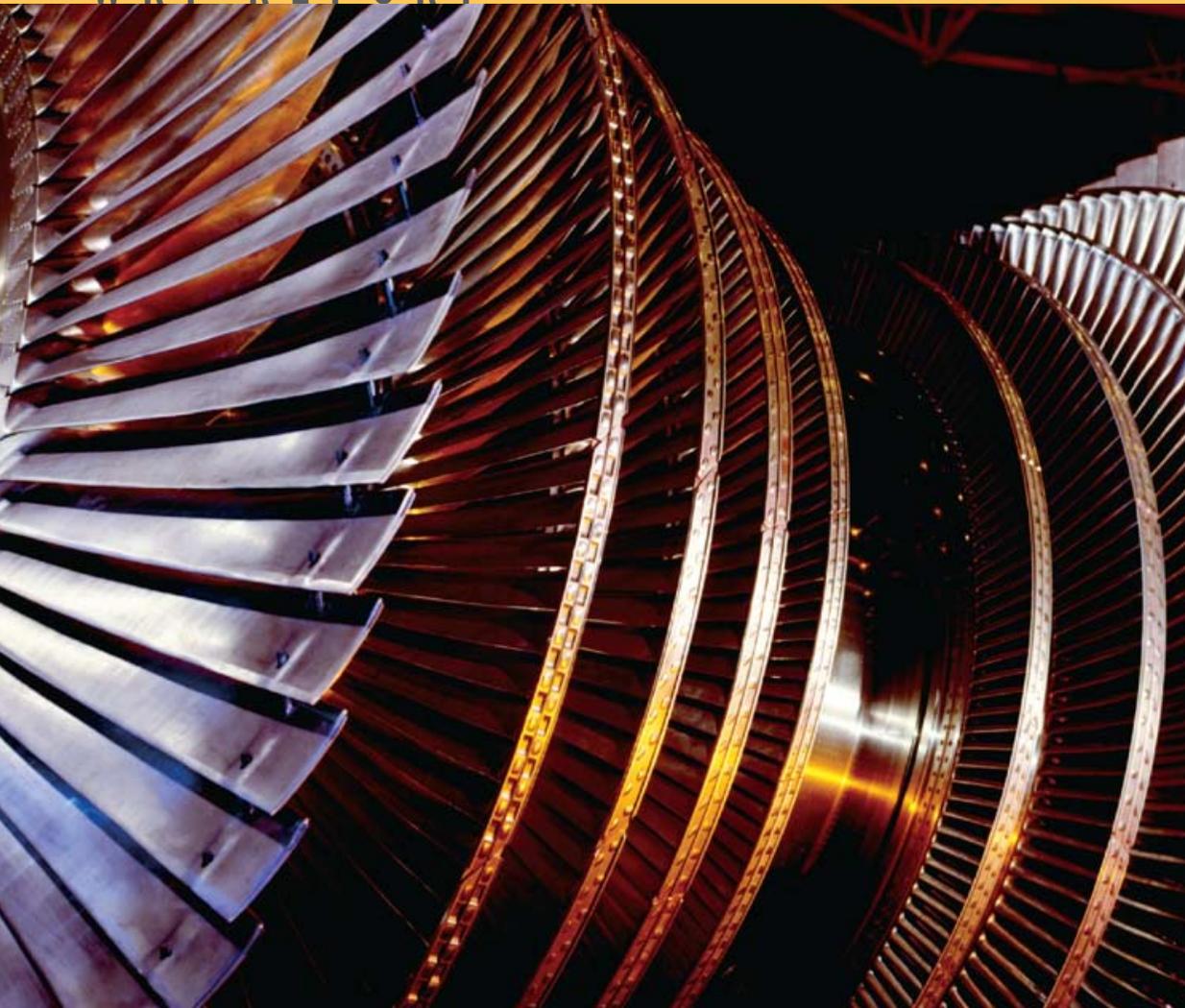


W R I R E P O R T



XIAOMEI TAN

DEBORAH SELIGSOHN

IN COLLABORATION WITH:

ZHANG XILIANG

HUO MOLIN

ZHANG JIHONG

YUE LI

LETHA TAWNEY

ROB BRADLEY

SCALING UP LOW-CARBON TECHNOLOGY DEPLOYMENT

Lessons from China



SCALING UP LOW-CARBON TECHNOLOGY DEPLOYMENT

Lessons from China

XIAOMEI TAN

DEBORAH SELIGSOHN

IN COLLABORATION WITH:

ZHANG XILIANG

HUO MOLIN

ZHANG JIHONG

YUE LI

LETHA TAWNEY

ROB BRADLEY



WORLD
RESOURCES
INSTITUTE

HYACINTH BILLINGS
Publications Director

DEVER DESIGNS
Design and Layout

COVER/TITLE PAGE IMAGE:

Getty Images

INTERIOR IMAGES:

Page vi: China National Development and Reform Commission

Page ix: Xiaomei Tan

Page 1: Siemens press picture, Siemens AG, Munich/Berlin

Page 2: Siemens press picture, Siemens AG, Munich/Berlin

Page 5: Siemens press picture, Siemens AG, Munich/Berlin

Page 11: Ryan Pyle

Page 19: Weifang Special Steel Group Co. Ltd

Page 26: Xinhua News Agency

Page 29: Xinhua News Agency

Each World Resources Institute report represents a timely, scholarly treatment of a subject of public concern. WRI takes responsibility for choosing the study topics and guaranteeing its authors and researchers freedom of inquiry. It also solicits and responds to the guidance of advisory panels and expert reviewers. Unless otherwise stated, however, all the interpretation and findings set forth in WRI publications are those of the authors.

Copyright © 2010 World Resources Institute. All rights reserved.

ISBN 978-1-56973-751-4

Printed in the United States of America on chlorine-free paper with recycled content of 50%,
15% of which is post-consumer.



Table of Contents

FOREWORD	iv
EXECUTIVE SUMMARY	v
ACKNOWLEDGMENTS	ix
ABBREVIATIONS	x
Chapter 1 INTRODUCTION	1
Chapter 2 SUPERCRITICAL AND ULTRASUPERCRITICAL COAL-FIRED POWER GENERATION	5
Technology overview	5
Where does China stand?	6
The life cycle of SC/USC technology adoption and localization in China	7
Chapter 3 ONSHORE WIND POWER	11
Technology overview	11
Where does China stand?	11
Wind energy technology transfer—barriers and drivers	14
Chapter 4 EFFICIENCY IN THE STEEL SECTOR	19
Technology overview	19
Where does China stand?	20
How was advanced efficiency technology transferred to and deployed in China?	20
Chapter 5 CONCLUSIONS	26
Findings	27
Key messages and lessons learned	28
REFERENCES	30
ENDNOTES	33
ABOUT THE AUTHORS	34

Foreword

Since Bronze Age man first crafted metal tools, technological progress has powered human civilization. Looking forward, it is expected to play a crucial role in tackling climate change, one of the biggest challenges of the twenty-first century. In line with this expectation, developing and deploying clean, low-carbon energy technologies is emerging as a key priority for governments, businesses, and intergovernmental organizations.

Traditionally the pace of technology deployment within low- and middle-income countries is slow. Technologies of all kinds invented between 1975 and 2000 and used across the industrialized world have reached the 50 percent deployment threshold in a mere 9 percent of developing countries, according to the World Bank. Clean energy technology deployment, in general, aligns with this disappointing trend.

In recent decades, however, China has broken free of the developing country slow innovation paradigm. The world's biggest developing country and largest gross emitter of greenhouse gases, has accelerated its low-carbon technology deployment at an astonishing pace. Fifteen years ago, China made its first purchase of supercritical coal-fired power generation technology from the United States; today China has the second highest diffusion rate of supercritical/ultrasupercritical coal technology in the world, behind the United States. Fourteen years ago, China initiated the "Riding the Wind Program" to import wind energy technology; today China's installed wind energy capacity ranks fourth in the world.

While China's experience is not entirely replicable due to its unique domestic circumstances, it provides relevant lessons on how other large developing countries can slow emissions growth by shifting to clean technologies to power economic development. With the developing world already responsible for around 50 percent of global greenhouse gases—a figure likely to rise to 65 percent by 2030—such containment efforts are critical to global efforts to stabilize emissions and prevent dangerous levels of warming.

Low-carbon technology developed in China should also produce lower-cost options for middle- and low-income countries than technology developed in the Western world, speeding deployment. This report, a collaboration between the World Resources Institute and Tsinghua University, examines how three low-carbon technologies have been successfully introduced, adapted, deployed, and diffused in China, with the aim of identifying scalable lessons.

Scaling Up Low-Carbon Technology Deployment: Lessons from China focuses on three energy technologies: super-

critical/ultrasupercritical (SC/USC) coal-fired power generation technology; onshore wind energy technology; and blast furnace top gas recovery turbine (TRT) technology in the steel sector. Collectively, these present diverse opportunities for future international deployment. If widely adopted, they could make a significant dent in global emissions of carbon dioxide, the main greenhouse gas.

The report does not endorse particular technologies or offer definitive, off-the-shelf solutions. Rather its aim is to illustrate how developing country governments can create a national technology deployment infrastructure that spurs effective, scaled-up and sustainable clean tech industries. Through in-depth case study analyses, the report identifies a number of key building blocks. These include: a comprehensive, long-term strategy to create domestic low-carbon technology markets; direct, substantial R&D funding to promote clean energy innovations; and national and sectoral laws, incentives, and regulations to scale up commercialization of low-carbon technologies and drive down costs.

While such ambitious efforts require significant human resources, time, and money, the reward is substantial. China's experiences to date indicate that crafting and implementing clean tech policies serves both its national economic interest and the global interest of reducing atmospheric greenhouse gas emissions. Despite sometimes tricky commercial and intellectual property issues, its booming clean tech sector has also generally benefited overseas technology companies engaging in joint ventures, licensing agreements, and other forms of collaboration with Chinese business.

Low-carbon technology deployment is only one piece of the puzzle that must be completed to contain climate change at manageable levels. Given the stalled state of international climate negotiations, however, individual country-initiated programs to deploy clean technology can play a critical role in curbing fossil fuel emissions. Developing domestic expertise in these industries can also help emerging nations capture a share in the low-carbon markets of the future. China is already heading down this path. The World Resources Institute hopes this report will encourage other emerging countries to follow suit.



JONATHAN LASH
President
World Resources Institute

Executive Summary

The low-carbon energy imperative

Among the issues domestic and international policy-makers must address in combating climate change is how to deploy and diffuse current low-carbon technologies in developing countries.

Developing countries, while bearing little responsibility for historical releases of greenhouse gases (GHG), now account for an increasingly large percentage of global atmospheric emissions. Today, they make up around 50 percent of emissions (CAIT 2005) and by 2030 this figure will rise to 65 percent (EIA 2009). Thus, without widespread deployment of low-carbon technologies in China, India, and beyond, global efforts to stabilize emissions and prevent dangerous levels of warming will be severely undermined.

Globally, while the pace of technology deployment has dramatically accelerated over recent decades, technology deployment within low- and middle-income countries remains slow. Only 30 percent of developing countries have reached the 25 percent penetration threshold and only 9 percent have reached the 50 percent threshold for technologies invented between 1975 and 2000 (Comin & Hobijn 2004). Low-carbon technology deployment generally aligns with this rule, with a few exceptions, notably China.

China's leadership and approaches

The speed and scale of technology deployment is highly correlated with income level. Despite being a lower-middle-income country, China has bucked this trend, boasting technological achievements greater than those of many high-income countries. In particular, China's government has poured money, R&D resources, and a combination of incentives and regulatory levers, into developing and deploying technologies in the cleaner energy (such as supercritical/ultrasupercritical coal-fired power generation), renewable energy, and energy efficiency sectors. It has also invested in a range of partnership models with overseas governments and companies, including joint ventures, licensing agreements, and joint design. As a result, China has transformed itself over the past two decades from a low-carbon technology importer to a major manufacturer of a number of low-carbon technologies.

Scaling Up Low-Carbon Technology Deployment: Lessons from China examines how low-carbon technologies have been introduced, adapted, deployed, and diffused in three greenhouse gas-intensive sectors in China. By focusing on

key policy and program drivers, the report identifies the building blocks for China's successful low-carbon technology deployment infrastructure. Its purpose is twofold: to draw lessons of use in informing broader international cooperation on technology transfer and deployment; and to help governments and industries in middle- and low-income countries to pursue an effective transition to a low-carbon economy.

