://www.mhi.co.jp/en/news/story/1006151363.html>; and from submitted DPhil thesis by Mehdi Majidpour, SPRU, University of Sussex, UK.

R&D alliance is an example of this. But it is difficult to discern the extent to which supplier firms are involved in any innovation processes apart from research institutes, if their research can be seen as supplying the manufacturers. Links with international technology leaders clearly remain important, particularly with regard to key components of the power plants.

Catching up strategies

Chinese manufacturers, through a combination of means, have developed their technological capabilities to some extent. Once again, it is a pattern of capability-building that is somewhat familiar across all our cases. Licensing, collaborative R&D (with foreign manufacturers and local research institutes) and reverse engineering have all been important. Also, of course, the experience of operating plant would help to develop at least some of the capabilities. With respect to supercritical and ultra-supercritical technologies, there has been a particularly clear strategy by the Chinese government for progressively acquiring and absorbing these technologies (Tan, Seligsohn et al. 2010).

While Chinese firms have successfully conducted collaborative R&D, and created their own IPRs, they have been unable to develop full capabilities in some key technologies. These technologies are still manufactured under license from leading international suppliers. This could be for a number of reasons. First, for design software, it would be relatively easy to keep the knowledge secret, even in a joint R&D venture (it will be 'embedded' in computer code). Second, the knowledge required to produce steel materials that can withstand the high temperatures of USC processes is also likely to be easy to hide. That is, there may be much that is tacit knowledge about alloys, and the physical process of steel-making may involve considerable automation and knowledge.

With respect to advanced gas turbines that are a key component for IGCC plants, the barriers to entry are simply very high. As noted earlier, licenses have been acquired by Chinese firms for this technology. However, the terms of these licenses mean that cutting edge technologies and knowledge embodied in high tech parts (such as the first stage turbine blades) are not shared. This controlled approach to knowledge sharing in return for market access has been standard practice among the leading international gas turbine manufacturers for many years (Watson 1997).

3.2. Domestic finance and policy in China

This section first provides an overview of Chinese policy frameworks for low carbon technology development and deployment, and then examines the specific policies in place with respect to our four case study technologies. As noted in section 2, public policies are crucial if private investments are to be diverted into low carbon forms of energy, particularly where these low carbon sources are not yet competitive with fossil fuels or they require further research, development and demonstration (Watson 2008; Carbon Trust 2006). This is clearly the case for many renewable sources of energy, and for carbon capture and storage technologies that have the potential to dramatically reduce emissions from fossil fuel facilities.

The need for financial incentives and other forms of policy intervention is also strong for energy efficiency measures. Energy efficiency measures account for a large share of potential emissions reductions in many countries. This is particularly the case in China's industrial and power sectors. Whilst many energy efficiency measures appear to have short payback times and negative net costs, experience shows that many of them are rarely implemented (Mallett et al. 2010). Potential investors in energy efficiency – whether in homes or businesses – face a range of economic, financial and other barriers including, for example, high upfront costs or a lack of access to finance. These barriers are particularly important in developing country contexts.

Chinese energy and climate policies are implemented within a broader framework provided by successive five year plans. Strategic programmes and plans developed by the government have been characterised by both vertical³² and horizontal³³ implementation, and by multiple time horizons (short, medium and long-term goals and perspectives). The most recent 11th five year plan is one example of this policy approach (Lin et al. 2008). Started in 2006, the plan is based on the assumption that China needs a more sustainable, scientifically-oriented and harmonious development. As a consequence of this plan, during the last four years, the Chinese government has created its first renewable energy law, its first energy efficiency law, its first climate change plan, and its first energy efficiency plan. In addition, the country established an environment ministry with Provincial reach (Ronping and Wan 2008). The energy intensity target – which mandated a 20% reduction in overall energy intensity between 2005 and 2010 – is also part of the 11th five year plan (Andrews-Speed 2009). As noted earlier in this report, official Chinese government sources have recently stated that a 19% reduction in energy intensity has been achieved.

As outlined in section 1 of this paper, a new target for a 40-45% reduction in carbon intensity between 2005 and 2020 was announced in autumn 2009. This is coupled with a target that 15% of primary energy should come from non-fossil sources, also by 2020. Progress towards these targets will be partly dependent on relevant policies being incorporated into the next two five year plans. Targets for the 12th five year plan have now been announced and include a 16% reduction in energy intensity and a 17% reduction in carbon emissions intensity during the period 2011-2015 (Wen Jiabao 2011). It also states that non fossil sources should account for 11.4% of primary energy by 2015. As a first step towards these targets, the NDRC has set goals for a 3.5% reduction in both energy and carbon emissions intensity of the Chinese economy during 2011 (NDRC 2011).

The NDRC has also stated that these high level targets for the 12th Five Year Plan will be accompanied by a range of other reforms. Their report to the National People's Congress mentions, *inter alia*, a campaign to improve the energy efficiency of 10,000 enterprises, pilot scale trials of emissions trading, and further price reforms to improve economic incentives on firms. A further signal that these targets will be taken seriously is provided by the planned evaluation of the performance of government officials against the targets in the 11th Five Year Plan. The NDRC states

³² We use 'vertical' to mean national, local and multi-sectoral.

³³ We use 'horizontal' to mean plans, programmes, laws, regulations and enforcement settings.

that 'we will organize evaluations of provincial governments' work on fulfilling targets for energy conservation and emissions reductions during the Eleventh Five-Year Plan period and implement reward and punishment measures accordingly' (NDRC 2011).

Other longer term plans with implications for low carbon technologies include the 'Medium and Long-term National Plan for Science and Technology Development (2006 – 2020)', intended to increase the role of innovation in the country's future. It is difficult to be specific about the eventual implications, but it is clear that China has an important goal of improving its own capabilities in indigenous innovation (Zhang 2010; Levi, Economy et al. 2010). Efforts to establish a better institutional and legal framework for both foreign investors and local companies have increased considerably during the past five years. While investors and partners may still harbour doubts, it is widely perceived that the legal policy framework has become more attractive for foreign investors over the last decade (USTR 2005). One example of this can be seen in the wind sector. The barriers to entry for wind power developers have reduced recently due to a revision of the local content rules so that foreign suppliers no longer have to source 70% of their wind plant components from local suppliers (Broehl 2010).

Another important context for Chinese policy frameworks for low carbon innovation is the extensive role of the government in the energy sector. This was repeatedly referred to in our interviews. Because of the strategic importance the government attaches to the energy sector, the State either owns or has a substantial share of strategic firms and industries – for example through ownership of power companies such as The China Huaneng Group and manufacturing firms such as the Dongfang Electric Corporation. In some of the newer emerging technologies such as solar photovoltaics (PV), the role of the State is less direct – but State involvement in overall policy and industrial strategy remains strong.

In some respects, the presence of the State as the main investor in energy projects reduces investment costs and risks, as state-owned companies are more likely than private actors to sustain investments that can expect financial returns only over the medium to long-term. Moreover, the Chinese government has promoted large-scale energy projects in a range of technologies, such as hydroelectric power (Chang et al. in press), wind energy (Changliang and Zhanfeng 2009), nuclear power (Zhou and Zhang in press), natural gas (Higashi 2009) and energy efficiency (Andrews-Speed 2009). These have taken the form of substantial direct investments that aim to create a wider variety in China's energy portfolio, reduce its dependency on imported or highly polluting energy resources such as oil and coal, and stimulate more sustainable development. Nevertheless, the direct involvement of the State in such activities has had some negative impact on international technology transfer. This has in some cases made foreign technology providers cautious about China, most tangibly over its guarantees on the protection of their property rights (e.g. Levi, Economy et al. 2010).

At present, it is difficult to obtain reliable data on direct Chinese government spending on promoting low carbon innovation. One source suggests that in 2009, China's investment in energy efficiency and renewable energy amounted to \$34.6bn

(£21.5bn). The vast majority of this investment went into technology deployment (Pew Charitable Trust 2010).

With respect to Chinese government R&D support for cleaner energy technologies, some information is available. The '863 programme' has been supporting new technologies since 1986. It was instigated by Deng Xiaoping in response to a letter from four prominent scientists who expressed concerns that China was lagging behind other countries in its technological capabilities (Osnos 2009). From 2001, the 863 programme included a substantial focus on energy R&D. During the 10th Five Year Plan, 20bn Yuan (around £2bn) was spent on a range of advanced technology areas (Tan 2010). During the subsequent 11th Five Year Plan, energy R&D funding totalled over 200m Yuan (£20m) per year, and focused on four areas: hydrogen and fuel cell technologies, energy efficiency, cleaner coal technologies (including for example supercritical technologies), and renewable energy technologies. A complementary funding stream known as the '973 programme' was founded in 1997 to fund basic research. Funding for energy research under this programme amounted to approximately 800m Yuan (£80m) between 1998 and 2008.

Energy efficiency in the cement industry

One of the most important domestic policy contexts for the Chinese cement industry over the past few years has been the energy intensity target within the 11th Five Year Plan. According to Xie Zhenhua, the impact of the Plan has been to reduce the energy intensity of cement production by 16% between 2005 and 2010³⁴. The target led to a policy focus on the most energy intensive firms within China. As a result, the 'Top 1000 Energy Consuming Enterprises Programme' was launched by the NDRC in 2006 (Wang and Watson 2009). Its aim was to reduce energy intensity within these firms, which accounted at the time for 33% of China's final energy consumption. Projected savings at the inception of the Programme were 100 million tonnes of coal equivalent from baseline annual energy demand by 2010 – a figure that is equivalent to 260 million tonnes of CO₂ compared to 'business as usual'. It has targeted nine industrial sectors: iron and steel, power, chemicals, petroleum and petrochemicals, coal, non-ferrous metals, construction materials, paper and textiles. Cement is included within the construction materials sector.

The Programme included a number of elements (Price, Wang et al. 2008). Targets were agreed with individual provinces, which were then translated into agreements with individual firms. Performance evaluations of provincial officials were adjusted to take account of their relative success in meeting targets. Firms were required to develop goals and plans, and funding was made available for energy efficiency projects specified in these plans. Funding for energy efficiency and pollution abatement from the Chinese central government was 23.5bn Yuan (over £2bn) in 2007 and 27bn Yuan (£2.5bn) in 2008 (Ohshita and Price 2011). The 2008 figure included 4bn Yuan (£400m) for phasing out small inefficient plants – a policy that was backed up by surcharges on their electricity tariffs. Further financial incentives for efficiency took the form of a reduction in export tax rebates for energy intensive products.

³⁴ Xie Zhenhua, Speech to 2011 International Conference on Low Carbon Energy and Climate Change, Tsinghua University, 24th March 2011.

As researchers from the US government's Lawrence Berkeley Laboratory have noted, the evaluation of the Programme has been difficult at times due to a lack of data (Price, Wang et al. 2008). With respect to cement, they found it was not possible to validate stated energy efficiency savings because of the variety of cement technologies (with different energy intensities) in use. With respect to the efforts to close smaller, less efficient plants producing steel, electricity, cement and other products, some progress has been made. Recent figures show that of the 250 million tonnes of cement capacity earmarked for closure within the 11th Five Year Plan, 140 million tonnes had been closed between 2006 and 2008 (Ohshita and Price 2011). It is not clear whether further progress has been made since then.– but one of our interviewees pointed out that national closure programmes are often only partially successful. For example, central government policy for the cement sector has prohibited shaft kilns, and has mandated the phasing out of such plants. However, some of our interviewees suggested that some are still kept in operation by local officials, despite being officially declared closed, for economic and employment reasons.

Our case study (see Appendix A) provides a more up to date picture of the impact of these policies. Interviewees within the Chinese cement industry confirmed that incentives for cement plants to implement more efficient technologies and processes are seen as significant. They had accessed grants from energy saving project funds, subsidised loans and taken advantage of tax breaks. Examples of measures financed with the help of government funding have included variable frequency fans and low temperature heat recovery for electricity generation. Interestingly, some interviewees stated that these measures may have been implemented in the absence of government support – but this would have been done more slowly. They also stated that more could be done – for example to accelerate the uptake of more efficient New Suspension Pre-heater Dry Process (NSP) technology.

Electric Vehicles

In the area of electric vehicles, there are two specific ways in which public policy is providing incentives for innovation in China. The first is in R&D support. As noted in the case study (see Appendix B), there has been substantial Chinese government funding for R&D since at least 2002. Under the 863 programme, 860 million Yuan (£80m) was spent between 2002 and 2006 on electric, hybrid and fuel cell vehicles. A follow-on programme which ran from 2006 has spent a further 1.1 billion Yuan (£105m) on these technologies.

The second area of support is through demonstration and deployment support programmes. There is a programme to deploy 60,000 'new energy vehicles' in 13 cities, and a plan that these vehicles should account for 5% of total car sales in 2011. This would amount to more than 600,000 vehicles (total sales in China in 2010 were 13 million). Looking slightly further ahead, it is hoped that 0.5-1 million new energy vehicles will have been sold by 2015 (Levi, Economy et al. 2010).

Within this, our case study indicates that the Chinese government intends to spend 20 billion Yuan (£1.9bn) on the promotion, manufacture and sale of electric vehicles. This will underpin a new 'Ten Cities, One Thousand Vehicles' plan which plans to

demonstrate 1,000 new EVs each year. A recent Accenture report quoted a higher figure for government support for EVs of 115 billion Yuan (£10.9bn) between 2011 and 2020 (Accenture 2011). This includes funding for R&D, commercialisation, component manufacture and electricity infrastructure. The report notes that consumers could receive a subsidy of 50,000 Yuan (£4,700) to purchase plug-in hybrid EVs, and slightly more for a pure EV. It also highlights electricity charging infrastructure as a potential bottleneck, stating that as recently as 2009, 'there were only a handful of public charging stations located in a few cities, such as Shenzhen' (Accenture 2011: 61). Of course, it is possible in principle for electric vehicles to be charged in their owners' homes – though this is not always possible, and it would limit their range in the absence of public charging infrastructure.

Offshore wind power

The Chinese government's policies and incentives for wind power have been well documented (e.g. Lewis 2007; Barton 2007; Levi, Economy et al. 2010). Legislation such as the 2005 Renewable Energy Law and incentives such as concessions and mandates have led to rapid deployment during the past five years. As noted in section 3.1, targets for onshore wind power have been revised upwards as rapid growth has unfolded. The installed capacity of wind power in China – the vast majority of which is onshore – is now estimated to be over 42GW³⁵.

Despite this progress, there have been misgivings about the policy approach to renewables. For example, there have been criticisms that incentives aimed at encouraging wind power have focused on the construction of capacity rather than maximising output at the best wind sites. There has also been an ongoing problem of connection to the electricity grid. Some wind farms have not been able to generate and sell their electricity due to bottlenecks in electricity transmission capacity. Recent reforms have sought to tackle this issue, with a greater emphasis on enforcing priority access for wind plants.

With respect to offshore wind, developments are relatively recent. The potential resource has been estimated by a number of official assessments. As noted in our case study (see Appendix C), the Chinese Meteorological Association estimates this to be 750GW in water depths of less than 20m. However, some other assessments have provided lower estimates – and have led some officials to urge caution with respect to offshore wind (Prideaux and Qi 2010). An initial 100MW demonstration plant was constructed by Sinovent for the World Expo in Shanghai in 2010. Coastal provinces are now required to develop plans for offshore wind, and specific targets have been agreed in some cases. The current 'wind base' programme includes a target of 7GW of offshore wind capacity off the coast of Jiangsu Province by 2020.

To provide incentives for a first tranche of offshore wind capacity, a concession process was launched in 2010 to build 1GW of capacity in Jiangsu Province. Under this concession policy – which is well established for onshore wind - local grid operators are required to sign a long term power purchase agreement with winning bidders. With respect to onshore wind, these agreements typically last for 25 years,

³⁵ 'China has world's most installed wind-power capacity' Xinhua News Agency, 13th Jan 2011; http://www.china.org.cn/business/2011-01/13/content_21733120.htm

with the price paid being fixed for the first 10 years. At present, the rules for offshore wind stipulate that projects should be either developed by Chinese firms or by joint ventures with foreign firms in which the Chinese partner has a controlling share.

As in the case of EVs, the Chinese wind turbine industry has also benefited from government R&D funding under the 863 programme. Support has also been provided under the companion 973 programme (see above) which is more oriented towards basic research. As Xiaomei Tan has explained in some detail, early efforts by the Chinese government to fund joint ventures between Chinese and international firms as a way of building technological capabilities had limited success (Tan 2010). She argues that this led to direct funding of wind power company R&D centres under the 863 and 973 programmes. For example Goldwind (one of the leading Chinese wind power firms) received a series of grants under these programmes to scale up its wind turbines – and develop independent capabilities in turbines of up to 1.5MW. The firm also received support from the government of the Xinjiang Autonomous Region in the form of further R&D support and tax concessions. As noted in our case study, Goldwind is now one of ten firms that have been officially accredited by the Chinese government as being capable of building offshore wind projects.

Coal fired power generation

In common with the cement industry in China, there has been a general policy of improving the efficiency of coal-fired power generation over a long period of time. As noted earlier, the power sector was covered by the Top 1000 Energy Consuming Enterprises Programme under the 11th Five Year Plan. As part of this Programme, a large number of small coal-fired plants were earmarked for closure. The NDRC reported that between 2006 and 2008, 38GW of these plants had been closed (Ohshita and Price 2011). Wen Jiabao's recent report to the National People's Congress states that by the end of Five Year Plan period (i.e. the end of 2010), 72GW of small plant capacity had been closed down (Wen Jiabao 2011). The share of coal-fired power generation capacity with unit sizes of over 300MW rose from 47% in 2005 to 69% in 2010³⁶.

In parallel with this closure programme, the Chinese government has also placed more emphasis on economic incentives for improved power plant efficiency. It reduced the prices paid to power plants with capacities of less than 50MW, and some plants of 100-200MW (Andrews-Speed 2009). This was designed to make larger, more efficient plants more attractive to operate. New dispatching rules were trialled, to prioritise the use of the most efficient coal-fired plants. However, the government has been slow to remove controls on final electricity prices until very recently (IEA 2006). Historically prices to end consumers (industrial and domestic) have been kept artificially low – a situation that has placed financial burdens on power companies facing a rising cost of coal. Given that power companies are State owned, these burdens are ultimately borne by the State. According to China's National Energy Administration, 43% of China's coal-fired power plants operated at a loss in 2010³⁷.