Focus technologies

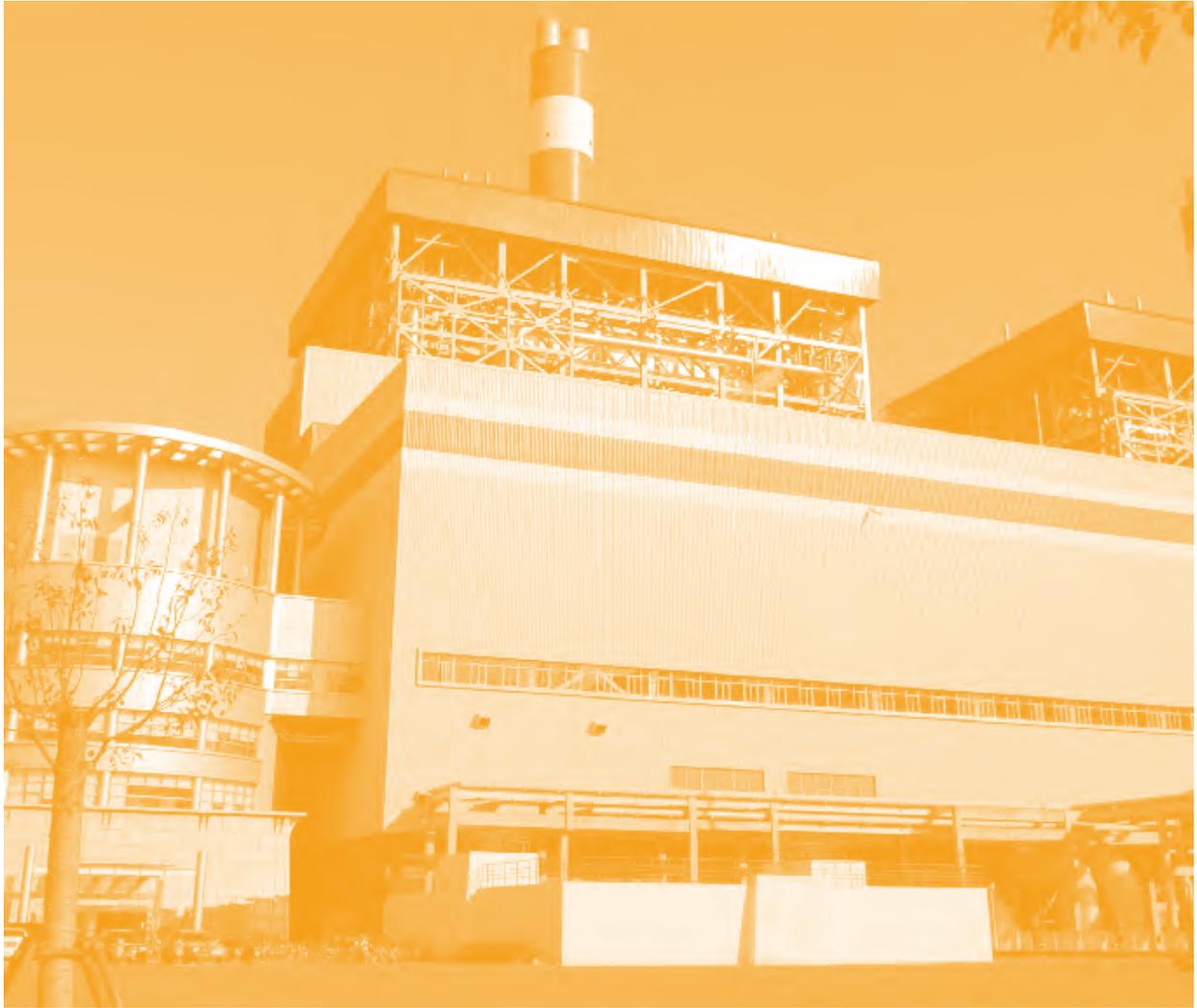
This report focuses on three energy technologies:

- supercritical/ultrasupercritical (SC/USC) coal-fired power generation technology;
- onshore wind energy technology; and
- blast furnace top gas recovery turbine (TRT) technology in the steel sector.

Why these particular technologies? First, all three if widely deployed could make a significant dent in emissions of carbon dioxide, the main greenhouse gas. As the power and steel sectors are major global energy consumers, efficiency improvement in these sectors entails large carbon dioxide reduction. Wind, the fastest growing renewable energy source, is the most likely renewable technology to capture a big share of the global electricity mix. Coal will likely remain a key global energy provider for decades to come. Second, these three technologies present diverse opportunities for future deployment both in China and internationally. Such diversity enables the lessons contained in this report to address issues across a broad spectrum of low-carbon technology deployment—thus maximizing its potential impact.

Key findings

- China has accelerated its low-carbon technology deployment in recent decades, making the transition from technology importer to major manufacturer of a number of low-carbon technologies. China has made comprehensive efforts to put in place the infrastructure to achieve accelerated deployment and diffusion of the three technologies examined in this report. This indicates its commitment to becoming a global player in the low-carbon economy, securing a domestic energy supply, and reducing carbon dioxide emissions.



- China's experience highlights the important role of effective domestic policy in stimulating low-carbon technology. While the government took different approaches for each of the three technologies examined in this report, its building blocks for technology deployment infrastructure include:
 1. Making a deliberate, holistic plan and long-term commitment to the localization of a low-carbon technology. This approach is taken in all three cases.
 2. Establishing direct R&D funding programs to support the launch and scale-up of low-carbon technology innovation. This approach is especially prominent in the case of SC/USC coal-fired power generation technology.
 3. Improving businesses' technological absorptive capacity through directly funding their technology learning. The success enjoyed by two leading Chinese clean energy companies—Goldwind's surge in the global wind market and Shanxi Glower Group's dominance of the domestic TRT market—are both indebted to this measure.
 4. Capitalizing on public-private and industry-academia synergies to bring together multi-sector expertise. The success of the localization of SC/USC in particular is built on such multi-sector synergies.
 5. Designing national-level and sector-wide laws, policies, and regulations to scale-up commercialization of low-carbon technology, create domestic markets, and drive down the costs. The rapid development of domestic wind energy greatly benefited from such a legal and regulatory infrastructure.

6. Relying on international cooperation to pursue new-to-market technology and knowledge. TRT technology's transfer and deployment resulted from China-Japan cooperation in the steel sector.

- China's ambitious localization process for low-carbon technology has raised concerns about intellectual property rights (IPR) within some foreign governments and among Organisation for Economic Co-operation and Development (OECD) companies. The case studies found the situation regarding technology transfer to be more complex, including issues related to ambiguous ownership and contractual arrangements as well as IPR. While our case studies show that some foreign firms have benefited significantly from China's low-carbon technology sector, both the SC/USC and TRT case studies reveal that while the Chinese government viewed these models as successful, international companies involved were less convinced. Our survey of multinationals involved in China's low-carbon technology sector also revealed that such firms typically do not transfer all parts of a technology to China, holding back some of their IPR. This approach addresses the international companies' concerns about IPR protection, but compared to an atmosphere of higher trust is suboptimal both for Chinese and overseas companies.

Conclusions and lessons learned

■ *For Chinese policymakers*

1. China's comprehensive efforts to put in place the infrastructure to achieve accelerated deployment and diffusion of low-carbon technology has been very successful in the three technologies examined in this report. Within 20 years, China emerged from a technology importer to a major manufacturer of low-carbon technology. If the same level of effort continues, China could soon be a player at the forefront of low-carbon energy technology innovation. However, underlying China's success are some concerns that need to be addressed.
2. China's preoccupation with localizing key energy technologies may be viewed by foreign companies and governments as going against standard international business practices, such as relying on trade to acquire technologies. The global wind industry, for example, is a globally integrated industry. China's ambition to localize key wind energy technologies, such as bearing and electric controls, leaves China outside the global integration process—a process that can be harnessed to reduce the cost of wind technologies by increasing economies of scale, fostering competition, and encouraging innovation (Kirkegaard et al. 2009).

3. In spite of the national government's effective technology deployment policy, China has not yet addressed the pressing issue of deployment of low-quality technologies. The low entry barrier for domestic wind energy developers highlighted by the wind case study, in particular, underscores the importance of setting high technology standards at the beginning of technology deployment.
4. China's business sector still has lessons to learn in conducting international business negotiations. On the one hand we see government-managed processes in the coal and steel sectors that—while effective—may have left some legacy of distrust; on the other hand we see the hyper-competitiveness of the wind industry with its minimal barriers to entry. Nurturing a more sophisticated domestic business sector through market means is a key task for Chinese policymakers seeking to minimize costs and barriers and maximize trust and cooperation so as to scale-up low-carbon energy industries.

■ *For U.S. policymakers*

1. China's ambition is to emerge as a global science and technology power and Beijing is keenly aware that the next phase of the science and technology revolution will likely center on low-carbon technology. While the term "indigenous innovation" has been interpreted in international policy circles as encompassing a very narrow group of government procurement policies, in fact, the policies are much more ambitious and involve the kinds of long-term support for RD&D that are detailed in these three case studies.
2. There are major business opportunities for U.S. companies in China's low-carbon technology deployment efforts. The success of Japanese and German companies in the wind and power sectors indicates that through joint venture, licensing, or joint design, foreign technology providers can benefit from China's financial resources, manufacturing capacity, and enormous market. While China's ambitious localization process for low-carbon technology has raised concerns about intellectual property rights in some foreign governments and among OECD companies, major multinationals surveyed as part of the study did not view IPR as a major issue. In the three case studies, the issue was somewhat more ambiguous. There did not appear to be any outright IPR violation, but instead different perceptions of ownership and contracts have colored some of the arrangements.

3. China's experience highlights the importance of effective domestic policy and long-term government commitment. Without clear and lasting signals from the government and a central role for government-funded R&D, the market will not automatically embrace low-carbon technology.

■ ***For technology providers***

China's preference for domestically manufactured technologies can present a competitive risk for foreign companies seeking a foothold in China. However, in practice, depending on the technology investors' own conditions and needs, foreign technology providers can make a profit through various approaches, including:

1. **Joint venture:** Benefits include easy access to the Chinese market and freedom for foreign companies to use their own business model to sell products. One disadvantage is the possibility of leaking intellectual property rights to local partners. Because of this drawback, many joint-venture companies in China act as manufacturers or post-sale maintenance facilities instead of technology developers.
2. **Licensing:** Its benefit is guaranteed patent fees and royalties free of concerns about the technology users' business model. The disadvantage is that China's exports might swamp the marketplace and the patent owners receive only a small portion of the profit, usually from 3–6 percent of profits.

3. **Joint design:** If technology providers lack manufacturing capacity and financial resources, joint design offers good access to China's financial capital and enormous market. The drawback is that in most cases all patent rights are lost to the Chinese partner companies.

4. **Wholly foreign-owned investment:** Benefits include freedom for foreign investors to use their own business models and easy access to China's large skilled and relatively inexpensive labor force. For China this is a mechanism for training up a workforce in new technologies and related services. The disadvantage for the foreign company is that the Chinese government and scholars do not view wholly foreign-owned investment as a technology transfer mechanism. Therefore the foreign investors are less likely to receive administrative or financial support from the Chinese government.

■ ***For other countries who are adapting technology***

Other countries might lack the tremendous scale of resources for domestic investment in R&D that China can bring to bear, but China's experience demonstrates some clear successes from which other countries can benefit. These include: the active role of the government in pursuing bilateral engagement internationally (in the case of steel); the importance of providing clear and lasting policy signals for clean energy markets (in the case of wind); and the central role that government-funded R&D can play (as illustrated by the localization of all three technologies).

Acknowledgments

The report has been greatly assisted by WRI's review and editing team, Janet Ranganathan and Polly Ghazi. The authors would like to convey their deep appreciation for their guidance and help throughout the process.

The report also benefited enormously from peer review. We gratefully acknowledge input from the following reviewers: Jennifer Morgan, Ruth Greenspan Bell, Dennis Tirpak, Sarah Forbes, Alex Perera, Joanna Lewis, David Pumphrey, Julian Wong, Wang Ke, Qingyun Sun, and Kelly Gallagher.

We also benefited from the editing, design, and production support provided by Jennie Hommel, Hyacinth Billings, Natalie Bushell, and Greg Fuhs.

Finally, without financial support, this report would not have been possible. We are therefore deeply grateful for the support of the British Foreign & Commonwealth Office and the Doris Duke Charitable Foundation.



Abbreviations

<i>ACEG</i>	AVIC Chengdu Engine Group
<i>BPRT</i>	Blast furnace power recovery turbine
<i>CCS</i>	Carbon capture and storage
<i>CE</i>	Combustion engineering company
<i>CISA</i>	China Iron & Steel Association
<i>CMIF</i>	China Machinery Industry Federation
<i>DEC</i>	Dongfang Electric Corporation
<i>ETC</i>	Economic and Trade Commission, China
<i>FDI</i>	Foreign direct investment
<i>GAP</i>	Green Aid Plan
<i>GHG</i>	Greenhouse gas
<i>Goldwind</i>	Goldwind Science and Technology Company
<i>HEC</i>	Harbin Electric Corporation
<i>IGCC</i>	Integrated gasification combined cycle
<i>IPR</i>	Intellectual property rights
<i>JISF</i>	Japanese Iron and Steel Federation
<i>METI</i>	Ministry of Economy, Trade, and Industry, Japan
<i>MIIT</i>	Ministry of Industry and Information Technology, China
<i>MMI</i>	Ministry of Metallurgical Industry, China
<i>MOF</i>	Ministry of Finance, China
<i>MOST</i>	Ministry of Science and Technology, China
<i>NDRC</i>	National Development and Reform Commission, China
<i>NGCC</i>	Natural gas combined cycle
<i>OECD</i>	Organisation for Economic Co-operation and Development
<i>R&D</i>	Research and development
<i>RD&D</i>	Research, development, and deployment
<i>SAMI</i>	State Administration of Machinery Industry, China
<i>SC/USC</i>	Supercritical/ultrasupercritical
<i>SDPC</i>	State Development and Planning Commission, China
<i>SEG</i>	Shanghai Electric Group
<i>SETC</i>	State Economics and Trade Commission, China
<i>SGG</i>	Shanxi Glower Group
<i>SOE</i>	State-owned enterprise
<i>SPC</i>	State Power Corporation
<i>TRT</i>	Blast Furnace Top Gas Recovery Turbine Unit
<i>VAT</i>	Value added tax
<i>XAR</i>	Xinjiang Autonomous Region
<i>863 program</i>	National High-tech R&D Program
<i>973 program</i>	National Basic Research Program



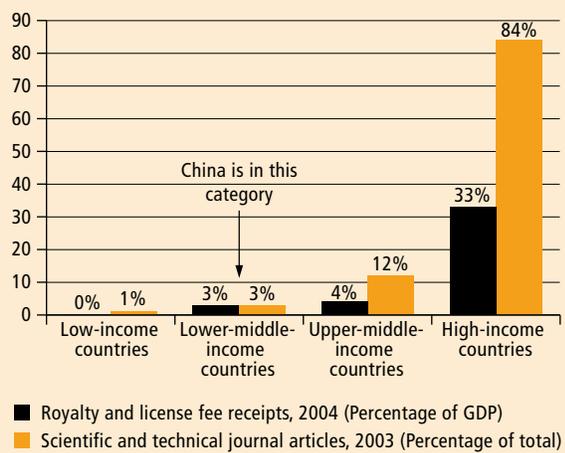
Introduction

IN CONTEXT: GLOBAL TECHNOLOGY INNOVATION AND DEPLOYMENT

Technological innovation has long powered human progress and remains central to global development across many sectors. In the decades ahead, developing and diffusing low-carbon technologies will play a particularly essential role in countering climate change while fueling sustainable development.

Historically, technological innovation has been highly correlated with a country's income level (Klenow & Rodriguez-Clare 1997; Caselli & Coleman 2001; Jerzmanowski 2002; Comin & Hobijn 2003). This correlation is reflected in the significant technological gaps between low-income and high-income countries (Figure 1). Since the Industrial Revolution, a few high-income countries have dominated the technological frontier, innovating and adopting new technologies first. Lower-middle and upper-middle-income countries, conversely, have approached technological innovation primarily through the absorption and adaptation of preexisting technologies, rather than inventing new localized technologies (World Bank 2008). This situation is especially prominent in low-income countries, where innovation is cramped by poverty and illiteracy.

Figure 1. The technology gap: science and innovation outputs by income



Source: World Development Indicators and World Intellectual Property Office Data



Only 36 percent of the world's developing countries have reached the 25 percent penetration threshold and only 9 percent have reached the 50 percent threshold for technologies invented between 1975 and 2000 (Comin & Hobijn 2004). For example, supercritical/ultrasupercritical coal power generation technologies were invented in the late 1950s but until 1990 were used primarily in developed countries. In the past decade China has become a leader in this technology, but to date is the only country outside the developed world to boast a comparatively wide diffusion.

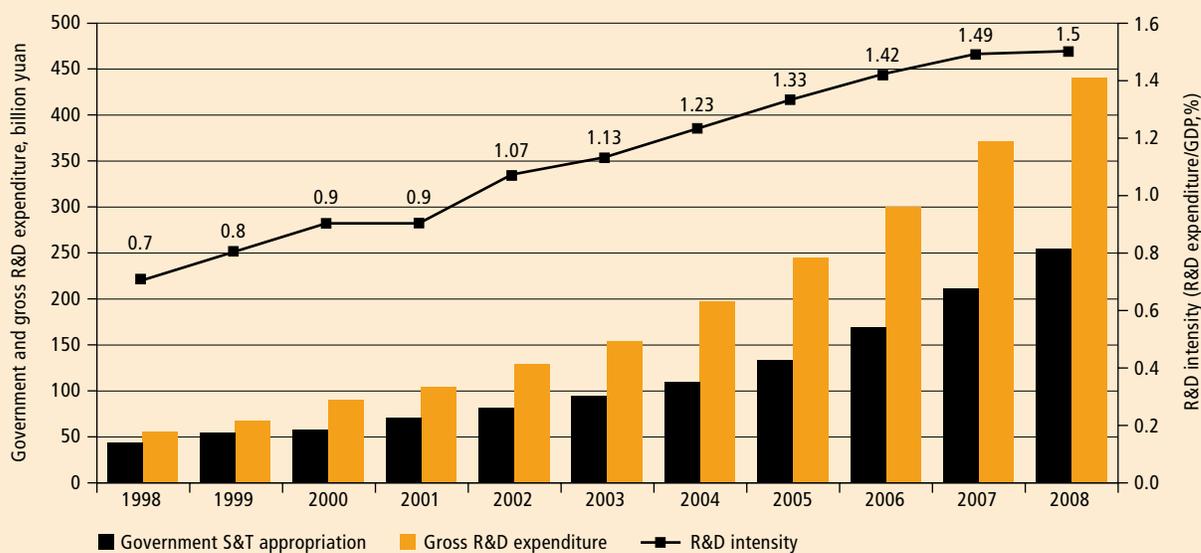
FROM IMPORTER TO MANUFACTURING POWERHOUSE: TECHNOLOGY DEVELOPMENT IN CHINA

There are exceptions to this general rule. China, for example, is a lower-middle-income country which boasts technological achievements greater than those of many high-income countries. Nevertheless, income level remains a major factor in level of innovation. This income divide poses a significant challenge given that the energy sector in the developing world needs to rapidly implement low-carbon technologies in order to meet the twin challenges of development and climate change.

In the past two decades China has emerged from a technology importer to a major manufacturer of a number of low-carbon technologies. This technological surge has been built on Beijing's belief that the next phase of the science and technology revolution will center on low-carbon energy and its ambition to lead this revolution. Consistent with this belief and ambition, China's government R&D appropriations have increased dramatically, from 43.9 billion Yuan (US\$6.8 billion) in 1998 to 254 billion Yuan (US\$39 billion) in 2008. Accordingly, three other measures—gross R&D expenditure, R&D intensity,¹ and government science and technology appropriations—have also enjoyed rapid growth (Figure 2). The state funding for low-carbon

Globally, the pace of technology deployment has dramatically accelerated over the past 200 years. On average, the time it takes for a technology to gain a foothold has declined from almost 100 years in the 1800s to about 20 years today (World Bank 2008). However, technology deployment within developing countries remains slow.

Figure 2. China's R&D expenditure, 1998–2008



Source: China Science and Technology Statistics Data Book, 2009



technology is primarily channeled through programs such as the National Basic Research Program (973 program) and the National High-tech R&D Program (863 program).

The deployment of low-carbon technology in developing countries, especially major developing economies, will critically decide the cost, pace, and success of any response to climate change. With this in mind, this report examines efforts made by China—the world’s largest gross emitter of greenhouse gases—to create and nurture technology deployment infrastructure in three energy technologies: SC/USC, onshore wind, and TRT technologies. These three technologies were chosen because of their scale and the diverse deployment potentials they present. In terms of scale, steelmaking and power generation are the largest energy consumers in China. Scaling-up the deployment of energy efficiency technologies in these two sectors alone, therefore, will make a significant dent in CO₂ emissions. Wind power, on the other hand, is the fastest growing renewable energy in China. The lessons learned from its deployment process will help China to draw a new series of policy prescriptions for solar, biomass, and other renewable energy technologies.

The other consideration for choosing these three technologies is the diversity they present with regard to potential deployment opportunities both domestically and internationally. In the case of TRT, opportunities for further domestic deployment are diminishing, because a majority of current steel plants have already deployed the technology and few new plants will be needed as China’s infrastructure expansion slows down. Therefore, China is now targeting international markets for its TRT technology. The case of wind presents another extreme. China’s ambitious renewable energy target foretells a huge domestic market for its wind energy technology. In fact, China’s rapid development in wind energy technology in the past decade has primarily relied on a large domestic market. SC/USC seems to fit in the middle. The technology still has deployment potential domestically because China is continuing to build new coal-fired power plants. Although China started to export SC/USC to India and Turkey in recent years, it is unlikely that the international market will outgrow the domestic market in the near future. The diverse deployment opportunities presented by these three technologies allow us to address issues arising from across the spectrum of low-carbon technology deployment.

CHINA CASE STUDIES: TERMS, METHODOLOGY, AND VALUE ADDED

Building on the case studies of the three low-carbon technologies, the report develops an analytic framework to reveal the building blocks for a technology deployment infrastructure in developing countries. The framework is based on several concepts illustrated in Box 1. The definition of these concepts is drawn from existing literature, especially that on innovation (Schumpeter 1934; Rosenberg 1976, 1990; Kim & Utterback 1983; Kim & Kim 1985, 1988; Kim 1997; Kline & Rosenberg

Box 1. Defining terms

Technology transfer: the process of sharing skills, knowledge, methods of manufacturing, samples of manufacturing, and facilities among governments and other institutions to ensure that scientific and technological development are accessible to a wider range of users who can then further develop and exploit the technology into products, processes, applications, materials, or services (Hargadon 2003; EC 2008). There is a gap between international and Chinese scholars’ understanding of this term with many international studies considering actions of wholly foreign-owned enterprises a form of technology transfer if they bring in the new technology, adapt it to local conditions, and train a local labor force. Chinese scholars and government officials do not view the technology as transferred unless the ownership of the intellectual property has actually been transferred to a Chinese-owned entity.

Technology localization: a life cycle where existing knowledge and technology is introduced, decoded, and manufactured in a domestic environment and possibly exported to other countries. By its nature, technology localization is an innovation process, because through adapting introduced technologies to local conditions, important roadblocks and areas for improvement can be identified. This consequently leads to innovation (Tan 2010). In developing countries, technology deployment is primarily a process of technology localization.

Technology decoding: refers to the technology-learning benefits that arise through utilizing a technology. It is an aggregate term that involves many different mechanisms: learning-by-copying, learning-by-operating, and learning-by-implementing. All these mechanisms contribute to knowledge acquisition and eventually cost reduction (Sagar & Zwaan 2006). This type of decoding has at various times led to allegations of “reverse engineering,” a term that encompasses a number of fully legal practices as well as some practices that are IPR violations, at least in some jurisdictions. In the case studies in this report, there were licenses in all cases.

Technological capacity: the ability to make effective use of technological knowledge in efforts to assimilate, use, adapt, and change existing technologies. It has three elements: production, investment, and innovation (Kim 1997).

Front-end support: a range of technology-nurturing support on the front end. This includes direct government support for the following: R&D, both long and short term; technology prototyping and demonstrations (P&D); public-private R&D partnerships; monetary prizes for individual inventors and innovative companies; and technical education and training (Weiss & Bonvillian 2009).

Back-end support: regulatory mandates that are implemented on the back end in order to scale-up technology deployment. This includes standards for particular energy technologies, regulatory mandates such as renewable portfolio standards and fuel economy standards, and emission taxes (Weiss & Bonvillian 2009).

Box 2. Technology transfer in the Chinese context

Technology transfer plays an important role in deploying and scaling-up low-carbon technology solutions in emerging countries. Yet discourse between the Chinese and OECD country governments over technology transfer of all kinds has been contentious. The discussion is often framed as a simple conflict: China (and other developing countries) asks Western governments to facilitate technology transfers, while Western governments promote the need for increased intellectual property protection. As our case studies illustrate, however, the reality is more complex and difficult, involving a large suite of governance issues. These include the relationship between government and companies, corporate governance, contract law, privacy and business confidential information protection, as well as intellectual property rights.

In the OECD and in many developing countries, listed companies operate on behalf of their shareholders and have a fiduciary responsibility to do so. By contrast, the best interest of Chinese firms often lies in meeting government targets, or the political requirements of specific government actors, rather than in maximizing profit for shareholders. Predicting the behavior of a potential partner, supplier, or customer therefore requires a complex understanding of Chinese politics. As a result, Chinese firms' lack of alignment with international norms can lead to misunderstandings and lack of trust.