³⁶ Xie Zhenhua, *op. cit.*

³⁷ Reported at <http://www.prlog.org/11349430-chinas-power-plants-operate-at-loss-cost-of-coal-and-energy-efficiency-blamed.html>

Turning to the specific technologies that are the focus of this case study, it is clear that Chinese government policy has played a strategic role in directing acquisition, innovation and deployment. There are important differences, however, between the outcomes with respect to supercritical and IGCC technologies.

For supercritical and ultra-supercritical technology, Xiaomei Tan argues that the Chinese government has implemented ‘a number of policies, measures, instruments and co-operative arrangements ... to facilitate the localization and to accelerate the diffusion of the technology’ (Tan 2010: 2918). She describes this process in some detail, starting with the operation of China’s first supercritical units in 1992. These were sourced from leading international firms - ABB for boilers and General Electric for steam turbines. The government managed and funded an iterative process of assessment, collaborative R&D and reverse engineering so that Chinese firms developed independent capabilities in supercritical technology. The first Chinese manufactured 600MW supercritical unit entered service in Henan province in 2004 (Chen and Xu 2010).

The acquisition of more efficient ultra-supercritical technology started in 2000. This process was supported by a number of government R&D programmes including funding from the 863 and 973 programmes. It resulted in China’s first ultra-supercritical unit at Yuhuan Power Plant. This was also part-funded from the Shanghai government’s own R&D fund (Tan 2010; Tan, Seligsohn et al. 2010). This plant, which entered service in 2006-07, included collaborations between Chinese and international firms for the main components. The boilers were co-supplied by Mitsubishi Heavy Industries and the Harbin Boiler Company, and the turbines were manufactured by Shanghai Electric and Siemens (to a Siemens design)³⁸. Our case study notes that by June 2009, 23 ultra supercritical units were in operation in China – and a further 100 were on order.

With respect to coal gasification – a key element of IGCC plants - the 863 programme played a particularly important role. It supported coal gasification research at the Thermal Power Research Institute (TPRI) in Xian (Osnos 2009). The institute comprises over 1200 employees and is owned by a consortium of power companies, with Huaneng Power Group as its major shareholder. Towards the end of 2010, Huaneng Power Group restructured its technology projects, and TPRI became part of a new organisation called the Clean Energy Research Institute. The Institute’s coal gasification technology is being used in the first full scale IGCC plant in China (GreenGen) which is currently under construction. Perhaps more remarkably, it has also been licensed for use in the Good Spring IGCC plant which is planned for construction in Pennsylvania in the United States. According to some reports, this was chosen over competing technologies from Shell and GE due to its higher efficiency (Osnos 2009). However, it is important to note that other IGCC plant components (most importantly, the gas turbines) are not being sourced or licensed from China.

3.3. International Finance and Policy

³⁸ Detailed plant specifications are available at: <http://www.power-technology.com/projects/yuhuancoal/>

At a global level, the availability of finance will be one of the most important challenges to overcome to meet the goal of deep global reductions in greenhouse gas emissions. The International Energy Agency (IEA) has argued that to stabilise the concentration of greenhouse gases in the atmosphere at 450 ppm (to provide a reasonable chance of limiting average temperature increases to 2°C), \$10.2 trillion will be needed by 2030³⁹.

Whilst many analyses show that private sources will provide the majority of finance, public funding has a key role to play in leveraging private sector investment (DECC 2010). Furthermore, international frameworks to support financing of low carbon technology transfer and deployment in developing countries will be an important complement to national policy frameworks, particularly now that many developed countries are in a difficult position due to the financial crisis.

The Cancun Agreements formalised financial commitments by industrialised countries to support mitigation and adaptation. The final text from the Ad Hoc working group on long-term cooperative action states that the Conference of the Parties:

Recognises that developed countries commit, in the context of meaningful mitigation actions and transparency on implementation, to a goal of mobilizing jointly USD 100 billion dollars a year by 2020 to address the needs of developing countries;

Agrees that ... funds provided to developing country parties may come from a wide variety of sources, public and private, bilateral and multilateral, including alternative sources; (UNFCCC 2010: 15)

This section of the report considers some bilateral and multilateral policy frameworks, with an emphasis on those that have provided finance for the development and deployment of our case study technologies in China.

Multilateral institutions

At present, a significant amount of the public finance available for low carbon technology development and deployment comes from multilateral institutions and mechanisms. The World Bank devotes significant lending to the energy sector, following a period of decline in the early 2000s. Lending in FY2009 was USD 8.2 billion worldwide. The Bank is currently reconsidering its strategic priorities in the light of changes in international circumstances, including the emergence of climate change as a prominent issue requiring international co-operative action (World Bank 2009). Other multilateral banks are also significant lenders – including the Asian Development Bank, which lent approximately \$22bn to China's energy sector between 1986 and 2010⁴⁰. Of course, much of this lending was not for low carbon investments or technologies.

³⁹ IEA World Energy Outlook 2009.

⁴⁰ The complete list of ADB funded projects (not only energy-related) in China can be found at: <http://www.adb.org/Projects/summaries.asp?query=&browse=1&p=ctryprc&ctry=PRC&offset=0>

Alongside its traditional lending, the World Bank has recently been asked to administer a set of pilot climate change funds – the Climate Investment Funds (CIFs)⁴¹. These consist of two funds: the Clean Technology Fund (CTF) for mitigation (CTF 2010) and the Strategic Climate Fund (SCF) for adaptation (SCF 2010). The CTF is targeted primarily at emerging economies to support the demonstration, deployment and transfer of low carbon technologies that could have transformational impacts on development and emissions reductions. Total finance available to date through the CTF stands at \$4.3bn, pledged from eight developed countries (CIF 2010). This has been allocated to thirteen country or region investment plans, with a further \$36bn of leveraged funds anticipated over time. It is notable that China has not sought funding from these Funds.

The World Bank is also a partner in the Global Environment Facility (GEF) which serves as the official financial mechanism of a range of conventions including the UN Framework Convention on Climate Change. Since it was created around the time of the UN Conference on Environment and Development in Rio in 1992, the GEF has provided financial assistance for environmental projects and programmes in developing countries. The amount of finance available has been limited. Whilst it was originally intended that industrialised countries would provide USD 125 billion per year (1993 to 2000) to fund the implementation of Agenda 21⁴², the contribution of the GEF has been far below this level (e.g. Porter and Brown 1996:142). GEF projects in China between 1994 and 2009 reached a total value of less than USD 500 million⁴³.

The GEF portfolio has included projects in China which have the specific aim of technology transfer. For example the energy efficient boiler project for China arguably had some success in subsidising licenses to Chinese firms. It was a difficult project that suffered from delays, and only resulted in licences from ‘second tier’ international suppliers⁴⁴ (Birner and Martinot 2005). It demonstrated how difficult it can be to offer licensing terms that are attractive to leading international firms.

Financial assistance from institutions like the World Bank and GEF are often related to wider policies and capacity building activities that are designed to encourage the deployment of low carbon technologies. One example of a World Bank commitment in promoting such activities in China is the ‘China Renewable Energy Scale-up Programme’ (CRESP⁴⁵). It commenced in June 2005 and is designed to last for five years. The programme aims to promote the adoption of renewables in order to substitute for coal-fired power plants. It aimed to study China’s renewable energy resources, promote policy learning with respect to renewable energy support mechanisms from developed countries, and to formulate policy frameworks to speed up renewable energy deployment in China. There is some evidence that the successful Chinese policy frameworks for wind power have been directly influenced

⁴¹ For more information on the CIF see <http://www.climateinvestmentfunds.org/cif/>

⁴² See 33.18 of Agenda 21: http://www.un.org/esa/dsd/agenda21/res_agenda21_33.shtml

⁴³ The data refer to the total of GEF projects (on-going or completed), including those not directly connected to energy and/or mitigation activities, since 1994 up to June 2009. <http://web.worldbank.org/WBSITE/EXTERNAL/COUNTRIES/EASTASIAPACIFICEXT/CHINAEXTN/0,contentMDK:20585167~pagePK:1497618~piPK:217854~theSitePK:318950,00.html>.

⁴⁴ So-called ‘second tier’ companies are smaller firms than the market leaders, although this does not imply that they sell inferior technology (Lewis 2007).

⁴⁵ <http://www.cresp.org.cn/english/about.asp>

by this and other international assistance programmes⁴⁶.

With respect to more efficient coal fired power generation, there has been a long-standing focus on the deployment of supercritical and IGCC technology in China by the Asian Development Bank (Watson, Oldham et al. 1998). The Bank financed an early supercritical plant (the Fuyang plant in Anhui province) in the late 1990s. It was also involved in funding feasibility studies for an IGCC plant in Yantai, also in the 1990s. Plans for this plant suffered from repeated delays, and it has not been constructed. More recently, the ADB provided a loan of \$135m (£85m) to the GreenGen IGCC plant⁴⁷ which is under construction in Tianjin.

UN agencies have also been involved in providing multilateral support for technology development and deployment in China. One of our interviewees notes that an important source of assistance for improved energy efficiency in the cement industry has been the UN Development Programme (UNDP). Our interviewees did not, however, mention other international initiatives outside the UN that have focused on cement such as the Asia Pacific Partnership and the Cement Sustainability Initiative. It is therefore unclear whether these other initiatives have had a significant impact in China.

The Clean Development Mechanism (CDM)

By far the most important international financial mechanism to date for funding low carbon technologies in developing countries is the Clean Development Mechanism (CDM). Created as part of the Kyoto Protocol, the CDM aims to combine, through the application of a market-oriented system, two different objectives: the reduction of carbon dioxide emissions, and the needs of developing countries for economic growth and development. The mechanism combines these objectives by stimulating the implementation of sustainable projects in developing countries through the purchase of emissions credits (Certified Emissions Reductions – CERs) generated by those projects. In addition to generating emissions reductions, CDM projects are also encouraged to contribute to sustainable development and to incorporate technology transfer.

The CDM is managed by an international entity (the Executive Board) under the UNFCCC, while the projects are monitored by a set of private independent institutions (Designated Operational Entities⁴⁸). Based on the concept of 'additionality'⁴⁹, the system provides a new tool for financing low carbon technology deployment. While the CDM started as a project-based system, it has become increasingly important amongst some beneficiaries for developing specific national policies and programmes (Schroeder 2009). As of March 2011, 2923 CDM projects had been approved by the Executive Board, 1,282 of which were in China⁵⁰. The

⁴⁶ This insight is based on work in progress by Jenny Lieu, doctoral researcher with the Sussex Energy Group.

⁴⁷ See <http://www.adb.org/Documents/News/PRCM/prcm201006.asp>

⁴⁸ Designated Operational Entities are not the same as Designated National Authorities (DNAs). DNAs are public national organisations entitled to approve the feasibility of CDM projects for a particular country, while DOEs monitor those projects that are implemented in that country.

⁴⁹ The concept of 'additionality' is that projects can be financed only if it is demonstrated that they would not have been developed without the contribution of the CDM.

⁵⁰ See 'CDM in numbers' at: <http://cdm.unfccc.int/Statistics/index.html>

total emissions reductions attributed to China's projects amounted to 287 million tonnes of CO₂ equivalent per year.

China has received more CDM project investment than any other developing country – with total investment of more than \$50bn⁵¹. Approximately 200 projects in China claim that they include a direct form of technology transfer, which is usually in the form of hardware transfer. The CDM has played a fundamental role in the development of at least two of our case study sectors: wind energy (Yang et al. 2010), and energy efficiency in large cement companies (Yan et al. 2009). Based on the available data, we can see that other sectors and technologies within China have also benefited from the CDM. These include developments in hydroelectric power, coal methane recycling, the substitution of coal with natural gas in power plants, and energy efficiency activities in the iron and steel industries.

The CDM has had a particularly important impact on Chinese wind power development. It is clear that the Chinese government has made strategic use of the CDM to support the rapid expansion of wind power. More recently, China's first offshore windfarm in Shanghai has also been part-financed through the CDM.

A recent analysis by Joanna Lewis shows that a large number of Chinese wind power projects have been registered as CDM projects and have requested CERs (Lewis 2010). More than half of wind projects built in 2007 and more than a third of those developed in 2008 were registered. As Joanna Lewis notes, there are questions to be asked about the extent to which CDM financing was a decisive factor in making many of these projects financially viable. For instance, one controversy occurred in December 2009 because the CDM Executive Board was concerned that the Chinese government had purposefully lowered the subsidies given to wind power in order to make them qualify as CDM projects; although there has yet to surface clear evidence indicating this was indeed the case (Lewis 2010). Moreover, by no means is this situation unique to China. For instance, Lohmann (2009) questions the validity of the additionality criteria claimed by Project Design Documents (PDDs) for projects in India, Brazil and Kenya as well as China. One reason for this lack of clarity regarding what constitutes additionality is that the additionality test is largely based on various countries' regulatory decisions. In China, the National Development and Reform Commission 'determines power tariffs in a proprietary, non-market-based manner – as is their right in making sovereign decisions about energy policy – [and so] there is no real way to know what is business as usual and what constitutes gaming of the CDM' (He and Morse 2010: 3).

He and Morse (2010) also point out other problems with considering additionality with Chinese wind power CDM projects: namely that the baselines used to determine additionality are based on benchmark analysis versus coal-fired plants (which they suggest is problematic in a country that is so coal-dependent for their electricity); that China's Internal Rate of Return (IRR) is based on political rather than profitable decisions, and that there should be a way to account for domestic policies when developing a CDM project⁵². Lewis⁵³ notes that some of these wind projects have

⁵¹ The data have been obtained from the design documents of CDM projects related to electricity production to date. The list of projects and their design documents can be found at:

<http://cdm.unfccc.int/Projects/projsearch.html>

⁵² See He and Morse (2010) p. 4 for further details

since been approved by the CDM executive board, and there has also been new methodological guidance ascribed to renewable energy projects.

With respect to the cement industry, the CDM has also been strategically important. Almost 50% of China's CDM projects that focus on energy efficiency (43 out of 88 projects) focus on cement plants. Whilst many of these projects do not claim technology transfer – and deploy established Chinese technologies – a number of the Project Design Documents refers to the Japanese origin of the hardware employed. More efficient coal-fired generation (at utility power plant scale) has not been a focus for Chinese CDM projects. However, one project has recently been approved by the CDM Executive Board in December 2010. This is for an ultra supercritical coal-fired power plant at Waigaoqiao, with a capacity of 2000 MW.

A key question for this report is the extent to which CDM projects lead to technology transfer. A number of authors have surveyed the intentions of project developers by analysing statements in project design documents (e.g. Haites et al 2006), and have found significant emphasis within these on technology transfer. According to our own analysis, technology transfer activities are said by project developers to be included in less than one third of CDM projects active in China. A substantial number of projects (all the hydroelectric ones, accounting for more than 50% of approved projects) apply technologies which are already mature in the country context. It is important to interpret such results with care since it is not possible *ex ante* to know the extent to which particular projects will lead to technology transfer in practice – and hence the improvement of innovative capabilities in recipient firms. Furthermore, it is not always clear to what extent the meaning of technology transfer within CDM project documentation is purely focused on hardware transfer – or whether it also includes knowledge transfer.

Bilateral arrangements

There are a large number of other bilateral and multilateral agreements with China that focus on low carbon technology co-operation. These vary widely in their scope, and it is therefore difficult in many cases to evaluate their impacts on technology development and transfer.

With respect to wind power, bilateral agreements have been important sources of finance and other assistance. Two clear examples illustrate this: the Danish-Chinese Wind Energy Development Programme⁵⁴ (with Denmark as partner) and the China Wind Power Research and Training Project⁵⁵ (with Germany as partner). These programmes have included capacity building, knowledge transfer, institutional and technical assistance and loans for project development. Both agreements have led to technology transfer from firms in Europe to their counterparts in China (from Vestas in the Danish case and RE-Power and Siemens in the German case). It is not clear, however, to what extent such agreements have focused in particular on offshore wind.

⁵³ Personal communication with the authors, February 28, 2011

⁵⁴ <http://www.dwed.org.cn/>

⁵⁵ <http://www.cwpc.cn/cwpc/en/cwpp>

A number of international collaborative activities are underway on electric vehicles (EVs) in China. One of the most prominent is a US-China co-operative programme that aims to develop standards, implement joint demonstration projects in a number of cities and a technology roadmap (White House 2009). To complement this, there are partnerships being built between Chinese and US firms (Levi, Economy et al. 2010). As noted in our case study (see appendix B), partnerships also extend to other countries. Daimler has formed a partnership with China's BYD Auto to develop its first EV.

Despite these collaborations, the gap between Chinese firm capabilities and those of firms in other countries remains substantial. Many component technologies for EVs are still primarily being developed outside China. Our case study interviews found that many firms in China cited a lack of substantive collaboration with foreign firms as a problem – and said those collaborations that existed lacked depth. As noted in section 3.1, there is another side to this: some international firms are wary about collaboration due to concerns that their designs will be 'reverse engineered' and re-manufactured at lower cost (Levi, Economy et al. 2010).

4. Conclusions and implications

This report has set out the results from the UK-China collaborative project on low carbon technology transfer. It has analysed four empirical case studies of low carbon innovation in China with respect to a number of key themes from the technology transfer and innovation literature. The main aim has been to identify new empirical evidence to help inform ongoing discussions within the UNFCCC and other fora about the development, transfer and deployment of low carbon technologies in developing countries.

As noted in the introduction to the report, our approach has been to analyse technology transfer to China in the context of broader processes of low carbon innovation within that country. Technology transfer from international firms and other organisations is only one source of low carbon innovation, and should not be analysed in isolation from other, indigenous sources of innovation. As our case studies have illustrated powerfully, both sources of innovation have the potential to contribute to technological capabilities in developing country firms and institutions. Furthermore, the report has emphasised the role of wider national and international policy contexts that affect rates of technology development, transfer and deployment.

This final section of the report draws together some key headline conclusions from our analysis and offers some tentative implications for policy, with a particular emphasis on the UNFCCC negotiations. Where relevant, these conclusions draw on our previous research on India as well as the findings of this report with respect to China. Six particularly salient conclusions can be drawn as follows:

1. In common with our previous UK-India studies, the analysis of low carbon innovation in China reveals important differences between low carbon technologies. The extent to which Chinese firms are 'catching up' with the international frontier varies widely. As might be expected, Chinese technological capabilities are stronger in more near-market technologies such as supercritical coal fired plants, more efficient cement processes and onshore wind. With respect to more early stage technologies such as electric vehicles (EVs) and possibly offshore wind, significant gaps in capabilities are more apparent. In the UK-India study, we also found differences between technologies, as well as between firms / institutes within specific sub-sectors. For example the Indian firm Suzlon is one of the most prominent international wind turbine firms. Solar PV firms in India included some interested in the most advanced technologies and others that were largely focused on established 'first generation' variants.
2. The case of China is unique, and should not be used as a proxy for developing countries in general. China is now the second largest economy in the world, the number one consumer of energy, and largest emitter of carbon dioxide. Whilst China still faces many development challenges, and many of its citizens remain on very low incomes, rapid economic development means that resources are available to support low carbon innovation and deployment. The strong role of the Chinese central government is evident in all of our case studies –in directing strategic technology acquisition, providing R&D support, developing comprehensive policy frameworks and in systematically taking advantage of

international mechanisms (especially the CDM). In India, we found that the role of the government was also important, but it has not played such a strong strategic role as it has in China. Of course, India is also a key emerging economy but its political system is different to that in China, with much less centralised planning. Furthermore, India arguably has greater development challenges than China – key indicators such as per capita income, per capita emissions and electrification rates are much lower.

3. A range of policy mechanisms have been used within China to promote low carbon technology development and deployment. The strong role for central government means that targets and regulations have often been favoured. Examples include the 11th Five Year Plan's energy intensity target and specific regulations to mandate the closure of inefficient industrial capacity. Whilst some of these policies suffer from deficiencies (e.g. poor implementation) and often need to resolve tensions (e.g. between economic growth and environmental protection), they have been extremely important. To complement this, we found examples of the use of economic incentives, such as reforms to coal-fired electricity tariffs to promote efficiency. As we argued above, the policies required to support low carbon innovation will differ between technologies and sectors. However, we agree with the recent statements from the NDRC (NDRC 2011) that a greater role for market-based mechanisms should be considered to help meet the new Five Year Plan targets.
4. Chinese firms and institutions are developing their capabilities in our case study technologies rapidly. But in some cases, these capabilities do not include the full range of capabilities to innovate. As noted above, domestic policy interventions have been important in supporting the acquisition and assimilation of many low carbon technologies. A combination of market support (e.g. from pricing reforms, grants and concessions), regulations (e.g. plant closure programmes) and R&D support (particularly the 863 and 973 programmes) have been crucial in many cases. However, there are some limitations – for example in access to advanced component technologies and associated knowledge, and in engineering and design skills. Some of these reflect the early stage of a technology (such as electric vehicles) whilst others reflect a significant competitive disadvantage (e.g. advanced gas turbines for IGCC plants). Whilst the Indian government may not have played such a strategic role as the Chinese government, our research found that domestic policies were also important.
5. Access to intellectual property rights (IPRs)⁵⁶ is not a fundamental barrier to the development of low carbon innovation capabilities in China. As we concluded in our UK-India studies, this does not mean that IPR issues are unimportant or that options to improve IPR access within developing countries should be excluded from the UNFCCC talks. In both countries, we found that the resources required to identify, acquire and assimilate low carbon technologies slowed the development of capabilities and/or diffusion of some of these technologies. Sometimes, the impression is given that Chinese firms have a wholly independent capability in some low carbon technologies, but this can be

⁵⁶ Further evidence on IPR issues has been gathered for a parallel study funded by the Foreign and Commonwealth Office led by Prof Wang Can. This had a particular remit to focus on IPR issues.

misleading. In some cases, there remain high barriers to entry for Chinese firms that are partly due to a lack of affordable access to IPRs, but are also due to gaps in knowledge and capabilities. We found examples of this in our case studies of EV and IGCC technologies. In other cases where barriers are not so large, licenses from international firms remain important (e.g. in larger wind turbines for offshore use and in supercritical boiler technologies). This has implications for the extent of independent Chinese capabilities in these technologies.

6. International institutions and policy frameworks have also played an important role in our case study technologies. The Clean Development Mechanism has been used in a strategic way by the Chinese government, and has therefore provided significant finance for the diffusion of both onshore wind power and cement industry energy efficiency. It has also been used in a more minor way for offshore wind (though this may develop further) and more efficient coal plants. In India, the role of the CDM and other multilateral mechanisms appears to have been much less important. Other institutions have been important in China including multilateral development banks (though they have been criticised for not focusing enough on low carbon technologies). The role of the Asian Development Bank in promoting IGCC technology in China has been strong – though it took many years to get the first project off the ground. There are also a large number of bilateral arrangements. Some of these (such as in onshore wind) have yielded tangible results for Chinese technological capabilities whilst the impact of others (e.g. for EVs) is contested.

Implications for the UNFCCC Negotiations

With respect to the UNFCCC negotiations, our research leads to a number of relevant implications. A key context for these implications is the agreement in Cancun that a new Technology Executive Committee should be established to replace the Expert Group on Technology Transfer. More important than this, the agreement included an intention to set up a new Climate Technology Centre (CTC) and Network (UNFCCC 2010). There is a lot of scope for further debate about the form of the CTC and Network, and the functions it could perform⁵⁷.

As implied by our first and second key conclusions above, and similar to our UK-India studies, low carbon innovation within the UNFCCC should not be approached from a 'one size fits all' perspective. The level of international assistance required (and its type) will differ by country and by technology. It is therefore important that the CTC and Network is implemented in a way that takes account of national, sectoral and market differences that characterise a complex low carbon innovation landscape. This suggests that a uniform model which is driven 'top down' by the UNFCCC and other agencies will not be appropriate – and that the role of the Network will be particularly important.

For developing countries like China that have significant resources and capabilities, the CTC and Network could therefore include existing institutions. The experience of China with respect to the CDM suggests that international mechanisms and

⁵⁷ A recent UNEP discussion paper (UNEP 2010) discusses many of the key issues in detail.

institutions can be particularly effective when integrated into existing national strategies and policy priorities. This does not mean that international mechanisms are a prerequisite for low carbon innovation (our research in India and China shows that this is not necessarily the case). But if such mechanisms are to add value, it is important that they recognise and work with national policy frameworks and capabilities.

There are many potential functions listed in the Cancun agreements that the CTC and Network might perform. These include activities in investment, diffusion support, a focus on 'soft technologies', collaborative R,D&D, and supporting national plans. The evidence from China (and from India) suggests that a CTC and Network that performs the full range of these functions will be required. Of course, the potential role of the CTC and Network will vary on a case by case basis. But China's recent experience shows that all of these functions have been important, including investment (e.g. in R&D), diffusion support (e.g. in wind power concessions), a focus on 'soft technologies' (e.g. in coal gasification), collaborative R,D&D (to some extent in EVs) and national plans (e.g. for industrial energy efficiency). A minimal version of the CTC and Network that is mainly concerned with sharing information and best practice would add little value to what is already on offer.

Finally, an important element of the implementation of the CTC and Network is evaluation of past programmes and the link to existing institutions. It is clear that some existing institutions such as the GEF are making a case that they are well placed to run the CTC and Network. In principle, it would be a good idea to constitute the CTC and Network within existing institutions – both at UNFCCC level and within the wider Network at national level. Whether or not the CTC and Network is implemented this way, it will be important to undertake systematic and regular evaluation of the effectiveness of its programmes. As a precursor to this, more evaluation of existing institutions that run programmes designed to fulfil some of the functions foreseen for the CTC and Network is required. Examples include the World Bank Climate Investment Funds (which aim to achieve transformational investments in low carbon technology diffusion) and smaller pilot innovation centres (such as those being run in India and Kenya by Infodev).

Avenues for further research

The findings of our research and the results of other studies suggest a number of avenues for further work. The following four suggestions might be particularly relevant in the context of ongoing UNFCCC negotiations on the technology mechanism, and the establishment of the CTC and Network:

1. There is now an increasingly rich literature on low carbon innovation in 'middle income' developing countries such as China and India. However, there remains scope for a more detailed understanding of the innovation process, the potential role for technology transfer, and policies to promote innovation. Suggestions from Chinese experts and policy makers at our final report workshop included the need to better understand the needs of small and medium sized enterprises in China (and to identify market based mechanisms to provide incentives for them to innovate), the need to look regionally within China (and to consider the

particular needs of lower income Provinces), and the need to identify more precise policy mechanisms to support low carbon innovation in China.

2. The evidence base on low carbon innovation is much less well developed with respect to lower income developing countries. Such lower income countries face greater development challenges. As noted above, the results of studies focusing on middle income countries will have little relevance to them. Further research to understand the needs of lower income countries, and the barriers to low carbon technology development and deployment in these countries is therefore required. Such research could seek to integrate this agenda with important challenges such as the need to improve energy access and to develop sustainable financial mechanisms for investment.
3. Allied to the second suggestion, there is scope for further research on the experience of south-south technology transfer and co-operation with respect to low carbon technologies. China has increasingly important relationships with other developing countries. It has been suggested that technologies that have been adapted and partly developed within China might be more suitable for deployment in less developed country contexts (e.g. Kaplinsky 2011). Further research might focus on the evidence for this, and some of the implications for international mechanisms and policies
4. As noted above, the development of the CTC and Network presents a clear opportunity to take into account empirical evidence such as that offered in this report, and to learn from past experience of such mechanisms. Our research in China has shown that international organisations, frameworks and mechanisms have had some impact on the development of low carbon capabilities. If the CTC and Network are to provide further support for the development of capabilities to underpin low carbon development, it is important that lessons are learned from existing and previous programmes and institutions. Examples include the Global Environment Facility, the CDM (particularly the extent to which it has led to technology transfer) and the more recent World Bank Climate Investment Funds.

Appendices

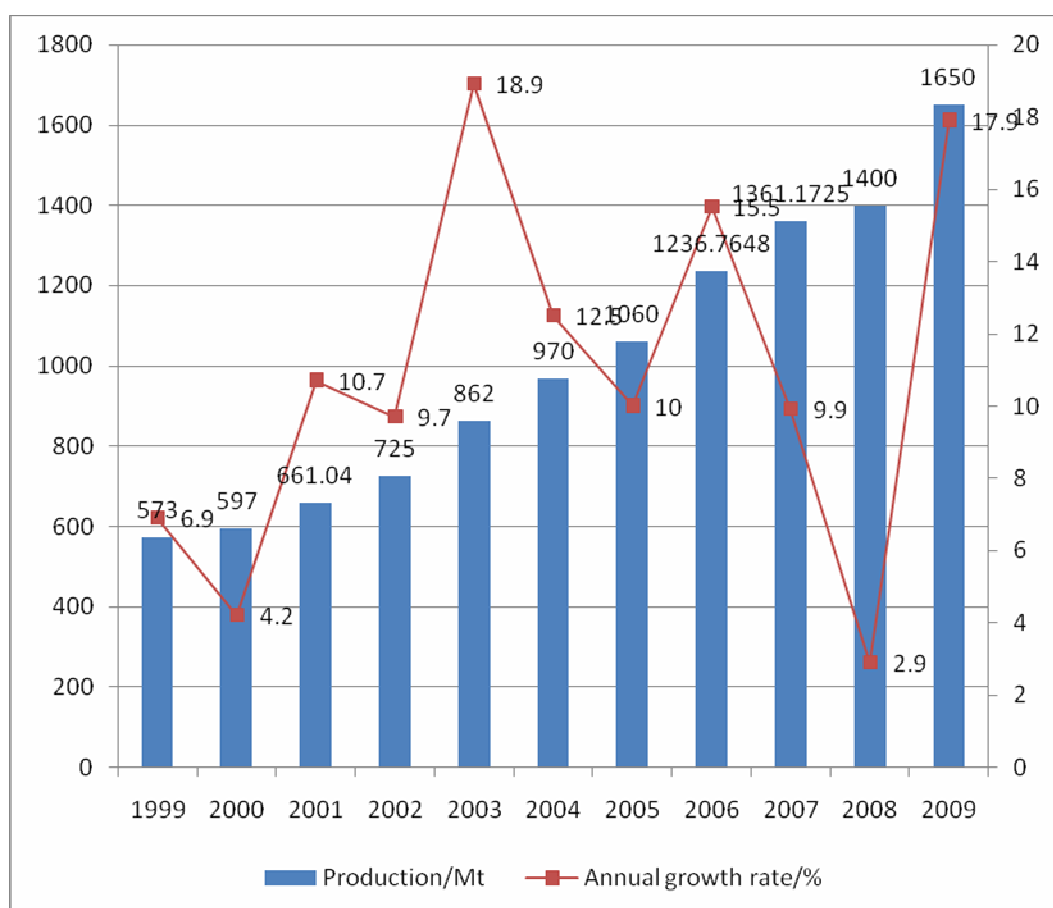
Appendix A: Energy efficiency in the cement industry

Zhang Tianhou

Overview of China's cement industry and advanced cement technologies

Globally, the production of cement contributes around 8% of anthropogenic CO₂ emissions⁵⁸, arising from the conversion of limestone into lime (about 55% of these emissions) and from the combustion of energy carriers to drive this conversion process (about 40% of the emissions) (Müller and Harnisch 2008:1-2). Cement is one of the important fundamental materials in the Chinese economy which is widely used in building, highway construction, hydropower construction, the petroleum industry, and many other areas. As the infrastructure construction and real estate business have developed quickly, the use of cement in China has increased rapidly. The cement production of China has been the biggest in the world for 24 years. As shown in Figure A.1, China's cement production in 2009 was 1.65 billion tonnes, which was over 50% of the total global cement production.

Figure A.1: China's cement production from 1999 to 2009



Source: China Cement Association.

⁵⁸ The figure of 8% is for 2006: see Müller and Harnisch (2008: endnote 4).

By the end of 2009, China had 65 cement companies each with a production capacity above 5 million tonnes per day (tpd) and 18 companies each with a production capacity over 10 million tpd. In 2009, there were 3077 cement companies with a sales income of more than 5 million Yuan RMB each (713 companies less than in 2008). The combined capacity of these 3077 companies is over 0.5 billion tonnes, which is 30% of the total cement production capacity in China.

One of the most significant structural problems of the sector is the wide use of high energy-consumption techniques. The sector concentration of China's cement industry is low, while the consumption of resources is high, and pollution is a serious consequence of this situation. The application and diffusion of new advanced energy efficiency technologies is improving the situation of China's cement industry. Technology transfer is part of this and so it is important for policy makers to understand the status of technology transfer and diffusion in order to make policy decisions on technology transfer and intellectual property rights (IPRs). There are several core issues to understand with respect to the status of technology transfer and diffusion. What kinds of energy efficiency technologies are needed by the cement enterprises to reduce energy use and CO₂ emissions in China? How much are those technologies applied in China's cement industry? How did China's cement companies obtain these technologies? What role have IPRs played in technology transfer? This case study tries to answer these questions by focusing on the three most advanced energy efficiency technologies, introduced in the following section.

Energy efficiency technologies in the cement industry in China

Here, we discuss three major energy efficiency technologies, which are the New Suspension Pre-heater Kiln, Pure Residual Heat Power Generation, and Refuse Incineration in Cement Production, as the study targets in this research.

New suspension pre-heater kiln

To meet the demands of economic development while restrained by limited budgets, China built many small cement plants that use shaft kiln technologies. The rapid economic development since 1990 has dramatically stimulated cement production. Although many modern and large-scale cement plants have been built, outdated shaft kilns still exist due to market demand and uneven economic development of different regions. The co-existence of advanced and outdated, large and small sized cement plants presents a distinct contrast in technologies. Considering clinker sintering facilities for example, there are advanced kilns, such as the new suspension pre-heater (NSP); and outdated ones, such as wet process kilns, Lepol kilns, hollow kilns, and shaft kilns.

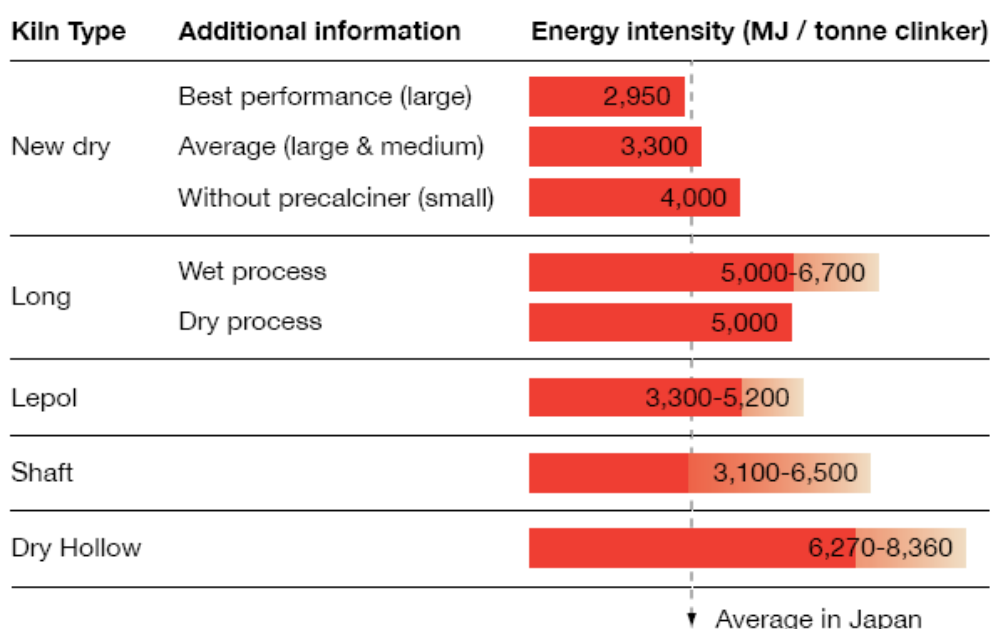
The NSP method for cement sintering is a leading technology developed originally in Japan since 1971 (JCI 2007). Production capacity is increased compared with the suspension pre-heater (SP) method by increasing the size of the kiln, although this creates some problems. These include increased wear of the kiln's refractory bricks, which then means extended kiln down-time during repair, and high levels of heat loss. The NSP method has been developed to overcome these problems. In the NSP method, approximately 90% of the material is sintered using equipment called a

calciner, and the remaining is processed with a conventional kiln. The calciner can be one of two types for sintering the raw material: a direct-firing burner, or a system that heats a fluidised bed which then fires the raw material.