The opaque ownership structure of Chinese firms also produces confusion among foreign companies as to whether, or to what extent, companies are controlled by the Chinese state. While Chinese firms often differ from the profit-driven business model typical in developed nations, even state-owned companies pursue their own individual interests and compete with one another. Indeed, it is precisely this competition (whether for government favor or domestic-market preeminence) that makes companies prime technology purchasers. Chinese firms may invest in technology without clear profit-producing payoffs if they believe it will improve their domestic prestige or market share (Down 2007). On the other hand, multinational corporations do not yet have the type of long-term, high-level partnerships in China that many European, American, and Japanese companies have with each other. This lack of high-level partnership may well be the cost of the type of government-managed jump starting that has benefited China technology businesses to date.

This issue of company ownership and governance is far more fundamental than an issue of IPR enforcement, because it involves many elements of China's political economy. Making progress on technology transfer and business-to-business partnerships will require foreign governments and international companies to accept this ambiguity and come up with approaches (including many that companies currently use) to managing both the risks and opportunities it presents. The Chinese government also needs to recognize the challenges their country's unique corporate structure creates for business-to-business relationships, including those involving technology.

Low-carbon technology collaboration

In the absence of fundamental change, international companies will continue to "manage" their relationships with Chinese firms (for example, holding back some of their IPR), and this may well involve caution in the speed and nature of technology transfers. The degree of caution will vary with the degree of risk and opportunity. For example, in both the SC/USC and TRT case studies featured in this report, international companies made deals in China when they faced a scarcity of other customers (Qin 2010). In the current global economic climate, where capital is scarce in much of the world but abundant in China, many companies may well choose to make the same risk calculation. It is arguable that the nuclear and solar industries already have done so. There are also clear benefits from the Chinese government's active role: plentiful R&D money, support for human capital development, and inexpensive financing. Nevertheless, a survey of multinational businesses for this report suggests that foreign companies are using tools to manage intellectual property concerns, including holding back some of their IPR (see Conclusion). This approach is a logical outgrowth of the contractual and IPR concerns, but is suboptimal both for Chinese and international companies compared with the advantages of cooperation in a more robust legal and contractual environment.

1986; OECD 1992; Lundvall 1992, 1995; Freeman & Perez 1988; Nelson 1993; Pavitt 1984; Mytelka & Smith 2001; Archibugi & Pietrobelli 2003; Block & Keller 2008; Zou et al. 2009; Bonvillian & Weiss 2009). In addition, the report draws on data from a number of sources. For international data, it relies on the International Energy Agency's (IEA) Low-carbon Coal Center, the Global Wind Energy Council, and the World Steel Association. An important source of domestic data is the China Statistics Bureau, China's official statistics agency.

Scaling Up Low-Carbon Technology Deployment: Lessons from China also draws on information collected from direct interviews with industry leaders, policymakers, and technology practitioners. The conversations were part of a series of surveys conducted in 2009 by WRI, covering six multinational firms in the three case study sectors. Interviewees were guided through pre-designed questions with the aim of complementing academic views with thoughts and insights from real-world implementers.

The existing literature often approaches technology deployment from the standpoint of developed countries. Its theories, therefore, often do not seem relevant for developing countries, which face very different challenges from technology frontier nations. This report fills that gap by seeking to craft a technology deployment infrastructure specifically adapted to the needs and conditions of developing countries, especially major developing economies. In so doing it contributes to the innovation literature and body of knowledge in three ways. First, it takes a different focus on technology deployment, centering on existing rather than cutting-edge technologies. Second, the report aims to accelerate the pace of absorbing, deploying, and diffusing existing technologies rather than expanding the technological frontier and creating cutting-edge technology. Third, it recognizes the decisive role the public sector plays in technology deployment in developing countries, whereas existing literature tends to highlight private sector dominance.



Supercritical and ultrasupercritical coal-fired power generation

TECHNOLOGY OVERVIEW

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

SC and USC technologies achieve high efficiency and consequently use less coal and result in reduced CO₂ emissions. According to the IEA Clean Coal Center, CO₂ emissions may be reduced by 23 percent per unit of electricity generated by replacing existing subcritical plants with SC/USC technology (Nalbandian 2008). Specifically, a 1 percent increase in efficiency reduces emissions by 2.4 million tons (Mt) CO₂, 2000 tons (t) NO_x, 2000 t SO₂ and 500 t particulate matter over the life of the facility (Balling & Rosenbauer 2007).²

Table 1. Approximate pressure and temperature ranges

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

Source: Nalbandian, 2008: p. 8

SC technology was invented in the late 1950s, initially in the United States and Germany. American Electric Power operated the Philo SC unit in 1957; the Philo SC was soon followed by Eddystone 1, a unit still in active service. USC facilities have been constructed and operated successfully since 1993 when Japan operated its 1000 megawatt (MW) Hirono 4. USC is routinely used for new pulverized coal power plants in Japan today. The efficiency gain also reduces fuel costs by 2.4 percent.³ More advanced

USC technology promises efficiencies of up to 55 percent for PC power plants. Its economic benefits are comparable to integrated gasification combined cycle (IGCC) and natural gas combined cycle (NGCC) technologies (Table 2).

Although SC/USC is a mature technology, the majority of existing coal-fired power plants worldwide are still using subcritical technology. The barriers to the diffusion of SC/USC technologies are not technical but largely economic and regulatory. First, the long lifetime of coal-fired power plants slows fleet turnover. Through much of the 1980s and 1990s low fuel costs eliminated the economic impetus for

the higher capital costs of higher efficiency cycles such as SC/USC. The United States, for example, has not built any new SC plants since 1991 (EPRI 2008), because the coal cost was low and stable over most of the past 30 years. In addition, uncertain regulatory environments and prolonged permitting processes have made capital expensive, skewing the economics even further toward increased fuel use and decreased capital costs. Of the more than 500 SC/USC units in the world, nearly half operate in Europe and Russia, 24 percent in the United States, and 10 percent in Japan. The remaining 19 percent are in China (EPRI 2008).

Table 2. Estimated costs and thermal efficiencies

	Average efficiency	CO ₂ emissions, g/kWh	Power generation cost, US¢/kW	Total plant capital cost, US\$/kW
Subcritical	36	766–789	4.0–4.5	1095–1150
Supercritical	45	722	3.5–3.7	950–1350
Ultrasupercritical	>45	<722	4.2–4.7	1160–1190
IGCC	42–44	710–750	3.9–5.0	1100–1600
NGCC	50	344–430	3.4–6.8	400–700

Source: Nalbandian, 2008: p.10

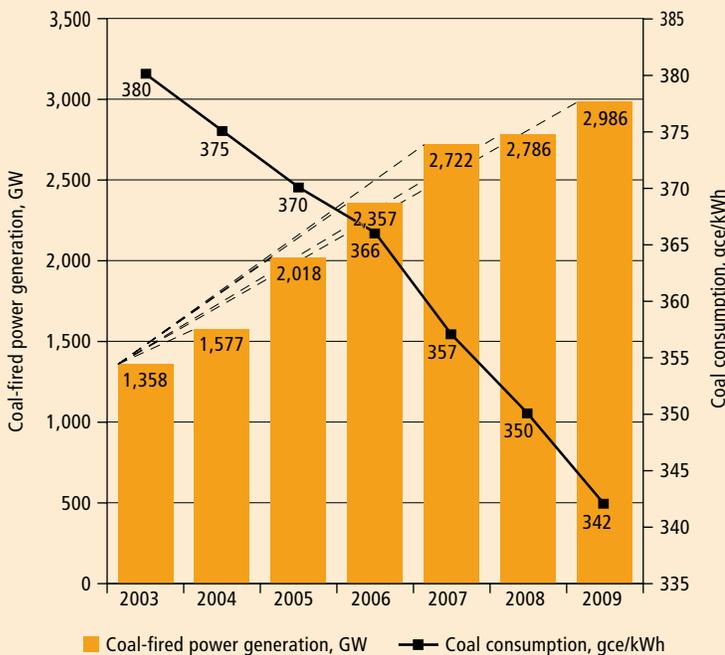
WHERE DOES CHINA STAND?

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

In the foreseeable future coal will remain the baseload fuel of choice in China. By 2030 China will add another 1344 gigawatts (GW) of coal-fired power generation (IEA 2009). Therefore, deploying and diffusing SC/USC technology, hopefully coupled with carbon capture and storage, is essential to China's effort to cut CO₂ emissions and improve the efficiency of fuel use. The national government has long considered SC/USC as a key low-carbon technology. A number of policies, measures, instruments, and cooperative arrangements have been made and implemented to facilitate the localization and accelerate the diffusion of the technology.

China now is the largest thermal power equipment manufacturer in the world (World Bank 2009). Shanghai Electric Group (SEG), Harbin Electric Corporation (HEC), and Dongfang Electric Corporation (DEC) have emerged as three key manufacturers in China. Their annual outputs all exceeded 35 GW in 2007, higher than any other major manufacturer around the world. All three manufacturers boast the capacity to design and manufacture SC/USC equipment. The successful operation of QinBei Power Plant's two 600 MW SC units in 2004 and Yuhuan Power Plant's four 1000 MW USC units in 2006 reflect this capacity. By the end of 2009, a total of 12 1000 MW USC units were in operation (Table 3), complementing a fleet of more than 80 SC

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



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



units across China. All of the USC units and the majority of the SC units were manufactured in China. In addition to supplying the domestic market, China has increased SC/USC equipment exports to other developing countries, including India and Turkey.

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

THE LIFE CYCLE OF SC/USC TECHNOLOGY ADOPTION AND LOCALIZATION IN CHINA

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

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

The large-scale imports of 300 MW PC sets and their drain on already stressed foreign exchange prompted the Chinese government to prioritize the localization, and particularly the domestic manufacturing, of advanced thermal power technologies. All of the existing PC manufacturers were state-owned enterprises (SOE), products of the state planning system. Their statist orientation and the fact that Chinese efforts began before SOE reform meant this was a planned process

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

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

Source: Tsinghua Study 2009; China NDRC website

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

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

Source: World Bank, 2009; Websites of SEG, HEC, and DEC

from the beginning. These companies collaborated in ways that one would not typically expect of competitors, and the work was undertaken more on the level of a national effort such as a space program than a private enterprise-driven system.

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

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

Through operating these two units, the Chinese experts started to accumulate knowledge about SC technologies.

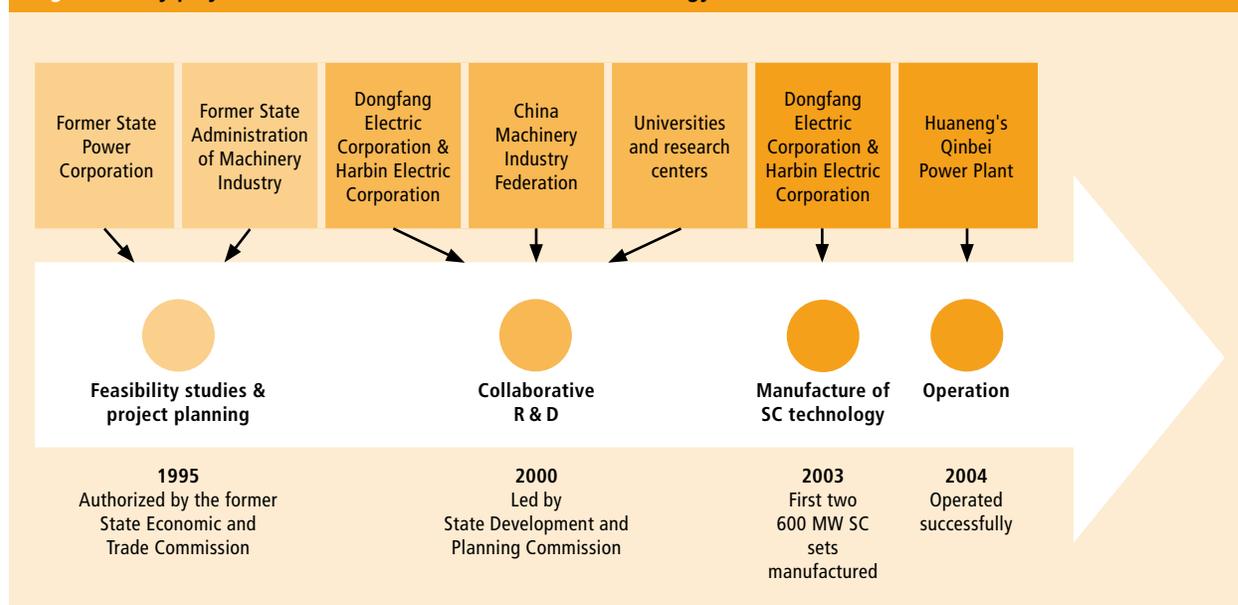
In 1995 the then State Power Corporation (SPC) and former State Administration of Machinery Industry (SAMI) conducted a feasibility study and began project planning for its own SC manufacturing capacity. The feasibility study included organizing a group of experts to assess whether China had the capacity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

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

few customers. However, because of the varied interpretations of these events, this history in part helped create a trust deficit between Chinese technology seekers and Western technology providers.