The calciner is a vertical round structure, and the locations of the burner and material input port vary slightly depending on the method of NSP technology used. In general, in the direct-burner type, the calciner is installed between the second lowest cyclone and the kiln in the SP so that the material can be sintered while heat is being taken in from the kiln. After being preheated in the SP equipment, approximately 90% or more of the material is sintered, and fed into the kiln through the lowest cyclone. The indirect calcination method, using a fluidised bed, enables the use of a wider variety of fuels (e.g. natural gas, coal, heavy oil). Also, the raw material resides in the NSP for a long time giving a high firing ratio.

It is reported that the use of the NSP technology increases the production capacity for an existing SP kiln by a factor of 1.5 to 2, and also decreases the sintering energy consumed during the entire cement production (e.g. see Worrell and Galitsky 2008). In other words, an existing cement plant with an annual production scale of 500 thousand tonnes could be upgraded to one with an annual production scale of one million tonnes. A cement plant with superior operation techniques would further improve its capacity. The most efficient NSP-based kilns are generally large (5000 tpd) and use a dry manufacturing process, which is less energy-intensive than a wet process (Müller and Harnsich 2008; Price and Galitsky 2006). Figure A.2 shows the thermal energy consumption of different types of kiln technologies.

Figure A.2: Comparative thermal energy consumption of different kiln technologies



Source: Müller and Harnsich (2008:18).

China has moved rapidly to medium and large-sized NSP-based cement production in recent years; using NSP kilns to produce 50% (623 Mt) of Chinese cement in 2006, up from 10% (56 Mt) in 2000 (Hasanbeigi, Price, Lu and Lan 2010:3462). By

the end of 2009, China had 1113 NSP-based production lines or almost 77% of total Chinese cement production (CCA 2010). This is reducing the average energy-intensity of the Chinese cement industry but it has some way to go, partly because there are still many small and inefficient kilns in operation, as mentioned above (Müller and Harnisch 2008). By 2007, the energy-intensity of cement production in China had fallen to 158 kgce/t (kilograms coal equivalent per tonne) but was significantly higher than the international advanced level of 127 kgce/t (Ohshita and Price 2010:53). Through a combination of independent R&D and technology transfer, Chinese firms have enhanced their manufacturing capabilities for NSP equipment; developing from 2000 tpd up to 10,000 tpd plant manufacturing capability.

Table A.1 gives a breakdown of cement production capacity in China. There are 41 lines with a 700 to 900 tpd of production each, 151 lines with a daily output of 1000 tonnes, 99 lines with a daily output of 1100 to 1400 tonnes, 53 lines with a daily output of 1500 to 1800 tonnes each, 76 lines with a daily output of 2000 tonnes each, 324 lines with a daily output of 2500 tonnes each, 53 lines with a daily output of 3000 to 3500 tonnes each, 46 lines with a daily output of 4000 to 4200 tonnes each, and 270 lines with a daily output of 5000 tonnes or more each. The designed clinker production capacity of the lines with daily production of 5000 tonnes or more accounts for just over 45% of the total designed capacity of NSP clinker production.

Table A.1: Cement production capacity in China

Capacity (tpd)	700-900	1000	1100-1400	1500-1800	2000	2500	3000-3500	4000-4200	≥5000
Production lines number	41	151	99	53	76	324	53	46	270

Pure low temperature residual heat power generation

Worldwide, the cement industry consumes about 1.5% of electricity produced (Müller and Harnisch 2008:22). In terms of the best available kiln technology, cement production consumes about 100 kWh/t of clinker (80 kWh/t of cement), accounting for 25% to 30% of production cost (Müller and Harnisch 2008:22). With the large amount of waste heat generated by cement production there is clearly potential to make use of it to replace primary energy use for electricity supply. One method of doing so makes use of steam turbines, although gas turbines can also be used (Worrell and Galitsky 2008). The process recovers exhaust heat (at low and medium temperatures of 350 to 380 °C) being emitted primarily into air from the SP or NSP. In the steam turbine system, the recovered heat fires a boiler to produce steam which then drives the turbine to generate power. When installing this equipment, a four-cyclone SP/NSP cement plant is used as the primary component.

Exhaust heat recovery from cement production can be achieved from two sources: recovery of the exhaust heat emitted into the air from the SP or NSP; and recovery of exhaust heat from the clinker cooler (exhaust heat temperature of 200 to 250 °C). The basic equipment configuration includes an exhaust heat recovery boiler, steam turbine, and electricity generator. This electric generator reduces the amount of hot

exhaust gas emitted from the cement plant into the atmosphere, and measures can be taken to enhance environmental protection.

Müller and Harnisch (2008:23) state that conversion of heat recovered can generate between 20 kWh to 45 kWh of electricity per tonne of cement, where larger plants are more efficient and so more cost-effective. The impact of this process on carbon emissions, of course, depends on the source of energy and conversion efficiency for electricity generation. The more fossil-intensive and inefficient is the displaced electricity generation the more CO₂ emissions can be avoided.

By the end of 2009, there were 498 NSP cement lines of 2000 tpd capacity with residual heat power generation systems installed in China, providing a total of 3.3 GW of electricity generation capacity or 22.2 billion kWh. This represents avoided CO₂ emissions of 20 Mt. Systems have been installed on cement lines other than 2000 tpd and a range of generating capacities are reported. For example, a 1350-tonne cement line was renovated beginning in May 2002 to generate electricity from heat recovery. Using local expertise to renovate the facility, this now generates more than 1.8 MW of electricity, or 11.34 GWh annually in excess of the needs of the plant (Price and Galitsky 2006:27). By 2006, Chinese domestic technology was reported to be able to produce in the range of 24 kWh/t to 32 kWh/t, foreign technology could produce 28 kWh/t to 36 kWh/t, and Japanese technology had reached 45 kWh/t of clinker (Price and Galitsky 2006:28).

Refuse incineration in cement production

Waste-derived fuel (WDF) has become an increasingly attractive alternative to the use of primary energy sources over recent years, as well as the possibilities for using biomass. The advantages of these alternatives – particularly WDF – include economic and environmental benefits, although the incineration of WDF is also controversial (Lemarchand 2000; Archer et al. 2005; FOE 2005; JCI 2007). Economically, WDF can reduce the costs of cement production by displacing the use of increasingly expensive primary energy sources, while the potential environmental benefits include the avoidance of landfill and the reduction of polluting emissions such as CO₂ (Habert et al. 2010).

There is a wide range of potential waste products from both industrial and residential sectors that can be successfully used in generating heat for cement production, including tyres, oils, solvents, paper-industry residues, chemical wastes, plastics and many others (Müller and Harnisch 2008:27). The extent of carbon savings depends on the carbon content of the waste material used, as well as the alternative use of the waste such as whether there is heat-recovery in the cement plant (Worrell and Galitsky 2008). But other benefits can be derived from waste-burning. For example, because the waste is burned at very high temperature and resides for long periods in the kiln, almost all organic compounds are destroyed and efficient scrubbing of the exhaust gases can result in much-reduced emissions besides carbon (Worrell and Galitsky 2008). Finally, depending on the fuel source burned, gypsum and various minerals can be recovered and used as inputs to the cement-manufacturing process (Müller and Harnisch 2008). Biomass sources include agricultural by-products and, potentially, biofuels (Müller and Harnisch 2008). However, it is not clear the extent to which the cement industry is making use of biomass as a source of alternative fuels,

although Price and Galitsky (2006:33) report that some kilns in Europe use up to 50% sewage sludge and animal wastes.

But the burning of WDF (or biomass) is not yet widespread in the cement industry in China, partly because it has only been a short time since the technology for the combustion of alternative fuels has been applied to the Chinese cement industry. While there is a question concerning the availability of high-quality WDF in China, one interviewee claimed that there is still considerable energy-saving potential from the use of industrial and residential waste.

At present, only about ten cement plants (of approximately 5000) in China are using industrial and municipal waste as alternative fuels. This low level of adoption means that few emissions reductions have so far been realised: less than 50,000 tonnes of coal equivalent. According to one interviewee, fuel substitution elsewhere in the world is much higher. In the EU it is about 20%, while in the Czech Republic it is of the order of 80 to 90%. In China, it is only 2 to 3%.

Other energy efficiency technologies

A range of other technologies and techniques are recommended for improving energy efficiency (see e.g. Worrell and Galitsky 2008). There is no space here to discuss all of them. However, our research identified some of those that have been adopted in China, including adjustable or variable speed drives (ASDs) for the kiln fan, grate coolers and process control systems.

ASDs can result in significant electricity savings. For example, a plant in Mexico using ASDs reported reduced electricity consumption of 40% together with improved reliability (Price and Galitsky 2006). In China, savings of more than 30% electricity consumption were reported by one firm owning 10 plants (Price and Galitsky 2006). ASDs are being made in China but some of the parts and instrumentation may still be imported from elsewhere (Price and Galitsky 2006).

Grate coolers lower the temperature of the clinker from about 1200°C to 100°C, and are the preferred option in modern kilns (Worrell, Galitsky and Price 2008). Heat recovery rates of grate coolers are reported to be in the range 65% to 72%, the latter achieved with a third generation grate cooler in a 2500 tpd precalciner kiln in China (Price and Galitsky 2008:23).

Process control systems can help to optimise the kiln combustion process and conditions, as well as improve the quality of the cement produced (Worrell and Galitsky 2008). These automated systems use various control techniques including 'fuzzy logic', expert systems or model-predictive control, achieving energy savings of between 2.5% to 8% (Worrell and Galitsky 2008:24). Some firms in China supply IT for optimising process control (Worrell et al. 2008).

China's domestic providers of major technologies in the cement industry

Energy saving technologies are being developed rapidly in China, and many cement production companies and technology R&D companies are involved in local technological innovation efforts. The capabilities of Chinese domestic providers of

the major technologies discussed above are introduced in this section.

The domestic providers of the NSP lines

Table A.2 lists the milestones of the development of NSP production lines in China.

Table A.2: Milestones in NSP production line developments in China

Year	Details
1981	Xinjiang Cement Plant 700 tpd clinker NSP kiln test line was put into production
1984	4,000 tpd clinker kiln NSP production equipment put into use in Jidong Cement company
1986	In Jiangxi Cement company, 2,000 tpd NSP kiln production line was researched, developed and designed domestically in China and the equipment was mainly domestic. The production line was built and put into trial run
1987	The second set of the 4,000 tpd (mining, packaging excluded) NSP line was built and put into use in Ningguo cement plant
1987	Beijing Yanshan Cement Factory 700 tpd clinker kiln NSP production line put into production, marking the 700 tpd clinker kiln NSP process technology has matured
1992	The first 4,000 tpd NSP line building with the foreign investment in Dalian Huaneng – Onoda Cement Co., Ltd. was put into operation
1992	700 tpd clinker kiln NSP cement production technology was exported to Thailand Salabuli cement plant, marking that the NSP technology of China has been sold abroad
2004	China exported one 5,000 tpd NSP clinker production line to Fushan Cement company in Vietnam, marking China's large-scale NSP production technology and equipment exportation enter a new stage
2004	China's first 10,000 tpd clinker kiln NSP production line was built and put into use in Tongling cement plant of the Conch Group. China has become the second country having the NSP line with production over 10,000T/D in the world after Thailand
2005	China Building Material Equipment Co., Ltd. undertook the design and building of a 10,000 tpd clinker kiln NSP production line in the United Arab Emirates, marking China's NSP process technology has been able to keep pace with the world's giant cement company

There are five companies in China with the technology and capabilities to construct 10,000 tpd production lines: Anhui Congyang Conch Cement Co. Ltd., Anhui

Tongling Conch Cement Co. Ltd., Xuzhou China United Cement Co. Ltd., and Zhengzhou Tianrui Cement Co. Ltd.

Below 10,000 tpd construction capability, there are many other firms with the capabilities to construct facilities of various sizes. These are given in Table A.3.

Table A.3: Cement production line construction capabilities in China⁵⁹

Production line capacity	Approximate number of construction firms
5000 tpd	320
2500 tpd	420
2000 tpd	130
1000 tpd	120

The domestic providers of pure low temperature residual heat power generation

There are about 50 companies in this field in China⁶⁰. Rather than describe them all, we give brief information on four Chinese domestic providers of residual heat power generation equipment.

Hangzhou Steam Turbine Power Equipment Engineering⁶¹

The company was established in August 2007 and is controlled by Hangzhou Steam Turbine Co., Ltd. It claims specialisation in cement and glass kilns, and energy-saving technologies, and installs generator and associated technologies.

Sinoma Energy Conservation⁶²

SEC describes itself as a professional in using waste heat or waste pressures, and a leader in integration in the industry. It claims to conduct 'effective technology innovation, industrial investment and turnkey projects'.

Sinoma Chengdu Design & Research Institute of Building Materials Industry⁶³

CDI was founded in 1953, and claims to have installed more than 100 precalcining production lines ranging from 1000 tpd to 10,000 tpd. But it also claims to have the capability to install residual heat power generation systems, citing two examples: Yunan Baoshan (4500 kW) and Liaoning Jiaotong (9000 kW).

CITIC HIC⁶⁴

CITIC HIC owns the IPRs for the 'Pure Low Temperature Waste Heat Generating Equipment'. The company claims a long engagement in R&D in power generation,

⁵⁹ Data from <http://www.ccement.com/> (Chinese) (<http://www.cementchina.net/index.asp> English)

⁶⁰ Data resource: <http://www.ccement.com>

⁶¹ See <http://www.hzqlct.com/en/index.asp>

⁶² See <http://en.sinoma.cn/about/200907/202.html>

⁶³ See <http://www.cdi-china.com.cn/en/index.asp>

⁶⁴ See <http://www.citic-hic.com/>

and that it can undertake turnkey contracts for waste heat generation in the heavy industries such as cement.

The domestic providers of refuse incineration in cement production

With the development of China's industrialisation process, industrial solid wastes (including toxic and other wastes) have become an increasingly serious hazard to the environment. A way to reduce their impact on the environment is to use them as an alternative fuel or raw materials in cement production; a solution that is becoming more common in the international cement industry. The technical development of cement kilns dealing with waste has made some progress in China, and it is nearing practical use. Some domestic cement companies have had experience in this field. Designed by Tianjin Cement Industry Design and Research Institute (TCIDRI), one cement production line operated by Beijing Cement Plant of Beijing Jinyu Group is handling 100,000 tonnes of waste annually.

The international cement technology providers and the cement technology transfer situation in China

For the past 100 years, the Chinese cement industry imported advanced equipment and technologies from abroad. There are several large cement technology providers, such as Kawasaki Heavy Industries, Ishikawajima-Harima Heavy Industries (IHI), Mitsubishi Corporation, FLSmidth, and others. These are the world's leading suppliers of plant and technology for cement producers.

China's cement industry has been innovating as well as trying to absorb advanced technologies from abroad. Since 1978, China's cement industry has imported technology from Japan (IHI, Kawasaki), Denmark (FLSmidth), Romania and other countries, introducing 3200 tpd and 4000 tpd large-scale kiln equipment. A series of large scale pre-heater production lines were established in Jidong, Ningguo, Liuzhou, Zhujiang, Huai-Hai and other locations. After 1990, some foreign-owned and joint-venture projects have entered the Chinese cement industry, such as Yantai Mitsubishi, Daewoo Sishui, Qinhuangdao Asano and other large enterprises. These have enriched China's NSP cement production technology design and installation experiences and helped to develop Chinese firms' capabilities.

In the residue heat power generation technology field, Kawasaki is one of the biggest providers. In the mid-1990s, the completion of the Conch Group Ningguo cement plant's pure low temperature residue heat power plant design introduced the Kawasaki Heavy Industries' technology and the main engine equipment. The Tianjin Cement Industry & Research Institute subsequently completed the research and development of the 12 kW mid-low temperature residue heat power generator at Lunan Cement Plant's 2000 tpd production line, securing independent IPRs in the process. Following this, TCIDRI cooperated with domestic boiler and steam turbine manufacturers, to develop pure low temperature residue heat power generation equipment suitable for 700 tpd, 2000 tpd, and 5000 tpd scale NSP production lines, which now experience wide application. Finally, Chinese firms have been exporting cement plant for some years to other developing countries.

Appendix B: Electric vehicles

Xunmin Ou

Current state of China's automotive industry, and energy and CO₂ issues

The rapid growth of vehicle sales in China has caused increasing demand for oil. China was the third largest automobile producer and the second largest consumer in the world in 2008 (NBS 2009) but has now reached number one in vehicle production and sales mainly due to two reasons: Chinese domestic financial subsidies for buyers and a shrinking market in the US and Japan due to the financial crisis (Xinhuanet 2010). Vehicle sales rose to a record high of 9.35 million in 2008 and motorcycle sales reached 25.5 million in 2007 (CATARC 2008). Vehicle ownership in China is however still much lower than that in industrialised economies and the world average, on a per capita basis, and so the potential for growth in vehicle ownership is high (Ou, Zhang and Chang 2010b).

More than 80% of transport energy demand originates with road vehicles in the US (Davis and Diegel 2009) and 83% in the EU (European Commission 2007). This share in China increased from 54% in 1990 to 65% in 2005 (IEA 2008), although it is still lower than those in the industrialised economies. According to the IEA's projection, this figure for China will reach 71% in 2015 and 77% in 2030 in a business as usual scenario.

Currently, 20% of fossil fuel CO₂ emissions are from the transport sector worldwide (IEA 2008), 33.6% in the US (Davis and Diegel 2009) and 26% in the EU (European Commission 2007). Although the related greenhouse gas (GHG) emission data have not been officially published, the IEA (2008) estimated that the share of the transport sector in China's total CO₂ emissions was 6% in 2000 and 8% in 2005. However, with rapid growing transport energy demand, this share in China is expected to become larger. Cai (2008) projected this figure to be 12-15% by 2020, and the IEA (2008) projected it to be 11% by 2030.

The Chinese government is making great efforts to curb oil demand and GHG emissions in the road transport sector by introducing alternative fuels and regulating vehicle fuel economy. Various initiatives have been taken for electric vehicle and fuel cell vehicle technology improvements along with market establishment (Ouyang 2006; Wan 2008).

EVs can play an important role in the future

In a broad definition, electric vehicles include pure electric vehicles (EV), hybrid electric vehicles (HEV) and fuel cell electric vehicles (FCEV) (CONCAVE 2006). They can all be considered low carbon electrical power train vehicles, and can play a role in the system transition from the conventional compression-ignition and spark-ignition internal combustion engine (ICE) to new generation vehicles. Developing EVs will help improve China's energy security and reduce CO₂ emissions, as well as lessen China's reliance on imported oil. In addition, the development of EVs will financially benefit associated industries such as companies that produce and supply batteries, electric motors, electric controls, automotive parts and infrastructure.

Despite having been in use for decades and having a simple structure, there are still bottlenecks for EVs related – particularly – to driving power and travel distance. However, EVs achieve actual zero-emissions during driving, have very low energy consumption per km driven and their fuel economy is considered to be 300% better than gasoline vehicles (Zhang, Shen et al. 2008). According to our calculations (Ou, Zhang and Chang 2010a), electric buses (currently in a demonstration phase in China) consume 150 kWh per 100 km driven and the fuel economy is 300% of the baseline diesel bus, which uses 45 litres diesel over the same distance. From life cycle analysis (LCA) covering all the stages of energy resource extraction, transportation, fuel conversion, distribution and storage, electric buses can save 27% of total primary fossil energy and reduce 10% of GHG emissions. With battery technology improvement, the advantages of energy-saving and GHG reductions will be more striking. For passenger EV LCA, it is estimated that there could be energy savings of 50% and GHG reductions of 35% in 2012 (Ou, Qin et al. 2009).

Moreover, GHG reductions from EVs could be further improved with the successful employment of CO₂ capture and storage (CCS) technologies for coal-fired power plants. Assuming that CCS technology reduces the conversion efficiency of coal to 32% but captures 80% of CO₂ produced in power plants, the LCA impact for EVs is dramatic. Although energy use increases slightly compared to the original scenario, GHG emissions are reduced 73% when compared to conventional vehicles (Ou, Yan and Zhang 2010).

In China's near-term initiative of 'new energy' and energy efficient vehicle R&D and industrialisation, a key task is to incorporate HEV technology into both passenger cars and commercial vehicles. Numbers of pilot HEVs have been developed and demonstrated in some cities with energy-saving rates of 15-30%. Moreover, according to estimates, the energy-saving rates for HEVs in 2020 could reach 35-45%, close to the current level in the United States (Chai 2008). By using FCEVs to supply the power train through the chemical reactions of hydrogen and oxygen in the air, the energy efficiency is much higher than ICE vehicles, although lower than pure EVs (Ou, Zhang and Chang 2010a).

Key EV technology categories

There are three main categories of technology related to EVs: electric motors, batteries and electronic control systems.

Electric Motors

Electric motors are one of key component parts for EVs. They are advantageous at times when lower speeds and throttle are required, such as in reversing, and the stop and go situations common to urban driving. Currently Chinese electric motor companies are actively developing this industry chain, as Table B.1 shows⁶⁵.

⁶⁵ According to the presentation of Prof Ouyang Minggao in EV workshop in Shanghai, 2010-08-05

Table B.1: Recent production capacity and investment by key electric motor companies

企业名称 Name of Enterprise	2009年 2009		2010年 2010	
	产能 Production Capacity	投资 (万元) Investment ('0,000)	产能 Production Capacity	投资 (万元) Investment ('0,000)
比亚迪 BYD	2000	1600	24000	----
中山大洋电机 Zhongshan Broad-Ocean Motor	500	12600	5000	11000
湖南南车时代 Hunan CSR Times Electric Vehicle	1000 (客车) (Passenger Vehicle)	2100	5000 (客车) (Passenger Vehicle)	4000
上海电驱动 Shanghai E-drive	12000	3000	50000	6000
天津清源 Qingyuan EV	30000	3000	50000	5500
湘潭电机 Xiangtan Electric Manufacturing Corp.	10000	1200	10000	4000
浙江尤奈特 Zhejiang Unite Motor	12290	4000	100000	5000
襄樊特种电机 Xiangfan Special Electrical Machinery	电机 3000 控制器 1000 3,000 Electric Machinery Controller 1,000	896	10000	7800
江苏微特利 Jiangsu Weiteli	300	1400	15000	8100
北京中纺锐力 China Tex Mechanical & Electrical Engineering	2000	320	3000	400
合计 Total	7.3万套 73,000 Sets	3亿元 RMB 300 million	27.2万套 272,000 sets	5.2亿元 RMB 520 million

Batteries and battery management systems

The most important technologies for EVs are those related to the battery, which is the energy store for an EV. Battery materials determine the electrochemical properties of the battery, such as capacity, power, energy density and operation security. The batteries that have been most commonly used in vehicles in the past are lead acid (Pb-acid); a technology that has been around for over 100 years. These have been popular due to their low cost and the fact that they are reliable and efficient (around 70-90%). However, due to various factors, including a shorter battery life, a lower power density and various environmental considerations, other materials are increasingly being used or investigated.

An increasing number of vehicles use lithium ion (Li-ion) batteries because of their higher power density, excellent efficiency (almost 100%), and their maturity and availability. The main attraction with lithium ion batteries is that they require less battery mass to produce the same amount of energy and power as lead acid batteries. Li-ion batteries represent the highest potential among battery technologies currently available. However, the cost of these batteries remains high and the charging process does have a 'wear and tear' effect on the batteries.

The costs of various kinds of batteries remain high and their capacities allow only short driving ranges. Improvements are needed to reduce the cost and mass of batteries while also increasing their capacity and life. As newer battery technologies become more common and battery management systems become increasingly

sophisticated, there is more potential for patents and IPRs to play a role in accessing the various technologies.

Electronic control system

Integration of electrical, mechanical, chemical and software technologies is required for EVs. To put all of these components together and ensure they function properly, an electronic control system (an advanced system integration technology) is essential. Moreover, such a technology in EVs can help to improve efficiency and reliability and reduce costs in other aspects of the vehicle.

An EV electronic control system coordinates the functions of the various subsystems, which are essential for stable and safe operation of an EV, and also indirectly affect the battery life time. At present, some key components of the control system (such as IGBT power switching devices, etc.) are mainly imported. At the same time, because the relevant fields associated with electronic control systems in EVs (electrical, electronic, control, automotive and others) have only a relatively short history in China, electronic control system design suffers from a low degree of automation, wide operational deviation, high failure rates, and so on⁶⁶.

Overview of the market situation of EVs in China

In this section, EV development initiatives globally and their development status (including R&D programmes, industry development) are summarised, based on information gathered at workshops attended during the project period.

Current EV development initiatives globally

Governments and companies are rushing into EV development globally. Currently, many OECD countries including the US, Japan, Germany, France and the UK are providing substantial subsidies for their automotive industries. Within these industries, EVs are key beneficiaries.

- US: EUR 17 billion loans for the production of fuel-efficient vehicles under the DoE's Advanced Technology Vehicles Manufacturing Loan Program; EUR 1 billion for battery makers, EUR 350 million for electric motor producers and EUR 280 million for test vehicles – funding 48 projects in 25 states
- Japan: Subsidies of approximately EUR 150 million over seven years to support the development of next generation batteries for use in automotive power trains
- Germany: EUR 500 million programme included in economic stimulus package to foster development of electro-mobility (EVs, components, infrastructure)
- France: EUR 400 million to support the development of HEV cars plus EUR 200 million in loans to companies working on EV projects
- UK: Approximately EUR 300 million over five years to promote low carbon transport including end-customer incentives

⁶⁶ Same as the footnote 65

EV development in China

China has established a policy framework to accelerate technology development and market transformation of EVs. The federal government has set the strategy to develop new energy vehicles and it has devised policies to support research and development, regulate the industry and encourage consumption. Some local governments have already started to implement these policies.

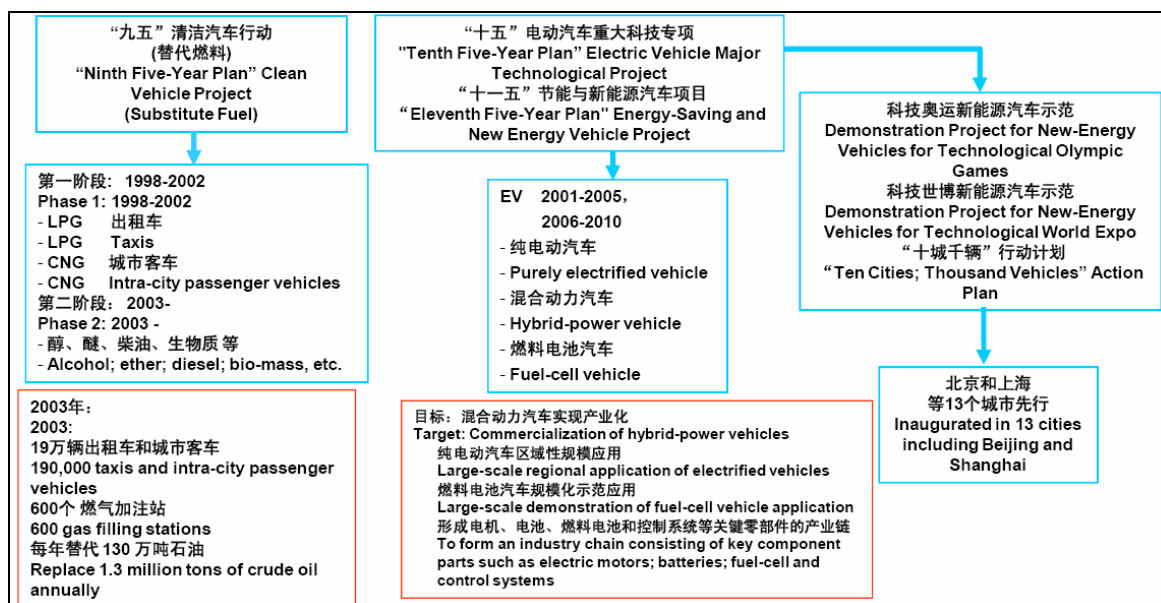
The Chinese government aims for 5% of total car sales to be for new energy cars by 2011. This will be more than 600,000 vehicles (total sales of cars in China last year were 13 million). The government has announced that they will spend twenty billion Yuan for the promotion, manufacture and sale of new energy cars, focusing on EVs. To help achieve these goals, the government has devised the Ten Cities, One Thousand Vehicles plan which is set to demonstrate the operation of 1000 new EVs in ten cities each year to encourage people to buy them.

In the following two subsections, we review technology R&D programmes that have received major support from Chinese government agencies.

R&D programmes supported by the Ministry of Science and Technology (MoST)

In China, EV development is supported by a series of initiatives, as Figure B.1 shows:

Figure B.1: Chinese EV supporting initiatives



Since 2002, a 3x3 R&D mechanism was initiated to develop EVs through the 863 programme in China with government investment of 880 million RMB. This is illustrated in Figure B.2 and the achievements are shown in Figure B.3.

Figure B.2: A 3x3 R&D mechanism for EVs in the 863 programme in China (2002-2006)

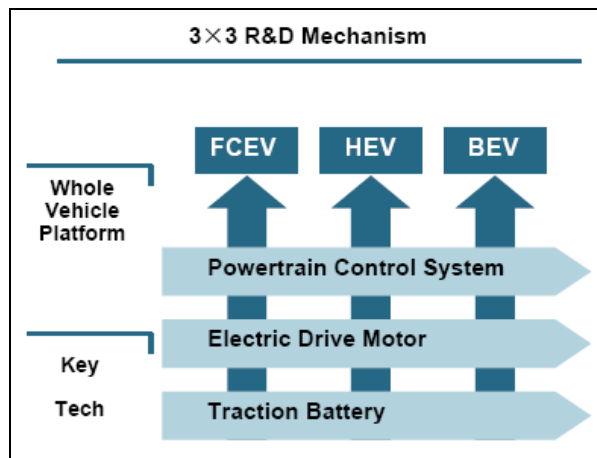
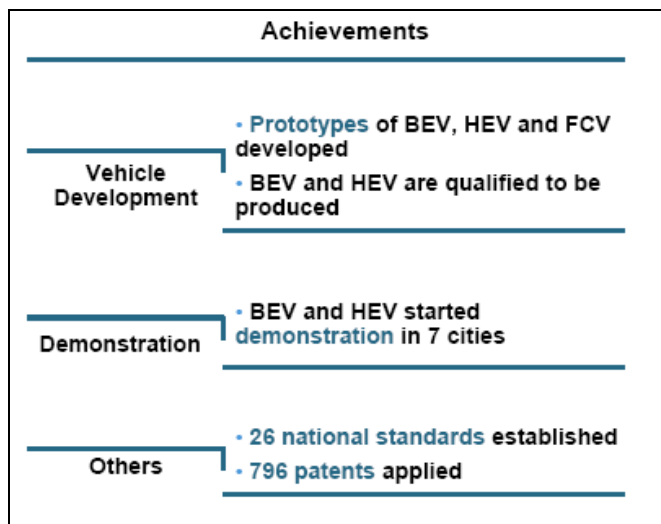


Figure B.3: EV achievements in the 863 programme in China (2002-2006)



Since 2006, all types of EVs are listed on the new round of 863 programmes and a new R&D mode is framed. With 1.1 billion RMB of government investment, China has made progress in some key EV technology developments although effort is needed from original equipment manufacturers (OEMs) (see Figure B.4 and Figure B.5).

MoST is driving a plan to support development of 'new energy vehicles' (NEVs) in April 2009. Prof. Wan Gang announced the plan in cooperation with the Ministry of Finance and the National Development and Reform Commission to promote the use of NEVs initially targeting 13 pilot cities. These include Beijing, Shanghai, Chongqing, Changchun, Dalian, Hangzhou, Jinan, Wuhan, Shenzhen, Hefei, Changsha, Kunming, and Nanchang. The plan will support the development of energy-saving technology for use in government fleets, including buses, postal and sanitation vehicles, and will deploy 60,000 energy-saving vehicles in China by 2012.

Figure B.4: A 3x3 R&D mechanism for EVs in the 863 programme in China (2006-2010)

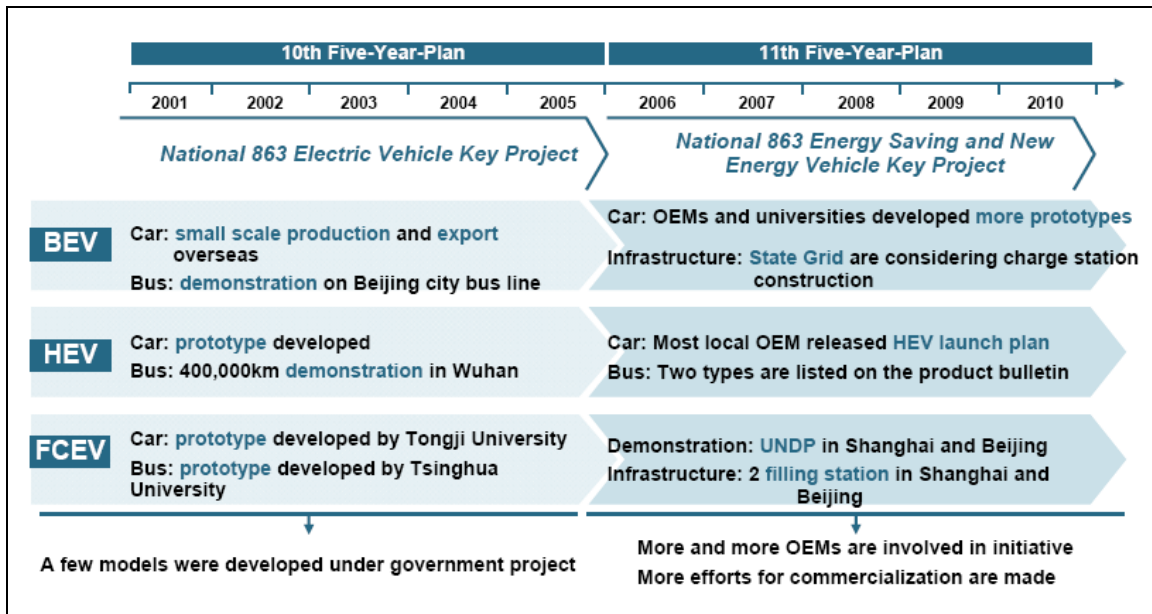
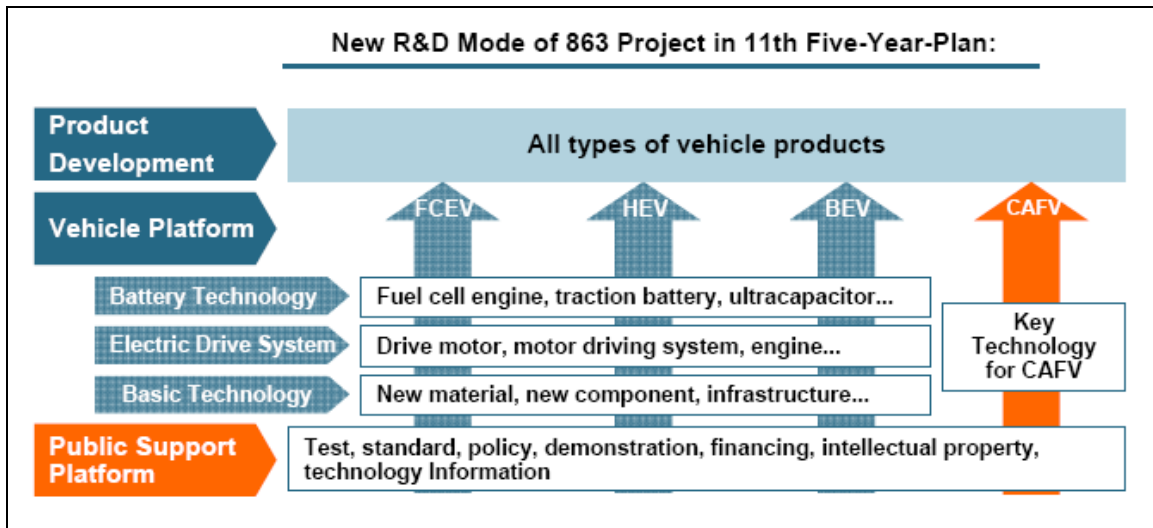


Figure B.5: EV technology R&D plan in 863 programmes in China (2001-2010)



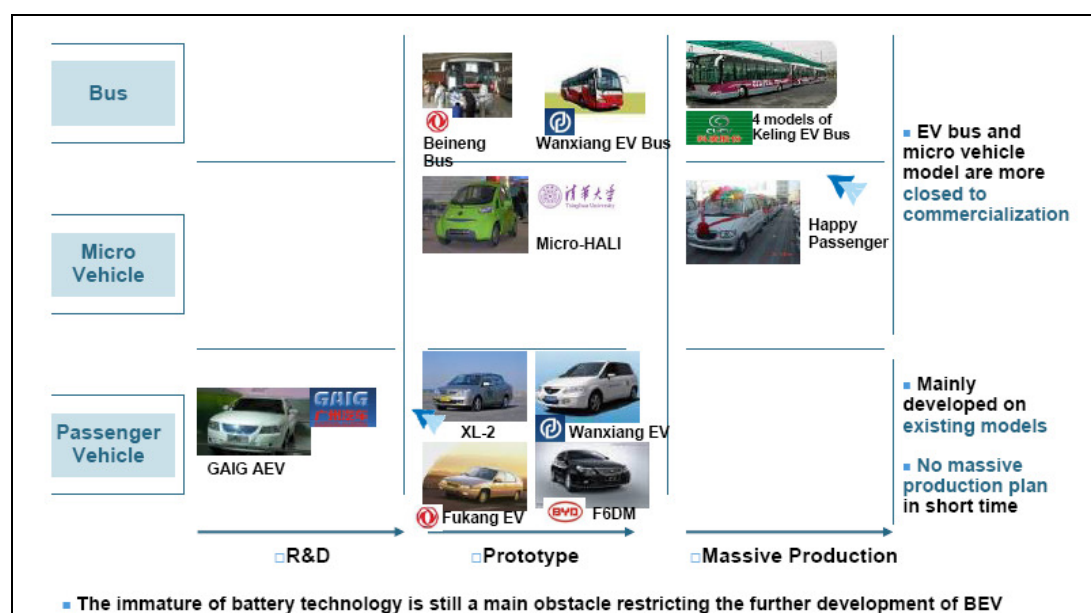
Key objectives of MoST are to promote industrial development and expansion of the 863 programme, and the HEV and EV development plan. MoST will provide technical support for research and development of NEVs, and their promotion, as well as industrialisation in the sector.