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

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





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

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

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

Having established domestic manufacturing capacity, the Chinese government designed and implemented an array of incentive policies as well as regulatory mandates

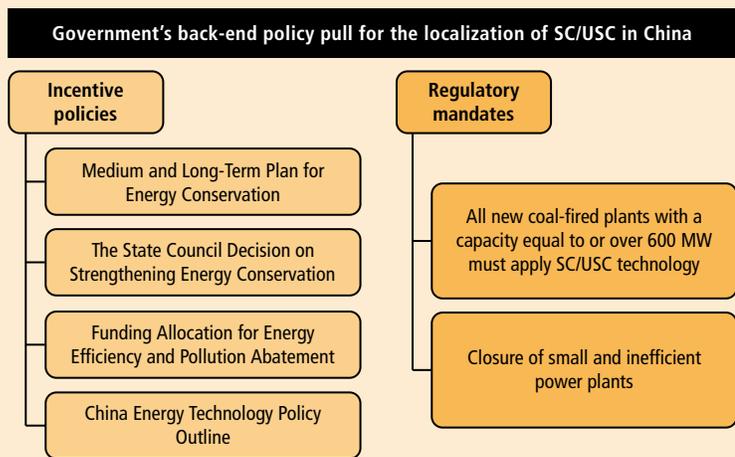
to motivate power plants to adopt SC/USC technologies. In 2006 China mandated that all new coal-fired power plants with 600 MW capacity or above must apply SC/USC technology. Simultaneously, the government published a list of small and inefficient power plants planned for closure by 2010. In addition, China has announced a series of economy-wide policies to encourage energy efficiency efforts, including the Medium and Long-term Plan for Energy Conservation (2005), the 11th Five-Year Plan (2006), the State Council Decision on Strengthening Energy Conservation (2006), the Top-1000 Energy-Consuming Enterprise Program (2006), the Revision of Energy Conservation Law (2007), the Allocation of Funding on Energy Efficiency and Pollution Abatement (2007, 2008), and the China Energy Technology Policy Outline (2007) (Figure 6). These policies and regulations provided incentives such as tax credits, low-cost financing, price guarantees, loan guarantees, government procurement, and new-product buy-down.

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

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

Government's front-end R&D supports for the localization of SC/USC in China			
National Basic Research Program (973 Plan)	National Key Technology R&D Program	National High-Tech R&D Program (863 Program)	Shanghai Key Research Projects
<p>Established a number of large-scale experiment and research bases:</p> <ul style="list-style-type: none"> • National Research Center for Clean Coal Combustion; • Large-Scale USC Hydrodynamic Experimental Platform; • National Lab for Multiphase Flows; • High Temperature Material Performance Lab; • Coal Characteristics & Combustion Test Lab; • Lab for Key Components of Steam Turbine & Boiler Pressure Parts Strengthen and Vibration 	<p>Established program-Development of 600 MW SC Thermal Power Complete Set:</p> <ul style="list-style-type: none"> • Optimization of 600 MW SC system and operating performance enhancement; • Localization of SC components materials, castings and forgings; • R&D of automatic control system and key instrument; • R&D of turbine; • R&D of boiler; • R&D of auxiliary equipment; • Verification study of USC 	<p>Established SC/USC 863 Plan, which includes 5 subjects:</p> <ul style="list-style-type: none"> • Technology selection for USC sets; • Key technologies for USC boiler manufacture; • Key technologies for USC turbine manufacture; • Purification technology for large coal-fired power plant flue gas; • Design and operating techniques of SC/USC power stations 	<p>Shanghai Municipal Government established the project:</p> <ul style="list-style-type: none"> • R&D of Special Materials for SC/USC Power Station Equipment

Figure 6. Policy incentive and regulatory mandates



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

By the end of 2008, China had a total of 100 SC/USC units in operation (Nalbandian 2008). This is only second to the United States, which has 120 SC units. The large-scale operation of SC/USC has significantly contributed to energy conservation and CO₂ reduction. In 2007 and 2008, China's coal consumption per kWh respectively

reduced 9 grams of coal equivalent (gce) per kWh and 7 gce/kWh. The efficiency gain in 2008 was equivalent to a savings of 27 million metric tons of standard coal, or the avoidance of 55 million metric tons of CO₂ emissions (Tsinghua Study 2009). In terms of capacity, temperature, and pressure, China's technologies are comparable to those in the countries owning the most advanced SC/USC technologies (Table 6).

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

SUMMARY

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

Table 5. Comparison of plant capital cost

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

Source: Hogan et al., 2007

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

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

Source: Nalbandian, 2008



Onshore wind power

TECHNOLOGY OVERVIEW

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

Other technological developments in wind include variable-pitch rotors, direct drives, variable-speed conversion systems, power electronics, better materials, and improved ratios between the weight of materials and generating capacity (IEA 2006). All these developments have helped to improve wind energy's affordability and reliability. Consequently, compared to other renewable energy sources, the price of wind power is the closest to that of fossil fuel energy. Potential breakthroughs in wind power development include better power electronics to improve the interface

with the grid, improved composite materials for lighter-weight and stronger blades, simplified power trains to end the need for gearboxes which account for 30 percent of costs, and online diagnostics for better monitoring.

Due to constant technological improvement as well as enabling policies, worldwide installed wind power capacity has risen rapidly, from about 14 GW in 1999 to 158 GW in 2009, of which the United States and Germany accounted for approximately 41 percent (Figure 7). The 158 GW installed capacity was estimated to generate 340 terawatt-hours (TWh) electricity and save 204 million tons of CO₂ in 2009 (Sawyer 2010). An ambitious scenario by the Global Wind Energy Council (GWEC) shows that if the current annual growth rate of over 30 percent continues, global wind energy capacity could increase to over 1000 GW by 2020 and 2,400 GW by 2030. This would lead to annual CO₂ savings of more than 1.5 billion tons in 2020 and 3.2 billion tons in 2030 (GWEC 2010).

WHERE DOES CHINA STAND?

China's wind industry has followed a strikingly different model from the Chinese thermal power sector. The wind sector is marked by multiple, competitive companies with varying amounts of support from government. The ownership of these companies varies from state-owned enterprises such as DEC to joint-stock companies such as Goldwind and to privately owned companies such as New Unite. Their integration with international markets has

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



Source: GWEC 2010; WWEA 2009

also varied. In recent years the Chinese government has strongly stimulated demand, but it has not forced suppliers to supply world-class product. Chinese wind suppliers can sell in the domestic market without certification and other quality controls demanded by international purchasers. The result is a domestic market with extremely low barriers to entry but less opportunity to engage in exports.

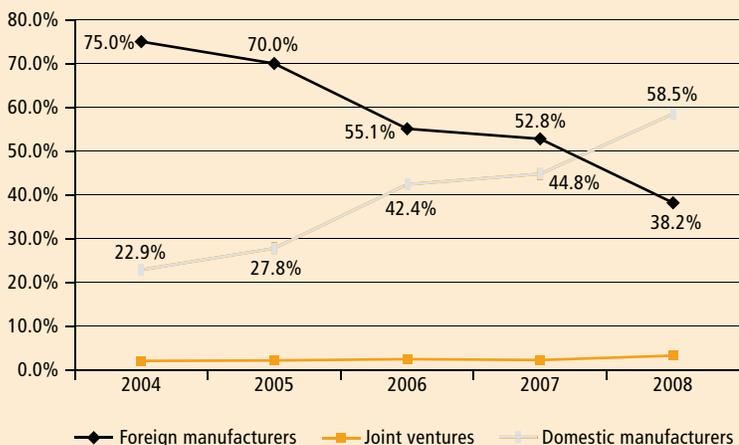
China has abundant wind resources. Its technically exploitable onshore wind resources at a height of 10 meters

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

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

First, a majority of turbines erected in China are small, with 600–850 kW turbines accounting for 80 percent of the market share (Figure 9). In 2006 the average size of

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



Source: China Mechanical Electrical Data Online



turbines in China was 830 kW, compared to 1634 kW in Germany, 1634 kW in the United States, and 1100 kW in Spain. Today, the United States is developing 10 MW turbines, while China just tested 3 MW turbines. In February 2010, China's first 3 MW offshore wind turbines independently developed by Sinovel Wind Group Corporation passed the 240-hour test (Sinovel News 2010).

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

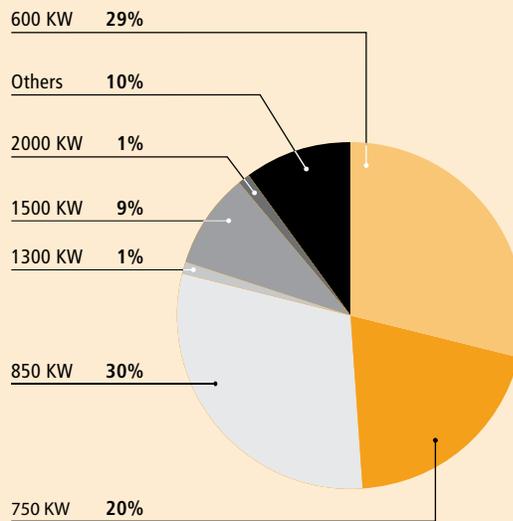
Finally, a more damaging aspect in China's wind energy development is the low utilization rate. The rapid growth in installed capacity has not gone hand in hand with growing generation capacity. According to Xinhua, only 8 GW of the 12 GW of installed turbines were grid connected at the end of 2008 (Xinhua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

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

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

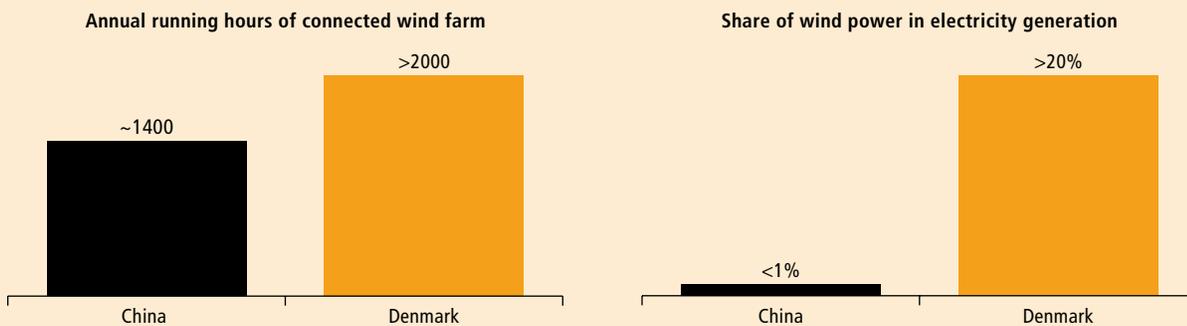
Source: Tsinghua Study 2009; Timken 2007

Figure 9. China's installed turbine capacity, 2006



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

Figure 10. Wind energy generation capacities, 2008



Source: McKinsey & Company, 2009

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

WIND ENERGY TECHNOLOGY TRANSFER—BARRIERS AND DRIVERS

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

Joint ventures

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

However, the joint-venture program has not been successful in meeting the goal of enhancing wind energy technology transfer. Most international wind energy companies have chosen to invest in China as wholly foreign-owned enterprises rather than joint ventures. Vestas, for example, maintains 100 percent ownership of its subsidiary company in China. By 2008 joint ventures only occupied 3.3 percent of the Chinese

turbine market (Figure 8). In addition, these joint-venture turbine manufacturers often function only as a provider of maintenance and post-sale services, with little R&D and innovation. This is also the case of the joint-venture automobile industry in China (Gallagher 2006).