EV industry development in China

At present, Chinese firms have developed some types of HEV and EV that are qualified for sale, and a small scale capacity of EV manufacture has been built (see Figure B.6).

- Progress has been made in the battery, driving motor and other key component technologies, and electronic control and system integration technologies
- An R&D system for key parts of EVs has been initially constructed
- Battery EVs are still at the prototype stage, and the main application area is in buses and micro vehicles

Figure B.6: EV development stages in China



Discussion of Chinese capabilities in EVs

The overall situation of EVs

Research and development of electric vehicles in China is essentially at the same starting line as other countries, and the technology and industrialisation level 'gaps' are small between China and other advanced countries. At present, China has listed a variety of HEVs and pure EVs in the national automotive product announcements. China has a small production capacity for EVs and is at the critical stage of shifting from demonstration to industrial development.

China has made significant progress in the development of key components of EVs including batteries, drive motors, and electronic control and system integration technologies. And key parts of an electric vehicle research and development system have been established to some extent. Among the three major categories of technology – battery, motor and system integration – the battery category is considered key because of its high percentage in the cost of EVs and technological

complexity. Because of this importance to China's industry, we discuss battery technology further below with a view to understanding better the gap between China and the advanced countries.

EV industrialisation in China

Although many domestic enterprises have introduced electric vehicles, there is still a long distance from research to mass production, requiring much more engineering research and development. Chinese firms are still very weak in engineering R&D and the government may play a role by increasing investment in this area.

Demonstration programmes are needed to test some technologies, which may help to stimulate the market. According to a number of our interviews, battery technology is one of the main bottlenecks in developing EVs and an indigenous industry. At present, the energy density of batteries is relatively low and so more batteries must be packed into an EV to improve its mileage. Moreover, the stability and life of the batteries need to be tested in demonstration programmes in order to discover and solve the many remaining problems, thereby improving battery performance through practical application. Also, as demonstration can stimulate market demand, the successful development of the battery industry could accelerate the pace of related technological improvements.

Key players in China

There are now many key players involved in EV technology development in China. Current firms involved in technology development for EVs in China can be divided into three categories (and see Figure B.7):

- Enterprises in the 863 programme
- Companies which are traditional vehicle parts manufacturers
- Various small and medium sized enterprises engaged in the EV field

Outstanding OEM: BYD

Among those companies involved in EVs in China, BYD⁶⁷ is outstanding based on its experience in the battery industry. In 2009, it introduced the first mass produced plug-in EVs (BYD F3DM and F6DM) to use a home outlet, but market acceptance remains challenging.

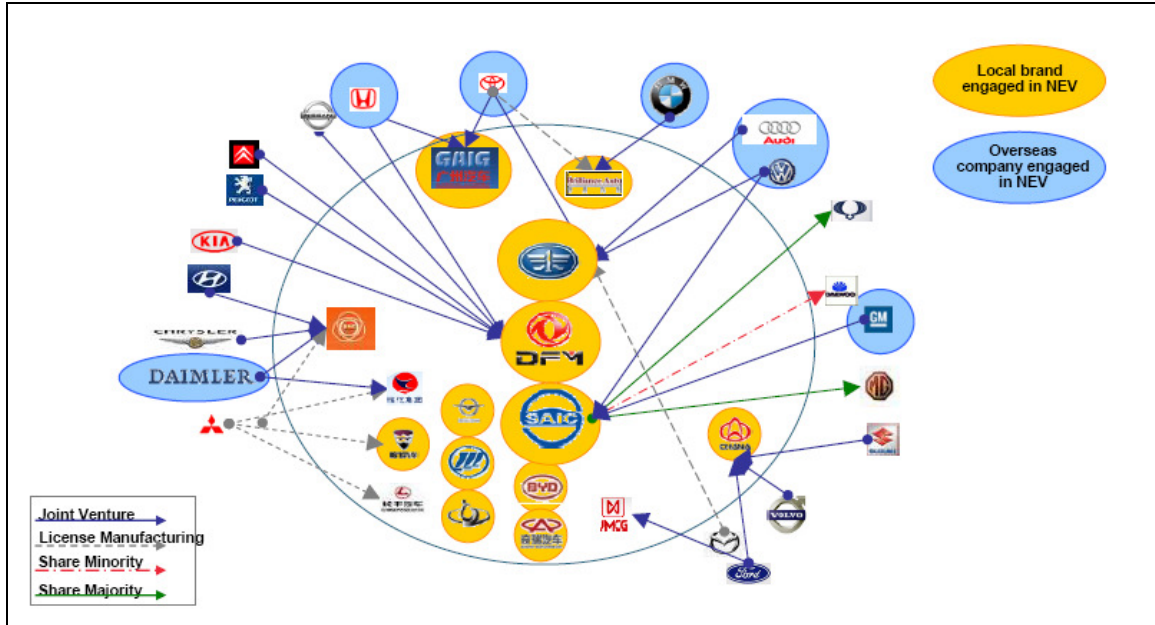
Some features of BYD's vehicles are listed below.

- Convertible between EV and HEV modes
- Market launch in December 2008 (fleet orders only)
- Retail sales to begin in September 2009
- Price of RMB 149,800
- Combined total power output of 125 kW
- Acceleration 0-100km/h in 9 seconds

⁶⁷ BYD was formerly a battery company that mainly supplied batteries for mobile phone OEMs. It came into the automotive industry through buying a vehicle OEM in 2003. See: <http://www.byd.com/>.

- Charging time of 7 hours with normal household power outlet
- Maximum distance on one charge of 100 km
- Sales available in 14 1st-tier and 2nd-tier cities in China

Figure B.7: OEM involved in new energy vehicle in China



BYD’s technology innovation approach has brought a huge cost advantage while improving performance. Some of the key factors are given below.

- Integrating battery manufacturing with the role of a traditional vehicle manufacturer, BYD has:
 - Integrated battery and EV R&D, while other OEMs conduct their R&D streams separately
 - Capitalised on the battery and automotive manufacturing resources and facilities
- Prioritising the role that local government (or utility) can play, BYD has approached local government as the first customer base to help create the market
- Working closely with these partners to develop the market in order to increase production size and drive down cost

Despite these advances, sales have been poor. In the first ten months of 2010, sales of the EV were only 54 and sales of the hybrid were only slightly higher at 290⁶⁸.

Most of the EVs that have been sold are used for taxi demonstrations. The joint venture, Shenzhen Pengcheng Company (BYD and Shenzhen Bus Group shared in the ratio of 45:55), originally ordered 100 BYD-branded EVs but only the first batch of 10 EV vehicles was put into operation quickly, while a further 40 were gradually transferred to Shenzhen Pengcheng Company. The planned dates for delivering the remaining 50 EVs continue to be delayed. In January 2011, though BYD announced

⁶⁸ See <http://auto.hexun.com/2011-01-11/126723512.html>

it had accomplished the key shapes and design elements of its first electric vehicle jointly with German Daimler, it decided to delay the sales of its fully electric cars in California, postponing until 2012. BYD once had a high-profile publicity campaign to advertise that it would sell this kind of EV in the US in 2011⁶⁹.

Media surveys have shown that the current promotion of electric vehicles is being hampered by four pressures: the high cost of EVs, which are three to four times that of an ordinary car; significantly increased management costs for EV taxis⁷⁰; the inconvenience and higher cost of maintenance; and the slow construction of charging stations in China.

EV development paths in China

China's conventional automotive industry has evolved from technology import and absorption into the development of independent R&D. For the emerging EV industry, it may take a similar path but others could be followed (see Table B.2). Among them, the path of independent R&D could help firms to master core technologies and improve competitiveness in the long-term, but large investment and long R&D cycles are inevitable. The path of technology transfer, absorption and acquisition could also help firms to master some key technologies but there is a risk of dependency on imports from foreign firms. Direct procurement of components may lower initial investments and production costs but could risk losing competitiveness to other countries.

Table B.2: EV technology development path in China

Path	Support	Advantage	Risk
Independent R&D	R&D department S&T agency	Long-term competitiveness	Investment; Long R&D cycles
Technology transfer, absorption and acquisition	Industry and enterprise	Getting Intellectual Property quickly and dominating some markets	Key technology will be controlled by foreign companies
Direct procurement of components	Companies (partially)	Low initial input and production costs	The industry will be driven by foreign firms

But China is a large and complex market that includes the potential to sell many different types of vehicles, from high to low price and from those suited to city or rural areas. This suggests that there may be space in the Chinese market for many types of firms – domestic and foreign, those selling high-priced and those selling low-priced vehicles. Under these circumstances, it is possible that all three paths listed in Table B.2 could be followed simultaneously.

Having said this, some firms in the advanced countries for EV development, such as Japan and the US, seem to prefer to develop the technologies by themselves. They

⁶⁹ See <http://roll.sohu.com/20110119/n302284466.shtml>

⁷⁰ The General Manager of Pengcheng commented, 'Management costs of 1000 of traditional taxis can only manage 100 electric taxis'.

are advanced in R&D and are scaling up manufacturing capacity. Certainly, there has been no R&D collaboration between Chinese and Japanese firms so far.

With no mature technology in producing materials, China purchases materials from overseas, e.g. Japan, and plays the role of manufacturing batteries for mature applications, e.g. mobile phones.

Appendix C: Offshore wind power

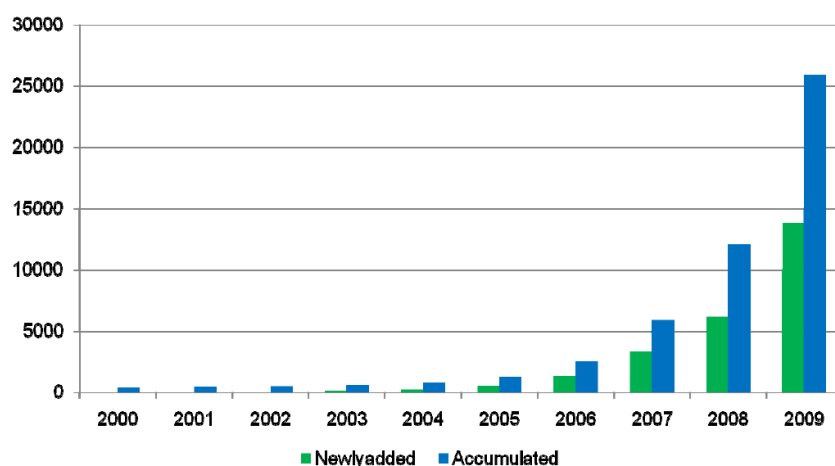
Zhang Da

Overview of China's offshore wind energy

In 2010, the first offshore wind power installation was realised in China. This first offshore wind power project has been connected to the grid, and the first series of concession bidding projects have marked strong support from the national government. It is possible that offshore wind power in China will expand rapidly in the future and, consequently, an understanding of its development pattern could be important for analysing the overall wind market in China as well as global offshore wind power development.

From 2004 to 2008, the installation of wind power in China doubled each year. In 2009, new installed wind turbine capacity in China reached 3.8 GW, and cumulative installed wind power surpassed Germany, making China the country with world's second largest wind power capacity. However, almost all of this capacity, more than 25.8 GW, is onshore wind power⁷¹. There was no completed offshore demonstration project before 2010, and offshore wind power only reached about 60MW in newly installed capacity in 2009.

Figure C.1: Newly added and accumulated wind power installation in China (2000-2009)



For wind power potential, an analysis conducted by Harvard University and Tsinghua University suggests that, at a contract price of 0.516 RMB/kWh, wind energy in China could generate an annual supply of electricity of 6.96 PWh, more than twice current consumption (3.4 PWh) and comparable to total demand projected for 2030 (McElroy, Lu et al. 2009).

The China Meteorological Administration estimates that offshore (water depths less than 20 meters) there is 750 GW of wind power potential, or three times that of the onshore wind power potential⁷². At the end of 2009, the China

⁷¹ Li Junfeng: China wind market is booming: Growth not only on-shore but off-shore.

⁷² Shi Pengfei: China Wind Power Outlook

Meteorological Administration published a new wind assessment, based on measurements at 50m height. This showed that China has a potential to develop 2380 GW of class 3 wind power (average wind power density greater than 300 W/m²) and 1130 GW of class 4 (average wind power density greater than 400 W/m²), while the offshore potential (water depth 5-25m) is 200 GW for class 3⁷³.

Overview of the market situation for China's offshore wind power

Demonstration and concession bidding projects for offshore wind power

The only completed demonstration project for offshore wind power in China is Shanghai Donghai Bridge project for the World Expo 2010. It has a total capacity of 102 MW, consisting of 34 x 3 MW turbines manufactured by the Chinese market leader Sinovel.

The first concession tendering process for offshore wind power was started in May 2010. There were four projects with total capacity of 1 GW in this round, and all of them were located in Jiangsu Province – two projects in Binhai and Sheyang with 300 MW capacity each, and two intertidal projects in Dafeng and Dongtai with 200 MW capacity each.

Offshore wind power development targets in China

In 2007, the government raised the total wind power capacity target from the original planned 30 GW to 100 GW by 2020⁷⁴. In the government's 'New Energy Resource Stimulus Program' the price model for wind power is highly favourable to investments. Multiple wind farms with a total capacity of 10 GW or more are to be built in Xinjiang, Gansu, Inner Mongolia, Hebei, Jiangsu, Jilin, and Liaoning provinces⁷⁵.

In 2008, the National Energy Administration (NEA) selected six locations from the provinces with the best wind resources, and set targets for each of them to be reached by 2020:

- Xinjiang Hami (10.8 GW)
- Inner Mongolia (20 GW in Inner Mongolia East and 37 GW in Inner Mongolia West)
- Gansu Jiuquan (12.7 GW; this started its first construction phase in August 2009)
- Hebei (14 GW in the Northern part and coastal areas)
- Jilin (23 GW)
- Jiangsu (3 GW onshore and 7 GW offshore)

⁷³ Global Wind Energy Council: <http://www.gwec.net/index.php?id=125>

⁷⁴ Speech by Zhang Guobao, chair of the National Energy Administration to the International Cooperative Conference on Green Economy and Climate Change, Beijing, China, 9th May 2010.

⁷⁵ China Wind Power Center: China has recorded newly added installed wind power capacity of 2.57 GW in the first seven months. <http://www.cwpc.cn/cwpc/en/node/5996>

The planning and development for this 'Wind Base' programme, aiming to build 127.5 GW of wind capacity in six Chinese provinces, is well underway with construction having started on some projects. The programme is important if the Chinese government is to achieve its 'National Mid and Long-Term Development Plan' of 3% non-hydro renewable electricity production by 2020⁷⁶.

In April 2009, each coastal province was asked by the NEA to compile an offshore wind development plan. The NEA then divided China's potential offshore wind sites into three categories, depending on the depth of water: an 'inter-tidal' zone for water depth of less than 5 m; an 'offshore' zone for water depth of 5-50 m; and a 'deep sea' zone deeper than 50 m. The provincial governments are required to draft offshore development plans for 'inter-tidal' and 'offshore' wind development for the period up to 2020⁷⁷. Before 2009, some provinces have already formulated planning for offshore wind farms.

Figure C.2: Offshore wind power plans for coastal provinces in China in 2008⁷⁸

Wind Farm		Under Construction or Completion	Existing Plan (10,000KW)
Hebei	Cangzhou	50,000 KW	100
Shandong	Weihai		110
	Qingdao		150
Jiangsu	Xiangshui		100
	Lianyungang		200
	Rudong		250
Shanghai	Donghai Bridge	100,000 KW	
	Fengxian		40
	Nanhui		40
	Hengsha		20
Zhejiang	Cixi		150
	Daishan		50
	Linhai		20
Fujian	Liu'ao		20
Guangdong	Nan'ao		30
	Jiahua Bay of Lufeng		125
	Dongshan Sea		<68
Hainan	Floating Wind Farm	20,000 KW	100
Total		170,000 KW	1710

⁷⁶ Global Wind Energy Council: <http://www.gwec.net/index.php?id=125>

⁷⁷ Global Wind Energy Council: <http://www.gwec.net/index.php?id=125>

⁷⁸ Market Research and Analysis Report of China's Offshore Wind Power Generation Industry during 2009-2012

Existing policies related to the development of offshore wind power

The Chinese Renewable Energy Law

The explosive growth of the Chinese wind energy industry has been driven primarily by national renewable energy policies. Active government engagement in renewable energy development began in 2004, when the nation drafted its first Renewable Energy Law. This was adopted in 2005 and began implementation in 2006. It created huge momentum for the development of renewable energy in China, and the wind industry has grown at a remarkable pace ever since.