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

Licensing agreements

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

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

To the Chinese, the disadvantages of buying licenses include the contingency of the technology providers' willingness to allow a third party to sell and support their technology, as well as high licensing and royalty costs for technology seekers. In fact, the Chinese government is concerned about high licensing costs for wind technology and how it will impact the industry's future development. According to a report published by the Chinese Ministry of Finance (MOF) in 2009, the costs of production licenses for 1–1.5 MW wind turbines had increased from US\$1.4 million–2.8 million in 2005 to US\$11 million–12.4 million in 2007. This is equivalent to US\$689,000 for each turbine (MOF 2009). This is about 6 percent of the total cost of a 1 MW wind turbine.⁴



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

Joint design

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

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

Policy instruments

In its pursuit of advanced wind energy technology, the Chinese government has designed many policy instruments to strengthen foreign investors’ confidence in the Chinese wind market (Zhang et al. 2009). The first

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

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

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

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

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

Source: Li & Hu, 2007

is laying a legal foundation for wind energy investments and the government’s interventions. China enacted its Renewable Energy Law in 2005. The law recognizes the strategic role of renewable energy in optimizing China’s energy mix. It sets the policy frameworks for the government’s role in pricing, supervision, allocating cost burdens, and incentivizing investors. In December 2009, the law was amended to ensure the state-owned grid companies accepted wind power when it was available:

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

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

Table 10. China energy policy relevant to wind

Tier	Wind Energy Policy
First tier	<p>Provide general direction and guidance, including speeches by state leaders and the Chinese government's general standpoint on the global environment</p> <ul style="list-style-type: none"> • 2003 Renewable Energy Promotion Law • 2005 Renewable Energy Law • Amendments to Renewable Energy Law, 2010
Second tier	<p>Specify goals/objectives and development plans, with a focus on rural electrification and renewable energy-based generation technologies</p> <ul style="list-style-type: none"> • 1996 Ride the Wind Program • 2003 Rural Energy Development Plan for Western China • 2006 Medium to Long-Term Development Plan on Renewable Energy • 2006 11th Five-Year Plan for Renewable Energy • 2007 National Plan for Renewable Energy Development • 2007 International Science and Technology Cooperation Program on New and Renewable Energy
Third tier	<p>Provide practical and specific incentives and managerial guidelines, aimed at reaching the goals and objectives set by the second-level policies</p> <ul style="list-style-type: none"> • 2006 Management Regulations on Electricity Generation from Renewable Energy • 2006 Notice on Management Requirements for Wind Power Construction • 2006 Provisional Management Measures on Construction Land Usage and Environmental Protection of Wind Power Stations • 2006 Interim Measures for Renewable Energy Development Special Funds • 2008 Tariff Adjustments for High-Power Wind Turbines and its Key Components • Circular on Preferential Tax Policy Issues for Developing the Western Region

Source: Li, 2006; NDRC Website

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

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

The fourth policy instrument is feed-in tariff and a power surcharge for renewables and premium. The Interim Measure of Renewable Energy Tariff and Cost Sharing Management, released by the NDRC in 2006,

mandated a 0.25 Yuan/kWh (US\$0.04/kWh) surcharge to subsidize biomass. For wind power, the feed-in tariff offered to cover the difference between the contracted wind price and local coal-fired power price to ensure parity between wind and coal. However, when combined with the artificially low bids in the concession process, wind farms remain unprofitable for foreign investors.

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

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



the 10th Five-Year Plan period, over 90 percent of the 600 kW wind turbines manufactured in China were domestically produced and Goldwind continued to pay Jacobs licensing fees for the IPR.

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

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

the end of 2008 Goldwind occupied the largest share of the Chinese market and ranked tenth in the global market.

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

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

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

The third tax break is a favorable tariff. Up until the early 1990s, imported wind turbines and related equip-

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

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

Source: Tsinghua Study, 2009

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

SUMMARY

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



Efficiency in the steel sector

TECHNOLOGY OVERVIEW

The iron and steel sector consumes about 19 percent of global final energy use and accounts for a quarter of direct CO₂ emissions from industry and roughly 4.5 percent of global CO₂ emissions (WSA 2008a). Steel production is very energy intensive with 20 percent to 40 percent of the cost of steel production derived from energy expenses (WSA 2008a). On average every ton of primary steel produced in a blast furnace results in one-and-a-half to two tons of direct CO₂ emissions in OECD countries (ArcelorMittal 2008). The energy efficiency of steel-making facilities differ greatly depending on production route, type of iron ore and coal used, the steel product mix, operation control technology, and material efficiency (WSA 2008b).

The promise of large CO₂ emission reduction in the steel sector lies in two directions. One is to accelerate the penetration of currently available energy efficiency technologies. The other is to find breakthrough technologies. The best steel mills are now limited by the laws of thermodynamics in how much they can still improve their energy efficiency. For these plants, further large reductions in CO₂ emissions are not possible using current technologies. A portfolio of breakthrough technologies will therefore be required to meet the CO₂ emission standard called for by governments and international institutes (WSA 2008a). Many regional initiatives are being undertaken to identify technologies that hold the promise of large reductions in

CO₂ emissions and to explore their feasibility at various scales from lab work, to pilot plant development, and eventually to commercial implementation. The central players include the EU Ultra-low CO₂ Steelmaking Project,⁵ the American Iron and Steel Institute, the Canadian Steel Federation, ArcelorMittal Brazil, the Japanese Iron and Steel Federation, the Korean POSCO, China's Baosteel, and Australia's Bluescope (WSA 2008b).

Among the portfolio of breakthrough technologies, the coal-based iron-making technologies associated with carbon capture and storage (CCS) technology are the most likely candidates for early maturity. Hydrogen and electrolysis are being explored by the European Union and the United States. Hydrogen could be used as a reducing agent, as its oxidation produces only water. Hydrogen—either pure, as a syngas produced by reforming methane, or as natural gas—can be used in conventional direct-reduction reactors or in more futurist flash reactors. Electrolysis can be used to generate the reducing agents. They are provided either by electricity, for which the corresponding process is the electrolysis of iron ore, or by bacteria. Biomass solutions are probably in the intermediate future. Integrating steelmaking with solar power generation or with new energy technologies may be on the horizon in the longer term.

WHERE DOES CHINA STAND?

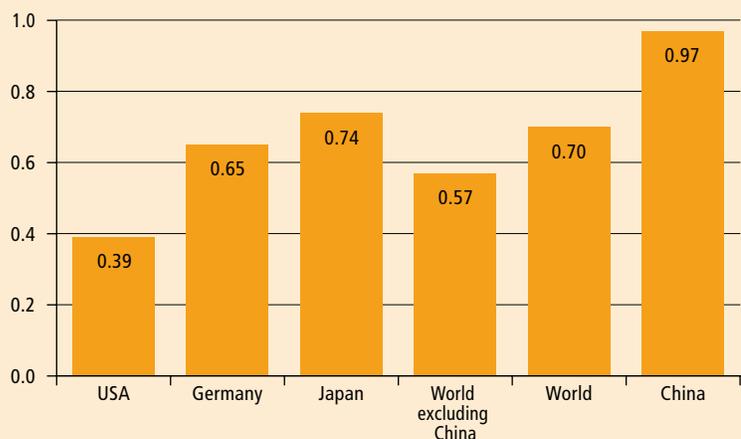
Steel production accounted for nearly 17 percent of China's primary energy use in 2008. Compared to developed countries' steel producers, China's steel sector has much higher primary energy intensity (Figure 11). This higher intensity can be explained by heavy reliance on coal, relatively higher iron alloy production, lower waste energy recovery, smaller scale of equipment, lower conversion efficiency of steam and oxygen, and relatively poor material quality (Huang 2008; Tsinghua Study 2009). Figure 12 shows high pig-iron versus crude steel

Figure 11. World steel sector energy intensity index by region, 2005



Source: Japan Iron and Steel Federation, 2005

Figure 12. Pig-iron vs. crude steel ratio, 2008



Source: Huang, 2008

ratio in China. According to a Japanese study, in 2005 China could have reduced CO₂ emissions by 180 million tons per year by increasing its steel sector's national average energy efficiency to match Japan's (Yamaguchi 2005).

China is keenly aware of its efficiency issues. The 11th Five-Year Plan (2006–2010) mandated that the steel sector's energy efficiency should improve 20 percent between 2006 and 2010. From 2006 to 2008 the sector's per GDP energy consumption was respectively reduced by 1.8 percent, 3.7 percent, and 4.2 percent. This fell short of the goal but shows an accelerating improvement. A key factor in the efficiency improvement was the closure of small inefficient mills. In May 2007 the NDRC released a list of outdated iron and steel mills to be closed by 2010. According to the list, an estimated 42 million tons of steel-making capacity would be closed down each year.

Shutting small mills alone will be insufficient to reach China's energy efficiency target and the global standards for energy intensity in China's steel sector and to reduce the steel sector's demand on the energy infrastructure. To further improve its energy efficiency in the steel sector, China needs to catch up with the rest of the world in steel-making technology. The existing technological frontier of steel production has little room to grow (WSA 2009a), but the Chinese steel sector can absorb, deploy, and diffuse preexisting but new-to-China technologies.

Technology transfer therefore plays a crucial role in the government's plans to reduce energy intensity. It categorizes steel energy efficiency technologies into three tiers based on the existing level of technology transfer and deployment. The first tier includes technologies that have been transferred, absorbed, and even domestically innovated. The second tier covers technologies that have been transferred and partly absorbed, but with limited deployment. The last tier consists of technologies that haven't been transferred (Table 12).

HOW WAS ADVANCED EFFICIENCY TECHNOLOGY TRANSFERRED TO AND DEPLOYED IN CHINA?

In the first 30 years of China's history, its steel sector focused exclusively on producing more steel to meet the demands of a country with growing industry. The 1st Five-Year Plan (1953–1957) established a blueprint for the development of China's steel industry. The plan proposed to build "3 large, 5 medium and 18 small-scale steel plants" across China. The former Soviet Union provided major aid for the construction of new plants and retrofitting of old plants. Accordingly, China's steel-making technologies were deeply influenced by the former Soviet Union where many Chinese leaders and technicians received training in running steel plants.



Table 12. China's categorization of energy efficiency technologies

Tier 1 Fully adopted and diffused	Mini-pellet sintering technology
	Recovering waste heat from sintering circulating cooler to produce steam, hot air sintering technology
	Low-temperature sintering technology
	The electric precipitator for removing dust at the head of sintering machine technology
	Deep-bed sintering and sintering bedding technology
	Remove dust recycling technology
	Top-pressure recovery turbine technology (TRT)
	Blast furnace pulverized coal injection technology (PCI)
	Coke oven gas HPF desulphurization technology
	Stove dual preheating technology
	Efficient continuous casting technology
	Boiler combusts all blast furnace gas technology
	Highly preheated air combustion technology
	Technology of hot conveyance and loading of successive casting
Tier 2 Partially adopted	Coke dry quenching technology (CDQ)
	Generating power by sintering waste heat technology
	Dry dusting in blast furnace technology
	Converter gas dry dedusting technology
	Lengthen service campaign by slag splashing in combined blown converter technology
	Clean steel production system optimization technology
	Iron and steel plants energy management center
Tier 3 To be transferred	Combined cycle power plant (CCPP)
	Sintering flue gas circulation technology
	Coal moisture control technology (CMC)
	Sintering activated coke desulphurization technology
	COREX smelting reduction in iron making technology

Source: Tsinghua Study, 2009

Energy efficiency technology was not a focus of the steel sector until the late 1970s when China opened its doors to the world. In 1978 the vice minister of China's Ministry of Metallurgical Industry (MMI) led the China Metallurgical Industry Association on a study tour in Japan. After the tour, the vice minister submitted a report to the State Council. The report summarized Japan's development in steelmaking and pointed out that Japan was eager to sell its steelmaking technologies and equipment to China due to the global recession. The report suggested that China's steel sector take advantage of this opportunity by importing Japanese technologies and equipment, including energy efficiency technologies. China's domestic energy shortage made this proposal more convincing and attractive. Two months after the tour, a Japanese delegation led by the CEO of Nippon Steel Corporation visited Beijing. Former Chinese Vice Premier, Li Xiangnian met the delegation with two requests. One was to help build a large steel plant in Shanghai, which became the

core of Baosteel. The other was to seek technology supports, namely to help the Chinese state-owned steel sector upgrade its backward steelmaking technologies.

These two visits inaugurated the long-term cooperation between China and Japan in the steel sector. Based on its experience of developing an advanced industrial economy with limited energy resources, Japan emphasizes energy efficiency and conservation not only domestically but also overseas (Ohshita 2008). As a result, Japan's cooperation with China in the steel sector has focused on energy efficiency from the very beginning. Through technology demonstration, project-type technical assistance, and training, Japan has played an important role in advancing China's efficiency technology in steelmaking.

Box 3. What is Blast Furnace Top Gas Recovery Turbine Unit (TRT)?

Blast Furnace Top Gas Recovery Turbine Unit (TRT) is an energy-saving equipment used for a blast furnace of a steel plant. Average blast furnace gas has a pressure of 0.2-0.236MPa (2-2.41kg/cm²) and temperature of approximately 200°C at the furnace top. TRT technology is a method of generating power by employing this heat and pressure to drive a turbine-generator. The system comprises ash collecting equipment, a gas turbine, and a generator. Generating methods are classified as wet and dry, depending on the blast furnace gas purification method. Ash is removed by Venturi scrubbers in the wet method and by a dry-type ash collector in the dry method. When ash is treated by the dry method, the gas temperature drop is small in comparison with the wet method, and as a result, generated output is at maximum 1.6 times greater than with the wet method.

Energy Saving Effects

Improvement effect	Generating capacity (kW)	7000 (approx.)
Reduction of energy consumption	Annual generated output (GWh)	55.4 (approx.)
	Reduction in crude oil equivalent (t-crude oil/y)	14669 (approx.)

Note: assume pig iron production of 1 million t/y and dry-type TRT

Investment Cost and Economic Evaluation:

Investment cost	Equipment cost: \$4 million	
	Construction cost: \$4 million	
	Generating capacity: 7MW	
Economic evaluation	Economic effect	\$9.9 million/year
	Years to recoup investment	
	<ul style="list-style-type: none"> • Equipment only 1.4 years • Including construction cost 1.8 years 	

Source: UNEP/GEF, Energy Efficiency Technologies Knowledge Base (EET KB), 2010

The Blast Furnace Top Gas Recovery Turbine Unit (TRT, see Box 3) is a tier one technology in China's categorization today (Table 12). Its transfer highlights how efficiency technology was adapted, deployed, and defused in China. TRT technologies originated in Europe but developed and matured in Japan. Mitsui, Hitachi, and Kawasaki are the global leaders in R&D and manufacture of TRT technologies. As early as 1996 all blast furnaces in Japan were equipped with TRT. This innovation partly explains why the Japanese steel sector boasts the best energy efficiency in the world.

Feasibility studies are often the first step of technology import in China. China's National Science and Technology Plan—the Medium to Long-Term Plan for the Development of Science & Technology—for example, requires an assessment of all imported technologies to evaluate whether China has the capacity to absorb and deploy

the technology. Contingent on the type of imported technology, a specific Chinese government agency is assigned to undertake the feasibility study.

China started a feasibility study on TRT in 1978, following the initial study tour to Japan. The MMI organized a group of experts from major steel plants and universities to conduct the study. The result of the study, delivered in 1981, was that China's steel sector should import TRT technologies as soon as possible because of TRT's clear economic benefits and ease of installation.

In 1982 Beijing Capital Steel and Shanghai Baosteel first purchased two wet-type TRT units from Japan. Later more steel plants imported TRTs, either wet- or dry-type, from Japanese suppliers (Tsinghua Study 2009). Most of these purchases were market actions without government involvement. These market-driven technology imports, however, did not lead to absorption and deployment. The causes of this failure were two-fold: Japanese technology providers didn't provide know-how to the Chinese companies; and Chinese companies didn't have the capacity to reverse-engineer the technology without government support.

Responding to the slow uptake of TRT technology, China and Japan launched the Panzhihua Demonstration Project, under Japan's Green Aid Plan (GAP, see Box 4). In 1994 NEDO signed the Panzhihua TRT Technologies Demonstration Project Agreement, with China's State Development and Planning Commission (SDPC) and MMI. The agreement commissioned Kawasaki Steel Corporation and the Panzhihua Steel Corporation to jointly design, construct, and install China's first wet and dry dual-use TRT device. Kawasaki was responsible for initial design and provided TRT units, including the main engine, bag filter, control instrument system, and valves to China. Panzhihua was tasked with construction, pipe installment, and operation/maintenance. The project started installation in February 1997. Exactly one year later the TRT facility successfully went into operation. The project's annual generation capacity is 35 GWh (Tsinghua Study 2009). The total investment of the project was 86 million Yuan (US\$11 million in 1998 dollars), of which Japan provided 60 million Yuan and the remainder came from China.

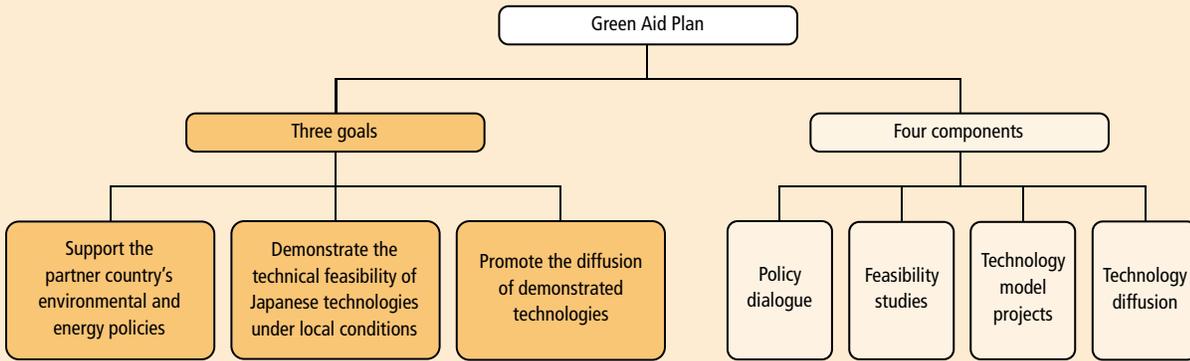
The collaboration between the two governments played a key role in the technology transfer. On the Japanese end, the government made two key contributions: (1) It directly provided funding to Kawasaki to cover the cost of equipment and training; and (2) It carried out a series of preparation steps and follow-up activities to insure the success of the Panzhihua Demonstration Project (Figure 13). Follow-up activities such as informational seminars and training workshops played a key role in facilitating the transfer of the demonstrated TRT technologies to Chinese experts.



Box 4. Japan's Green Aid Plan

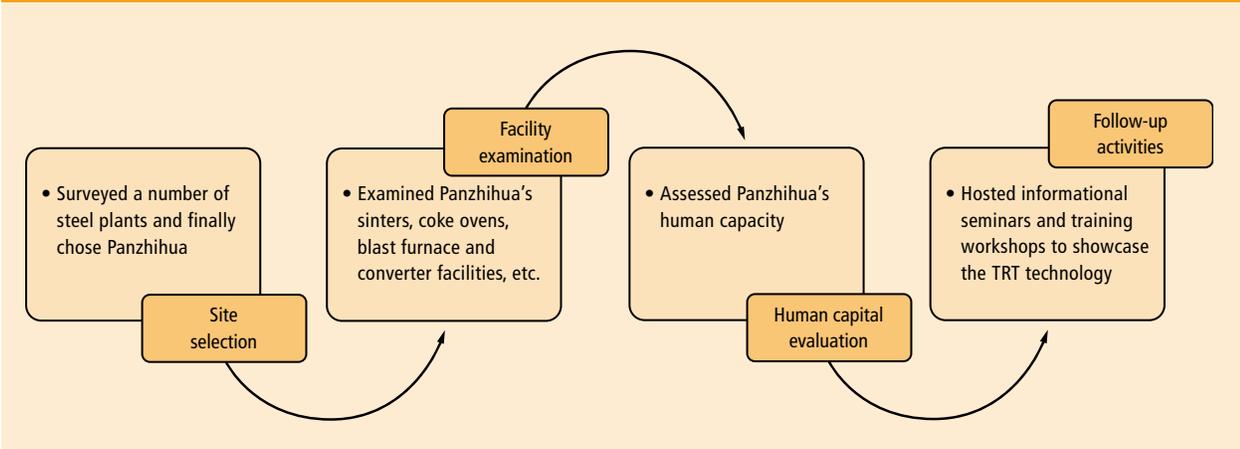
Japan's Green Aid Plan (GAP) was created in 1992. It is led by the Ministry of Economy, Trade, and Industry (METI) and implemented by the New Energy Development Organization (NEDO), Japan External Trade Organization (JETRO), and the Energy Conservation Center, Japan (ECCJ), as well as Japanese technology providers. A distinguishing characteristic of GAP

is that it enabled METI to engage in policy dialogues with governments in developing countries. The plan has a strong focus on China. Between 1992 and 2002, 18 out of 35 energy efficiency technology demonstration projects were carried out in China. And nine of the 18 projects were conducted in Chinese iron and steel enterprises.



Source: Ohshita, 2008; METI website

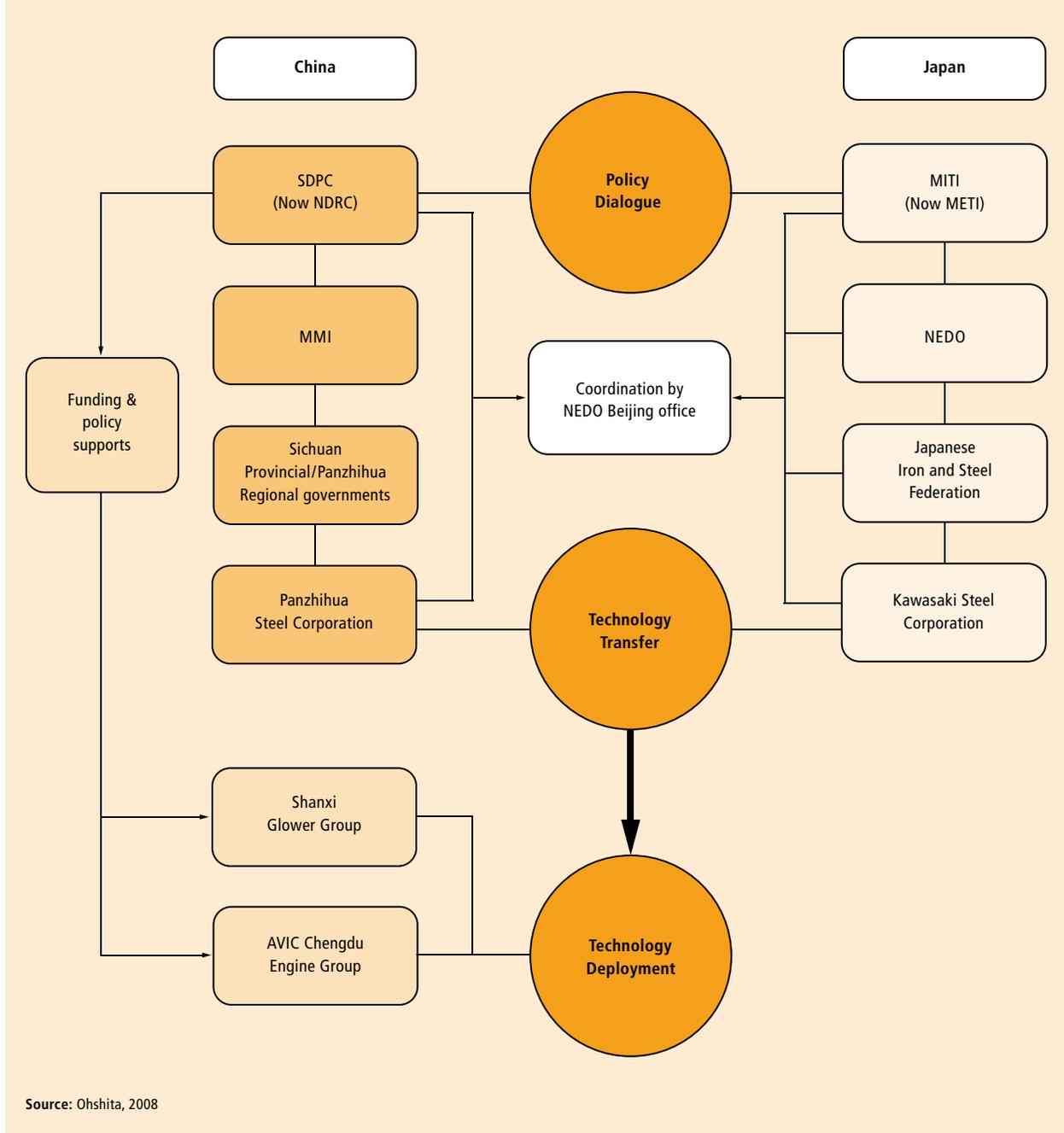
Figure 13. Japanese government's involvement in the Panzhihua Demonstration Project



The Chinese government also actively participated in the process as well. At the national level the SDPC and MMI engaged in the policy dialogue with MITI on the technology and site selections. These agencies also authorized Sichuan Provincial and Panzhihua municipal governments to establish the project as a strategic priority for regional development. This authorization ensured political and financial support from the local governments.

In addition to the government-to-government collaboration, industry associations from both countries also played a supportive role. The Japanese Iron and Steel Federation (JISF) and China Iron & Steel Association (CISA) hosted large gatherings of iron and steel companies in both countries to exchange ideas and promote technology transfer (JISF 2010). Figure 14 demonstrates the collaboration scheme between the two sides.

Figure 14. China-Japan collaboration in the Panzhihua steel TRT demonstration project



Following the project, the Chinese government took several steps to nurture the TRT innovation cycle. First they identified two Chinese companies, Shanxi Glower Group (SGG) and AVIC Chengdu Engine Group (ACEG), to decode the technology, and the government financially supported the two companies' learning activities. In the

early 1990s, the SDPC and Economic and Trade Commission (ETC) listed TRT as one of four key technologies that needed to be quickly diffused and thus it was entitled to a government grant.

In 2003, the NDRC mandated that all blast furnaces with a pressure over 130 kilopascals (kPa) should install



TRT. This was also written in a regulation published by the NDRC in 2004. The mandate created a huge domestic market for TRT units. In 2006 the S&T National Plan further incentivized domestic firms to pursue made-in-China energy efficiency technologies through tax credits. This policy effectively stimulated domestic demand for made-in-China TRT. Finally, in response to the 11th Five-Year Plan, the Ministry of Industry and Information Technology (MIIT) published in 2007 the *Blueprint for TRT Technologies Diffusion*, which highlights the priority and potential of future TRT deployments.