The Renewable Energy Law was an important shift in energy policy to a market supportive approach for renewable energy. It stipulated that grid companies were obliged to purchase the full amount of the electricity produced from renewable energy sources (RES). Already in 2005, when the law was passed, the annual growth of the Chinese wind market had reached 60%, followed by four consecutive years of over 100% growth.

Following the introduction of the Renewable Energy Law in 2006, a number of amendments and adjustments were made. In 2007, the first implementation rules emerged. In addition, the 'Medium and Long-term Development Plan for Renewable Energy in China' was released and set out the government's long term commitment to renewable energy up to 2020. This included stipulation of targets for electricity production from non-hydro renewable sources. By 2010 and 2020, these were to be 1% and 3% respectively. We will not discuss all policy developments in great detail but the following gives a brief account of these various developments.

Renewable Energy Law 2009 Amendments

These amendments reiterated priority grid access for wind farms, required grid operators to buy specified amounts of renewable energy and to enhance the grid's capability to absorb renewable power. There was also a Renewable Energy Fund established from which grid companies could draw subsidies.

The Renewable Energy Premium

The Renewable Energy Law stipulated that the price difference between the electricity from renewable sources and coal-fired power plants should be shared across the whole electricity system. The Renewable Energy Premium was introduced to fulfil this objective. Incrementally, the premium was raised from its starting figure in 2006 of 0.001 RMB/kWh (€0.01 cent) through 0.002 RMB/kWh (€0.02 cent) to 0.004 RMB/kWh (€0.04 cent) in November 2009.

Feed-in-tariff regulation

In addition to the premium, and also in 2009, the Chinese government introduced a feed-in tariff for wind power. This applies for the entire operational period of a wind farm (20 years). Four different categories of tariff are specified, depending on a region's wind resources, ranging from 0.51 RMB/kWh (€5.4 cent) to 0.61 RMB/kWh (€6.5 cent). This is considerably higher than the tariff paid for coal-fired electricity

and it gives investors a much clearer idea of the long-term framework for the wind power sector.

Administration of electricity generation using RES

Wind projects larger than 50 MW are authorised under a concession bidding process managed by the National Development and Reform Commission (NDRC). Concessions are usually allocated for a 25-year period and grid companies are required to sign a power purchase agreement (PPA) with successful bidders, the PPA including an agreed fixed price for the electricity for a ten year period. After this, the price is expected to adjust to the market price for the region. There are also favourable VAT and income tax benefits for renewable energy investments and the internal rate of return is allowed to be about 10% pa.

Interim measure of development and construction of offshore wind power

Under this measure, issued in February 2010, every coastal province should formulate planning for the development of offshore wind power under the guidance of the National Energy Bureau and the National Marine Bureau. When approved by the Bureaus, the concession tendering process starts the company selection process. A company that is local or joint-owned (with the Chinese firm holding the controlling share) has rights to invest and develop the project. The construction and operation of the project should also be under the guidance of the two authorities.

Access standard of wind power equipment manufacturing industry

To improve the efficient competition of the wind power equipment manufacturing industry, the Ministry of Industry and Information Technology (MITT) drafted the access standard for the integration of the industry. The draft was issued in March 2010, and key regulations for manufacturers are listed as follows:

- For the initial investment, the standard requires that the equity proportion of the initial investment of the wind power project should be no less than 30%. This is considered a solution to the 'overheating' situation of wind power investment in China
- For the location, the standard requires manufacturers should locate their factory near the 'wind base' and upstream suppliers to reduce the logistics cost
- For production capacity, the standard requires that manufacturers must have the capacity to produce 2.5 MW or more independently, and annual production more than 1 GW
- For R&D, the standard requires that the manufacturer should give priority to development of independent intellectual property rights of wind turbines with unit capacity of 2.5 MW or more and development of offshore wind power equipment

Capabilities of China's offshore wind power manufacturers

Overview of wind power equipment manufacturers in China

By the end of 2009, there were almost 80 wind turbine manufacturers, 30 of which had actually already sold wind turbines. In January 2009, a change in the VAT rules for wind turbine manufacturing another incentive for local governments to attract wind turbine manufacturing to their province, thereby further stimulating growth in manufacturing capacity.

The Chinese government has signalled that it is worried about an 'overheating' of the wind turbine manufacturing market. At present, the three largest domestic manufacturers (Sinovel, Goldwind and Dongfang) already have a combined production capacity of 8.2 GW for an annual market of 13.8 GW. Even in a booming market like China's it seems unlikely that all current Chinese manufacturers will survive this tough competition and many will be squeezed out of the market. However, the government has taken no concrete measures to counteract this situation to date, and it is important to emphasize that the concerns expressed are not aimed at discouraging wind farm developers, but solely manufacturers⁷⁹.

Table C.1: Main types and production capacity of China's top 10 manufacturers

Manufacturer	Turbine Type (MW)	Annual Production (MW)	Technology Source
Sinovel	1.5/3/5	3000	1.5 MW: Introduced from Fuhrlander 3.0/5.0 MW: Introduced from Windtec
Goldwind	0.6/0.75/ 1.5/2.5	2200	0.6MW: Introduced from REPower 0.75MW: Introduced from Jacobs 1.5/2.5MW: Introduced from Vensys
Xiangdian	1.5/2/5	2100	1.5/2MW: Introduced from TMPA 5MW: Introduced from Darwind
Dongfang	1.5/2.5/3	2000	3MW: Introduced from Moventas
Guodian	1.5/3	1000	1.5MW: Co-designed with Aerodyn
Zhongchuan	0.85/2	1000	0.85MW: Introduced from Frisia 2MW: Co-designed with Aerodyn
Mingyang	1.5/3	1000	1.5MW: Co-designed with Aerodyn
Suzlon	1.25/1.5	900	Independent R&D
Vestas	0.85/2.0	800	Independent R&D
Huayi	0.75/1.5	800	0.78MW: Independent R&D 1.5MW: Co-designed with Aerodyn

⁷⁹ Global Wind Energy Council: <http://www.gwec.net/index.php?id=125>

Manufacturers qualified in offshore wind power equipment

Less than ten manufactures are qualified according to the access standard issued by MIIT (production capacity of 2.5 MW or more independently, and annual production more than 1 GW) for the offshore wind power equipment manufacturing industry⁸⁰. This standard will diminish the opportunity to enter the offshore wind market for small manufacturers, and qualified manufacturers will be selected from the top ten manufacturers mentioned above. By the end of 2009, manufacturers that could produce wind turbines with capacity larger than 2 MW were Goldwind, Sinovel, Xiangdian, Dongfang, Shanghai, Zhongchuan, Mingyang, and Vestas in China. Most of the other top ten manufacturers were busy developing prototypes of large-scale wind turbines.

Technology transfer in wind power development in China

China was a relative latecomer in regard to the setting up of a wind power industry. Before 2005, there were few influential wind power equipment manufacturers in China. Nevertheless, thanks to technology transfer and the advantage of existing manufacturing capability, there are now about 100 final assembly manufacturers in China, and the number is still growing.

They can be divided into three categories: Chinese-capital, foreign-capital and joint ventures. There are 66, 9 and 11 major players in each category⁸¹. Therefore, we can conclude that several mechanisms of technology transfer have been in operation and analyse the sources of technology for the various manufacturers.

The first important mechanism is technology licensing. Licensing consists of the patent owner granting permission to another entity to perform, for the duration of the patent and in a certain country, 'one or more of the acts which are covered by the rights to the patented invention in that country' (WIPO 2004). Licensing contracts can vary in several ways, which may affect the degree of control that the licensor can retain over the technology, as well as the profits that he can obtain from the licensee (Vishwasrao 2007). More than 50 of the 66 manufacturers buy licenses from foreign manufacturers. Leading manufacturers in China have started by assembling under license. For example, Sinovel assembled turbines under license from Wintec, and Goldwind assembled under license from REpower. Licensing has enabled Chinese firms to build significant manufacturing capability in wind turbines.

Beyond licensing, another important mechanism for Chinese-capital manufacturers in technology transfer has been collaborative R&D. With strong imitation and reverse engineering, some major Chinese manufacturers obtained capabilities in wind turbine design. They tended to collaborate with license issuers or other manufacturers to carry out collaborative research, especially for the design of the turbine as a whole. For example, Sinovel and Windtec co-designed 3 MW offshore wind turbines for the Shanghai Donghai Bridge offshore projects, and Mingyang and

80 Access Standards of Wind Power Equipment Manufacturing Industry: MIIT, Apr.2010 (Only Chinese available)

81 WED 2010: Construction, Operation and Management of Wind Power Project in China

Aerodyn co-designed Super Compact Drive 3 MW turbines. Collaborative R&D is more effective in technology transfer because of the intensive exchanges it demands during the process.

Foreign direct investment (FDI) is another important mechanism of technology transfer. In principle, companies that invest abroad are expected, in some way, to transfer some form of technological information to the subsidiaries located in the host economy (Maskus 2004). FDI can be seen as a way of transferring technology among affiliated firms, being a mechanism that usually involves large resource commitments and provides a high degree of control over the technology that is transferred (Radošević 1999; Vishwasrao 2007; Leitão and Baptista 2009). Examples include leading manufacturers such as Vestas, GE and Repower, firms that set up their factories in China.

Finally, the other type of collaborative contract is the joint venture (JV). This involves the creation of an entity that embraces two or more firms that pool a portion of their resources in order to create a separate jointly owned organisation. As a technology transfer mechanism, a JV is likely to be effective as the technology owner has an incentive to ensure that the underlying tacit knowledge is effectively transferred (Stern 2006). Among these joint ventures, the Chinese capital usually comes from the private sector rather than state-owned enterprises.

Despite the operation of these different technology transfer mechanisms, and the significant building of manufacturing capabilities in wind power in China, there are still notable 'gaps' between Chinese manufacturers and the world advanced level. To narrow these gaps, some Chinese firms are trying a new modality of technology transfer. For example, following India's Suzlon model, Goldwind has acquired Vensys in Germany to strengthen its R&D ability.

Appendix D: More efficient coal fired power generation

Zhang Xiaofeng

Background of coal fired power generation in China

The composition of power generation in China

At present, in the Chinese power generation industry, there are multiform types of power stations: coal-fired power, gas-fired power, hydropower, nuclear power, renewable power. Table D.1 shows that the total power generation in China increased from 621 TWh in 1990 to 3451 TWh in 2008, an increase driven by China's rapid economic development over the period. In 2008, hydropower contributed about 16% of total power generation. Nuclear and other power, such as wind and other renewable power, only accounted for less than 3% of total power generation. Coal-fired power generation contributed by far the largest share at about 81% of the total. This reliance on coal-fired power in China is unlikely to change significantly for many years.

Table D.1: The composition of power generation in China⁸²

Electricity Generation			1990	2000	2008	2009 ⁸³	
1	Hydropower	TWh	126	243	566	572	
		%	20.3	17.8	16.4	15.5	
2	Coal-fired	TWh	495	1108	2803	3012*	
		%	79.7	81.0	81.2	81.8	
3	Gas-fired	TWh	-	-	-	*	
		%	-	-	-	*	
4	Nuclear	TWh	-	16.7	69.4	70.0	
		%	-	1.2	2.0	1.9	
5	Other	TWh	-	0.7	13.1	27.8	
		%	-	0.05	0.38	-	
Total			TWh	621	1368	3451	3681

Note: * 3012 TWh is all the electricity generation by thermal power, including coal, gas and oil-fired.

The efficiency of power generation in China

With the development of technology in China, the efficiency of coal-fired power generation has been improving over the period 1990-2009 (see Table D.2). These figures suggest that efficiency of coal-fired generation increased by about 25% over 20 years, and the average coal consumption declined by 87 g/kWh from 1990 to

⁸² International Energy & Electric Power Statistics. State Grid Corporation of China, 2009.

⁸³ Preliminary Statistics of Electric Power Industry in 2009, 2010.

2009. If the figures are correct then the improvement in efficiency has saved China significant levels of energy resources.

Table D.2: Coal consumption in China⁸⁴

Year	Coal consumption (g/kWh)	Efficiency (using actual coal consumption) (%)
1990	427	28.8
1995	412	29.8
2000	392	31.3
2005	370	33.2
2008	345	35.6
2009	340	36.1

The environmental impact of coal fired power generation in China

The continuing discharge of pollutants from large numbers of coal-fired power plants is causing serious environmental problems (WCI 2005; IEA 2005). The pollutants mainly include sulphur dioxide (SO₂), oxides of nitrogen (NO_x), particulates, trace elements and carbon dioxide (CO₂). SO₂ is produced from the combustion of the sulphur contained in many coals, and its emission can lead to acid rain and acidic aerosols (extremely fine airborne particles). Oxides of nitrogen are formed from the combustion process where air is used and/or where nitrogen is present in the fuel. They can contribute to smog, ground level ozone, acid rain and greenhouse gas emissions. Particulates emitted as ash from coal combustion can affect people's respiratory systems, impact local visibility and cause dust problems. Trace element emissions from coal-fired power stations include mercury, selenium and arsenic. They can be harmful to the environment and to human health. Carbon dioxide is a significant greenhouse gas, which contributes to global warming and climate change.

The structure of coal fired power generation in China

Also, the structure of coal fired power generation should be mentioned here. It is reported that, ten years ago, the major units of coal-fired power plants were in the range 100 MW to 200 MW, while now they tend to be in the range 300 MW to 600 MW. But the average capacity per unit was only about 50 MW in 2004. This suggests that there were many small coal-fired power units in China. The capacity of large-scale supercritical coal-fired units accounted for only about 4.3% of the total in 2004⁸⁵. The average coal combustion efficiency in China is lower than international advanced levels, but it is difficult to raise this average simply by installing a few highly efficient large units if the vast majority of coal-fired plants are small. In an attempt to change this situation, the government introduced strict regulation to close down the small coal-fired power plants. In the Eleventh Five-Year Plan, it is

⁸⁴ International Energy & Electric Power Statistics. State Grid Corporation of China, 2009.

⁸⁵ Mi J. H. Analyse of influence factor of power generation efficiency. Management of Chinese Power Corporation, 2006.

suggested that a total of 50 GW of small coal-fired power plants will be closed. The National Energy Administration (NEA) of China announced that small power plants accounting for a total capacity of 25.87 GW were closed by the end of June 2008⁸⁶. It is also reported that small power plants accounting for a total capacity of 64.17 GW were closed by the end of May 2010⁸⁷. The Twelfth Five-Year Plan, due to be published by the end of 2010, is expected to announce the new target for the shutdown of small coal-fired power plants.

Overview of cleaner technologies in coal-fired power plants in China

With worldwide attention to climate change and greenhouse gas (GHG) control, China also has taken actions to try to control GHG emissions from the power sector, which is considered the biggest source of CO₂ emissions. For the whole energy sector, the Chinese government announced that the proportion of energy from non-fossil fuel to the total energy will be increased to about 15% by 2020. Chinese companies are aggressively competing with each other to exploit wind, nuclear, solar, and bioenergy, among others.

In the coal-fired power industry, there is a two-pronged strategy. On the one hand, Chinese companies are actively adopting highly efficient coal-fired power generation technologies, such as supercritical and ultra-supercritical plants, IGCC and other efficiency improving technologies (see later for a discussion of these technologies). On the other hand, Chinese companies have constructed some demonstration projects for CO₂ capture. The first CO₂ capture demonstration project in China was put into operation at China Huaneng Group's Beijing thermal power plant in July 2008, which has 3000 tonnes per year CO₂ capture capacity (Xu and Gao 2009). Then, Huaneng Group operated the second CO₂ capture demonstration at Shanghai in December 2009, which has 120,000 tonnes per year CO₂ capture capacity. And China Power Investment Corporation operated a CO₂ capture demonstration having 10,000 tonnes per year CO₂ capture capacity at Chongqing in January 2010⁸⁸.

Overview of the market for highly efficient coal fired power generation technologies in China

From the available information, we can see that the Chinese government, Chinese companies, and many foreign firms, are investing in highly efficient coal-fired power generation technologies. At present, the major market for highly efficient coal-fired power generation is ultra-supercritical technologies, although there is also interest in various efficiency improving technologies for old and new coal-fired power plants. Chinese power companies are adopting ultra-supercritical coal-fired power technologies. They are also adopting various measures to improve efficiency, not only for old plants but also for new building plant. It is reported that the most highly efficient coal fired power plant in China uses 282 grammes of coal per kWh (at 75%

⁸⁶ National Energy Administration of China: http://nyj.ndrc.gov.cn/sdyx/t20080714_224054.htm

⁸⁷ China Energy News: <http://www.cnenergy.org/d270314747.htm>

⁸⁸ The Public Weather Service Center.
<http://www.weather.com.cn/static/html/article/20100302/198065.shtml>

capacity and with De-SO₂ and De-NO_x equipment in operation⁸⁹. Compared with the above technologies, IGCC and CCS for highly efficient coal-fired power generation only account for a small market share. Indeed, these two technologies are still in research and demonstration stages.

Highly efficient coal-fired power generation technologies

A range of advanced technologies has been developed, and continues to be enhanced, to improve coal power plant efficiencies. Three main technologies for coal fired power generation will be discussed.

Supercritical and ultra-supercritical power generation technology

Pulverised coal (PC) plants use boilers to produce steam, which drives turbines to produce electricity. In its current form, this technology has been in use for over 50 years and continues to be improved. PC technology has progressed from subcritical to supercritical to the latest ultra-supercritical boilers; this is a designation that refers to the temperature and pressure of the steam, with higher values bringing higher efficiencies. As power plant conversion efficiencies increase, the amount of coal inputted and CO₂ emitted per unit of electricity generated declines.

Typical subcritical PC plants have thermal efficiencies of 33-37% (based on higher heating value of the fuel, 33-37 percent of the energy stored in the fuel is converted to electricity) and operate at temperatures up to 550 °C and typical steam pressures of 16-19 MPa. Supercritical PC plants can achieve efficiencies of 37-42% at temperatures and pressures of 565 °C and 24 MPa, while ultra-supercritical PC plants are capable of 42-45% energy conversion at 600-615 °C and 32 MPa (AEF 2009). In most countries supercritical plant is now commercial, with capital costs only slightly higher than those of conventional plant and significantly lower unit fuel costs because of the increased efficiency and, in many cases, higher plant availability (Song 2002).

Table D.3: The typical parameters of a PC power plant

Type of PC	temperature (°C)	Pressures (MPa)	Efficiencies (%)
Subcritical PC	550	16-19	33-37
Supercritical PC	565	24	37-42
Ultra-supercritical PC	600-615	32	42-45

Integrated gasification combined cycle (IGCC)

In integrated gasification combined cycle (IGCC) systems, coal is not combusted directly, but reacted with oxygen and steam to produce a 'syngas' composed mainly of hydrogen and carbon monoxide. The syngas is cleaned of impurities and then

⁸⁹ Information from 2010 conference on supercritical & ultra-supercritical power generation technology in China.

burned in a gas turbine to generate electricity and to produce steam for a steam power cycle. And the separation of oxygen from air at the front end creates a gas stream without nitrogen and leads to smaller and lower-cost plant components. Thus, for capture plants, there is no nitrogen to separate from the CO₂. IGCC technology offers high efficiency levels; typically the designed efficiency is in the mid-40s, and as much as 95-99% of NO_x and SO₂ emissions are removed.

The further development and support of IGCC offers the prospect of net efficiencies of 56% in the future, and therefore its widening deployment will have an increasingly favourable impact on the environmental performance of coal. IGCC technology may also be chosen as pathway for the ultra low emissions system of the future, using carbon capture and storage technology (WCI 2005).

Optimisation of boiler combustion

The theoretical efficiency cap is defined by steam parameters designed before the construction of a power plant. Therefore, the major approach to get high power generation efficiency is through the above mentioned technologies. Although the efficiency cap is fixed for the older power stations under operation, there are many technologies for improving their actual efficiency, such as better operating conditions, good control strategies, and adjustment of equipment⁹⁰, according to the particular characteristics of the older power plants.

Optimisation of boiler combustion is one of the efficiency improving and environment favouring technologies for older power plants. Combustion is a complex chemical process, and there is no such thing as 'complete' combustion. In a typical furnace, poor and inefficient combustion results from uneven flow and temperature distribution across the furnace and higher levels of unburned carbon. Optimising combustion conditions is achieved by means of a better combustor to optimise primary and secondary air, together with the use of pulverised coal. This combination gives better combustion conditions so that the coal is fully burned, reducing the loss of fuel. This also raises the efficiency and lowers the emissions of the boiler.

Technologies in advanced countries

Supercritical and ultra-supercritical PC

After half a century of research, development and improvement, supercritical and ultra-supercritical PC technologies are mature, becoming commercialised. The countries which own the best technology of supercritical and ultra-supercritical PC, are Germany, Japan and France.

Siemens⁹¹, a German corporation, enjoy an 18% market share of worldwide steam power plant installed capacity. The company claims to be able to supply coal-fired power plant in the range of 300 MW to 1000 MW with subcritical, supercritical and

⁹⁰ Zhao J. X., Lin Y. Discussion on countermeasures of energy-saving and decreasing pollution in Power Plant. Shandong Dianli Jishu, 2009.

⁹¹ Siemens: <http://www.energy.siemens.com>

ultra-supercritical steam parameters.

Hitachi⁹², a Japanese firm, claims it can supply all the equipment for a fossil power plant: boiler, turbine, generator, and so on. The company claims that it has supplied 194 plants using supercritical or ultra-supercritical boilers of 75 MW or larger.

Alstom⁹³, a French company, pioneered supercritical and ultra-supercritical steam technology and claims to still be a world leader. It also claims to have a 25% share of the worldwide installed base, having directly installed 80 GW and licensed a further 134 GW of capacity.

IGCC technology

IGCC technology has comprehensive advantages for coal-fired power generation, such as higher efficiency, lower emissions, is water-saving, and easier for CO₂ control and capture. Although IGCC technology for coal is not mature compared to ultra-supercritical technology, there are some IGCC demonstration power plants operating in OECD countries such as the US, Netherlands and Japan.

GE⁹⁴, an American corporation, offers IGCC power plant. It claims to have been at the forefront of IGCC technology since the beginning and that it has supplied plant to installations since 1984.

Shell⁹⁵, a Dutch firm, started gasification research in the 1950s and claims that its technology can be adapted to use coal of varying qualities. The company also claims that it has sold 27 licenses around the world.

Mitsubishi Heavy Industries (MHI)⁹⁶, a Japanese company, has its own IGCC system. The company claims that its IGCC technology will become commercialised in the near future.

Optimising boiler combustion

Optimizing boiler combustion conditions, as noted above, can result in higher efficiency and lower emissions in coal-fired power plants. So, combustion optimisation technology has been researched and developed in advanced countries such as the US and Japan.

Babcock & Wilcox (B&W)⁹⁷, an American company, claims to have sold more than 120 GW of low NO_x combustion systems (more than 8,000 burners) in both new and retrofit boiler applications since 1971. It further claims that its low NO_x burner technology has been successfully applied to a broad range of its own and non-B&W units with varying fuel characteristics and boiler arrangements.

⁹² Hitachi: <http://www.bhk.co.jp/english/>

⁹³ Alstom: <http://www.power.alstom.com/home/>

⁹⁴ GE: <http://www.gepower.com>

⁹⁵ Shell: <http://www.shell.com/home/content/innovation>

⁹⁶ Mitsubishi Heavy Industries: <http://www.mhi.co.jp/en/products/index.html>

⁹⁷ The Babcock & Wilcox Company: <http://www.babcock.com/products/>

Babcock-Hitachi K.K.⁹⁸, a Japanese company, claims to have developed a unique low-NO_x burner system for pulverised coal combustion. This, the company says, can further reduce NO_x emissions, improve combustion efficiency and is easy to maintain.

Technologies in China

Supercritical and ultra-supercritical PC

In China, supercritical coal-fired power generation technology was first used in Huaneng Shanghai Shidongkou power plant in the early 1990s. Ultra-supercritical coal-fired power generation technology was first applied in Huaneng Yuhuan power plant in 2006 (Fan and Wu 2009). By the end of June of 2009, there were 23 ultra-supercritical coal-fired power plants in operation. And there were more than one hundred orders of ultra-supercritical units from Chinese power companies (Tang, Dong and Zhao 2010). The 700 °C ultra-supercritical technologies R&D alliance of Chinese companies and research institutes came into existence in 2010⁹⁹.

But, when compared to the leading companies and advanced countries listed above, China still has a significant capability gap in the ultra-supercritical technology. The core design software of ultra-supercritical PC has not been mastered by Chinese firms. The leading foreign companies have the IPRs for the design methods. Chinese firms, such as Shanghai, Harbin, Dongfang and other power equipment manufacturers design supercritical and ultra-supercritical PC while collaborating with the leading foreign companies such as Siemens, Hitachi and Alstom. Moreover, the high temperature components need to be imported from the advanced countries because of the weakness of research and development in this field in China (Song 2009). The special steel materials for high temperature use in supercritical and ultra-supercritical units were imported from foreign steel companies several years ago. Even now there are many major parts that need special steel which has to be imported.

IGCC technology

In China, IGCC technology is another attractive choice for future coal-fired power generation. China Huaneng Group has a 250 MW IGCC demonstration power plant under construction in Tianjin. Chinese firms have the capabilities to provide exhaust-heat boilers, air separation units, steam turbines, and so forth for IGCC power plants. Moreover, some local research institutes have developed coal gasifiers, a key piece of equipment for IGCC plant, and now own the intellectual property rights. In 2009, a coal gasifier technology owned by a Chinese institute was exported to the US market after international competition¹⁰⁰.

But, Chinese firms still face a huge gap in IGCC technology when compared to the leading companies, especially concerning the large scale syngas turbine technology.

⁹⁸ Babcock-Hitachi K.K.: <http://www.bhk.co.jp/english/energy/boiler-e/nox/index.html>

⁹⁹ See http://www.cpn.com.cn/szyw/201008/t20100804_324733.htm

¹⁰⁰ Xinhua net: http://news.xinhuanet.com/energy/2009-07/15/content_11712068.htm

The large scale syngas turbine still needs to be imported from the above mentioned leading companies. However, Chinese firms are learning the crucial technology of syngas turbines through cooperation with leading companies. Beyond this, they are also learning through independent research, development and demonstration activities. One example Chinese firm is Nanjing Turbine & Electric Machinery Group, an important company on the research and manufacture of gas turbines for natural gas and syngas¹⁰¹.

Optimising boiler combustion

In China, boiler combustion optimisation technology has also been researched and developed by some institutes and universities, such as Harbin Institute of Technology. The burner subsequently developed (which also has its own intellectual property rights) was adopted by some coal-fired power plants for increasing efficiency and reducing NO_x (Qin, Li et al. 2002; Chen, Li et al. 2005; Zhou, Zhao et al. 2005). But, the boiler combustion optimisation technology still has significant differences when compared to the leading foreign technologies. In recent years, foreign combustion technology has been widely used in new power plant construction, being directly imported from the leading companies, or being provided by local manufacturers having formed joint-ventures with those same leading companies (Fan 2006). Therefore, even though the locally designed burner noted above marks an important achievement in the development of Chinese capabilities, it is likely only to account for a small share of the market.

¹⁰¹ Nanjing Turbine & Electric Machinery Group: <http://www.ntcchina.com/website/cn/index.aspx>

Appendix E: Sample interview questionnaires

Interviews in China

Cleaner coal power sector (companies)

1. Can you briefly describe your company (kind of property, date of creation, number of employees, number of plants, annual power production, annual sales, market share)?
2. **(Question 2 only if the company owns also power plants different from coal ones)** Can you briefly describe the coal sector of your company (number of employees, number of plants, annual power production, annual sales, market share, share confronted to your other sources)?
3. Have you already introduced processes to reduce carbon emissions in your already existing coal power plants? **(If yes go to question 4, if no go to question 23)**
4. When and why have you decided to reduce carbon emissions in your already existing coal power plants?
5. Which kind of technology/technologies have you adopted to reduce carbon emissions in your already existing coal power plants?
6. Have you received any financial sustain for adopting this/these technology/technologies? **(If no go to question 9)**
7. If yes which kind of financial sustain (national public funds, international public funds, fiscal facilities, special loans, special grants, CDM, other to specify)?
8. Would you have adopted the technology/technologies even without the subsidy?
9. Which is the nature this/these technology/technologies (foreign or local)? **(If foreign go to question 10, if local go to question 14)**
10. Why have you decided to adopt a foreign technology?
11. How did you acquire the foreign technology (patents licensing, joint venture, foreign company acquisition, collaborative research and development)?
12. Which have been the most relevant problems in acquiring foreign technologies (cost of IPRs, accessibility to IPRs, difficulties in developing joint ventures, legislative limits, administrative limits, lack of know-how and/or technological knowledge)?
13. Are you planning to further develop carbon emissions activities in your already existing coal power plants in the future? If yes which will be the nature of these activities? If no why? **(Go to question 29)**
14. **(From question 14 to question 19 only for those who answered 'local' to question 9).** Why you decided to adopt local technology?
15. How did you acquire the technology (patents licensing, joint venture, company control acquisition, collaborative research and development, internal research and development, agreements with Chinese research centres)?
16. Which have been the most relevant problems in acquiring the technologies?

17. Do you think that Chinese technologies' state-of-the-art for emissions reductions for already existing power plants is comparable with international best practices?
18. Which are the main reasons why you did not adopt foreign technologies?
19. Are you planning to further develop carbon emissions activities in your already existing coal power plants in the future? If yes which will be the nature of these activities? If no why? (**Go to question 29**)
20. (**From question 20 to question 28 only for those who answered 'no' to question 3**). Which are the reasons why you have not yet introduced processes to reduce carbon emissions in your already existing coal power plants?
21. Are you planning to adopt this kind of processes in the future? (**If yes go to question 22, if no go to question 27**).
22. Which kind of technologies are you planning to adopt, and why are you choosing these technologies?
23. Are they Chinese or foreign technologies?
24. Are you planning to obtain financial helps for the technologies' adoption?
25. If yes which kind of financial helps (national public funds, international public funds, fiscal facilities, special loans, CDM, other to specify)?
26. Which are the biggest limits and problems for adopting these technologies? (**Go to question 29**)
27. (**From question 27 to question 28 only for those who answered 'no' to question 21**). Which are the reasons why you are not planning to adopt processes to reduce carbon emissions in your already existing coal power plants?
28. Which are the biggest limits and problems for adopting these processes? (**Go to question 29**)
29. Are you planning to close part of your old coal power plants? If yes which factors that made you choose this option?
30. Are you building/planning to build new coal power plants? (**If yes go to question 31, if no go to question 40**)
31. Are you adopting/planning to adopt technologies and processes to reduce carbon emissions in your new power plants? (**If yes go to question 32, if no go to question 41**)
32. Which kind of technologies are you adopting/planning to adopt? Why?
33. Are they local or foreign technologies?
34. How have you acquired / are you planning to acquire these technologies (patents licensing, joint venture, company control acquisition, collaborative research and development, internal research and development, agreements with research centres and universities)?
35. Which have been / can be the most relevant problems in acquiring the technologies?
36. Do you think that Chinese technologies' state-of-the-art for emissions reductions in new coal power plants is comparable with international best practices?

37. Have you obtained / are you planning to obtain financial sustain for the technologies' adoption?
38. If yes which kind of financial sustain (national public funds, international public funds, fiscal facilities, special loans, CDM, other to specify)?
39. Are you planning to introduce CCS in your power plants? If no why? If yes why and in which ways? (**Go to question 42**)
40. Why you decided not to build new coal power plants? (**Go to question 42**)
41. Why have you decided not to adopt technologies and processes to reduce carbon emissions in your new power plants? (**Go to question 42**)
42. Which kind of actions, policies, regulations, activities should be followed at national level to facilitate the adoption of low carbon technologies in your sector?
43. Which kind of actions, policies, regulations, activities should be followed at international level to facilitate the adoption of low carbon technologies in your sector?

International interviews

Questions for cleaner coal power sector

Particularly in regard to the experience of UK firms in China, we are interested in the following:

1. The frontier technologies for cleaner coal-fired power generation, the world leading firms, and the state of capabilities of Chinese firms.
 - a. What are the frontier technologies for cleaner coal-fired power generation and, if any of these are designed or manufactured by UK firms, which UK firms and what technologies?
 - b. What is the state of capabilities of Chinese firms in terms of being able to design or manufacture these frontier technologies, or in what ways can any 'gap' between Chinese capabilities and the capabilities needed for the frontier technologies be described?
2. How Chinese firms are 'catching up' in terms of building the necessary capabilities around cleaner coal-fired power generation technologies.
 - a. What is the role of international collaboration and/or 'technology transfer' in developing Chinese firms' capabilities to design and manufacture cleaner coal-fired power generation technologies? (e.g. licensing, joint ventures, takeovers, access to IPRs, etc.)?
 - b. What is the experience of UK firms in these processes?
3. The ways in which policies have been used in China to foster 'catching up', and any links there may be to the UK policy environment.
 - a. In what ways has China used policy to encourage (or discourage) foreign involvement in building capabilities around cleaner coal-fired power generation technologies in Chinese firms?

- b. In what ways has the UK (at government or firm/industry level) used policy to encourage (or discourage) UK firms to collaborate with Chinese firms in building capabilities around cleaner coal-fired power generation technologies?

Appendix F: Individuals and organisations interviewed

Name	Role and/or affiliation
(Anonymous)	Henan Tongli Cement Co. Ltd.
(Anonymous)	Huainan Shunyue Cement Co. Ltd.
Alessandro Costa	Director of the Sino-European Centre for Clean Energy Technology Transfer
Carlo Ferrara	Head of Carbon Strategy Development in China for ENEL – Italy
Catherine Hutt	Business Development Manager - Electric Vehicles, Society of Motor Manufacturers and Traders, London
Dr. LIN Chengtao	Assistant Professor of Department of Automotive Engineering
Duan Maosheng	Professor at the Institute of Nuclear and New Energy Technology – Tsinghua University
Fei Teng	Professor at the Institute of Nuclear and New Energy Technology – Tsinghua University
Hao Ming	Vice Dean of the University for International Relations, Beijing
Les Parfitt	China Market Specialist, Society of Motor Manufacturers and Traders, London
LI Junfeng	Deputy Director-General of the Energy Research Institute of NDRC & Director of the China Renewable Energy Industry Association
Lin Shaohong	Deputy Chief Engineer of China Strategy Institute of Building Materials
Liu Jinze	Vice Director of Climate Change Capital China
Massimiliano Varruciu	Director of EDF Trading China
Mr. Chen	Senior Engineer of a Chinese state power company
Mr. Wu	Senior Engineer of a Chinese state power company
Prof. Dr. Ernst Worrell	Professor Energy, Resources & Technological Change, University of Utrecht
Prof. GAO Chao	President of China Tex Mechanical and Electrical Engineering Ltd., Beijing
Prof. Julia King	Vice-Chancellor of Aston University, Birmingham
Qian Yiwen	Managing Director of Carbon Resource Management
Quiang Liu	Vice-Director of the Energy Research Institute (NDRC)
SHI Lei	Deputy Manager-General of Goldwind Company, Dafeng Office
SHI Pengfei	Deputy Director of Wind Energy Sector of China Renewable Energy Association
Steve Sawyer	Secretary General, Global Wind Energy Council
WANG Wei	Research Associate in Sino-Danish Renewable Energy Development Program

YU Zhenhua
Zeng Xuemin
Zheng Xipeng

Zhou Sheng

President of Prudent Energy Technology Co. Ltd, Beijing
Vice President of China Cement Association
Four years in DATANG (energy SOE) now working for a
financial corporation specialised in energy investments
Professor at the Institute of Energy Environment and
Economy – Tsinghua University

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