These measures taken by the Chinese government effectively induced the deployment and diffusion of TRT technologies. SGG and ACEG have not only decoded the TRT technology, but also re-innovated the technology to fit China's specific needs. For example, most Chinese blast furnaces are smaller and less efficient than Japanese furnaces. SGG designed and manufactured dry-type TRTs that fit blast furnaces smaller than 1000 m³ in order to meet this need. This re-innovation greatly boosted the diffusion rate of TRT among China's small-scale steel plants.

By the end of 2008, China had manufactured over 400 TRT units, which led to a nearly 80 percent TRT installation rate among blast furnaces in China. These TRT facilities generated a total of 8852 GWh of electricity in 2008 (Table 13), creating huge economic and environmental benefits. The *Blueprint for TRT Technologies Diffusion* laid out the priorities for China's future diffusion: retrofitting current wet-type TRT into the more efficient dry-type TRT and reaching a 100 percent installation rate among all the large blast furnaces (≥3000 m³). Currently over one-third of China's TRTs are wet-type. By converting these into dry-type, electricity generation will increase 10 kWh per ton iron. This leads to an increase of annual generation capacity at 1158 GWh, saving 0.38 million tons of coal a year. China also plans to invest 1.05 billion Yuan (US\$157 million) to build and install 17 dry-type

TRTs at 10 large-scale steel plants in the next five years. Their installed capacity will be 219 MW.

After many years of re-engineering and re-innovation, SGG and ACEG have started to be at the international forefront of TRT technologies. The Blast Furnace Power Recovery Turbine (BPRT) invented by SGG, for example, integrates TRT design with a blower system. This breakthrough technology greatly simplifies the TRT system and reduces its energy consumption. Anyang Steel Plant's 450 m³ blast furnace has successfully installed the BPRT.

The competitive edge of Chinese TRT manufacturers has become a successful model of state-led efforts to transfer energy efficiency knowledge in developing countries. However, this model didn't last long and it might not be replicable. In early 2002 Japan discontinued the Green Aid Program in China. According to Evans (1999) and Ohshita (2008), the conflicts of interest between the Japanese government and Japanese firms were the main cause. MITI relied on the private sector to carry out technology transfer efforts. Firms, however, have their own interests: maximization of long-term profits.

SUMMARY

The transfer and deployment of TRT technologies for steel manufacturing in China has been a joint effort by the Chinese and Japanese. The TRT case draws attention to the significance of international cooperation. Through technology demonstration, especially hands-on training and dissemination workshops, the Panzhihua Demonstration Project, jointly led by SDPC and MITI, not only provided TRT hardware, but also software to China. The Chinese consequently took advantage of this opportunity by increasing the technological absorptive capacities of its firms. This included financially supporting Chinese firms' technology learning, creating a domestic market for made-in-China TRT equipment and laying out a national TRT diffusion blueprint.

Table 13. TRT installation rate among China's blast furnaces, 2008

Volume		≥3000m ³	2000–2999 m ³	1000–1999 m ³	300–999 m ³	<300m ³	Total
Blast furnace	Number	27	52	79	301	54	513
	Annual iron production	252.3 million tons			107.6 million tons		359.9 million tons
TRT	Installation rate	95.6%			70%		79.3%
	Installation capacity	1760 MW			747 MW		2507 MW
	Annual generation capacity	6055 GWh			2797 GWh		8852 GWh

Source: Tsinghua Study, 2009

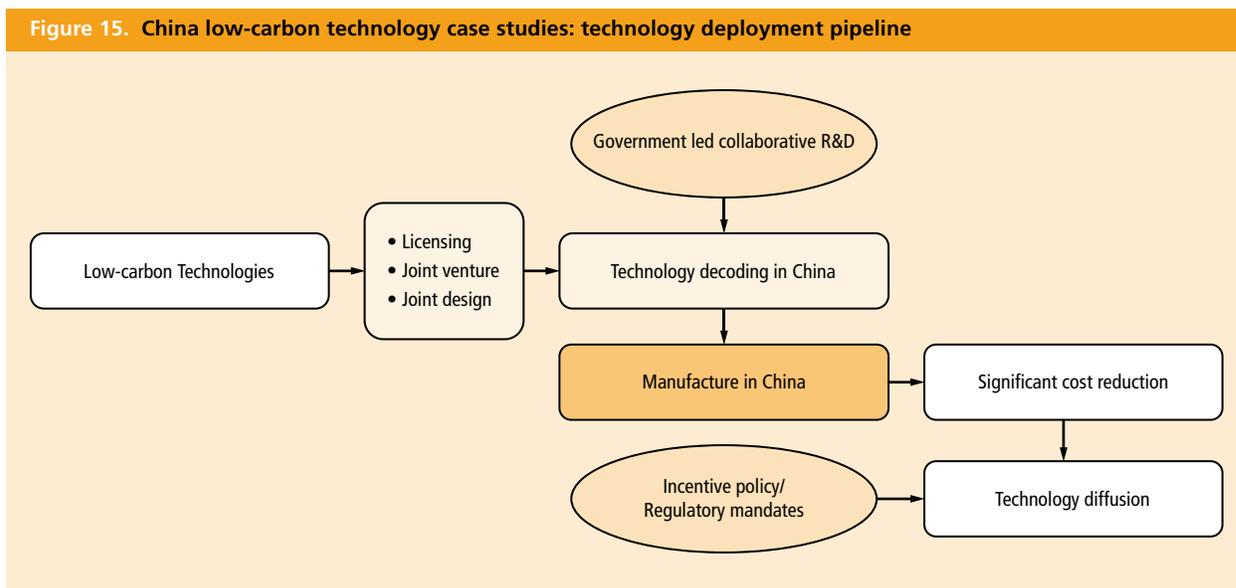


Conclusion

This report examines how low-carbon technologies were introduced, adapted, deployed, and diffused in three specific sectors in China: SC/USC coal power generation, wind energy, and steel manufacturing. While each case study reflects notable success, perhaps the most striking feature is the different approaches they adopted. This should caution against drawing conclusions too broadly: these brief case studies cannot be used to draw comprehensive lessons about technology deployment systems in

China. Nor, given the unique conditions of China, can we easily draw lessons that will apply across other countries. Results from other studies also show that there is little sign of a single optimum path to success (Lall 1998). Through focusing on key policy aspects and programs, however, the report reveals some important building blocks for technology deployment. While each sector told a different story, they all suggested a complex and iterative process as illustrated in Figure 15 below.

Figure 15. China low-carbon technology case studies: technology deployment pipeline





To localize core energy technologies, the Chinese government made a deliberate and holistic plan for each identified technology. At the early stage of localization, the 863, 973, and national Key Technology Programs were the main instruments to support decoding efforts. Once a technology has been decoded, a set of incentive policies and regulatory mandates were introduced to scale-up commercialization and drive down costs of the technologies. This formula has worked to meet the Chinese government's technology transfer goals but it has also included inefficiencies and had reputational impacts.

FINDINGS

- **Deployment:** China has accelerated domestic low-carbon technology deployment in recent decades, making the transition from technology importer to a major manufacturer of a number of low-carbon technologies. China's comprehensive efforts to put in place the infrastructure to achieve accelerated deployment and diffusion of the three technologies examined in this report illustrate its commitment to becoming a global player in the low-carbon economy, as well as to securing a domestic energy supply.
- **Role of Domestic Policy:** China's experience highlights the important role of effective domestic policy in stimulating low-carbon technology. While the government took different approaches for each of the case study technologies, its building blocks for technology deployment infrastructure include:
 1. Making a deliberate, holistic plan and long-term commitment to the localization of a low-carbon technology, as demonstrated in all three cases.
 2. Establishing direct R&D funding programs to support the launch and scale-up of low-carbon technology innovation. This approach is especially prominent in the case of SC/USC coal-fired power generation technology.
 3. Improving businesses' technological absorptive capacity through funding technology learning and creating domestic markets. The success enjoyed by two leading Chinese low-carbon technology companies—Goldwind's surge in the global wind market and Shanxi Glower Group's dominance of the domestic TRT market—are both indebted to this measure.
 4. Capitalizing on public-private and industry-academia synergies to bring together multi-sector expertise. The success of the localization of SC/USC in particular is built on such multi-sector synergies.

5. Designing national-level and sector-wide laws, policies, and regulations to scale-up commercialization of low-carbon technology and drive down the costs. The rapid development of domestic wind energy greatly benefited from such a legal and regulatory infrastructure.
6. Relying on international cooperation to pursue new-to-market technology and knowledge. TRT technology's transfer and deployment resulted from China-Japan cooperation in the steel sector.

- **Technology Transfer and IPR:** While Western governments raise IPR with Chinese counterparts as one of their principal trade issues, the multinational companies in our survey reported that IPR was fairly low on their list of concerns. This is not because the problem does not exist, but rather because they use a number of tools to manage it, including holding back some of their IPR. This approach, however, is suboptimal for both Chinese and international companies.

The SC/USC case study prompted significant IPR concern among international companies that their technology was transferred to one company and then re-transferred to others. In fact, the technology was first transferred to a state entity, the former State Economic and Trade Commission (SETC), and the single license then shared with multiple companies. It isn't clear whether the international companies involved understood that SETC was acting as the agent for more than a single Chinese company. This agreement happened almost 30 years ago, when China was first opening up, so confusion on both sides is not surprising. Nevertheless, it is clear that lessons learned from that case have increased international companies' caution and influenced how multinationals manage cooperative arrangements and licensing in China.

In spite of ongoing IPR concerns, many multinational companies benefit from China's huge market. While CE and ABB lost their Chinese market after China started manufacturing SC/USC components, Alston, Siemens, Mitsubishi, and Toshiba all benefited through selling production licenses to the Chinese SC/USC producers, even if they did not do the manufacturing themselves. In the wind industry, Chinese companies lack the design capacity to develop cutting-edge turbines and rely exclusively on foreign innovations accessed through purchased IPR. When foreign companies can work with Chinese partners and stay involved in manufacturing for both the domestic and international markets, there is clearly opportunity for a mutually beneficial relationship.

In essence, in both the SC/USC and the TRT case studies, the Chinese government managed the technology transfer on behalf of the Chinese companies involved, and the Chinese companies were treated as a cohesive unit rather than as competitors. The underlying issue, therefore, is not the nature of Chinese IPR protection, but the nature of Chinese contracts, business relationships (both business-to-business and business-to-government), and trust and transparency, as described in Box 2 in the Introduction.

A decade elapsed between the SC/USC and TRT cases. While the latter involved more transparency, both appear to have created similar legacies:

1. The Chinese government viewed these cases as successes and would like to use this government-managed model again.
2. The international companies involved were less convinced of the projects' success; company pressure led to the abandonment of Japanese government-sponsored transfers.
3. Business relationships considered normal outside China, involving private contracts and a high degree of trust, were short-circuited in favor of government-managed solutions that initially produced quicker results. But the government role appears to have slowed or restricted later development of these relationships.
4. International companies typically do not transfer all parts of a technology to China, and they often choose to delay deployment. This practice may be motivated by IPR, business secrets, or contractual control concerns.

KEY MESSAGES AND LESSONS LEARNED

■ For Chinese policymakers

1. China's comprehensive efforts to put in place the infrastructure to achieve accelerated deployment and diffusion of low-carbon technology has been very successful. Within 30 years, China has emerged from a pure technology importer to a major manufacturer of low-carbon technology. If the same level of effort continues, China will soon be a player at the forefront of low-carbon technology innovation. However, underlying China's tremendous success are some concerns that need to be addressed.
2. China's preoccupation with localizing key energy technologies may be viewed by foreign companies and governments as going against standard international business practices, such as relying on trade to acquire technologies. The global wind industry, for example, is a globally integrated industry. China's

ambition to localize key wind energy technologies, such as bearing and electric controls, leaves China outside the global integration process—a process that can be harnessed to reduce the cost of wind technologies by increasing economies of scale, fostering competition, and encouraging innovation (Kirkegaard et al. 2009).

3. In spite of the national government's effective technology deployment policy, China has not yet addressed the pressing issue of deployment of low-quality technologies. The low entry barrier for wind energy developers highlighted by the case studies, in particular, underscores the importance of setting high technology standards at the beginning of technology deployment.
4. China's business sector still has lessons to learn in conducting international business negotiations. On the one hand we see government-managed processes in the coal and steel sectors that—while effective—may have left some legacy of distrust; on the other hand we see the hyper-competitiveness of the wind industry with its minimal barriers to entry. Nurturing a more sophisticated business sector through market means is a key task for Chinese policymakers seeking to minimize costs and barriers and maximize trust and cooperation so as to grow low-carbon technology industries.

■ For U.S. policymakers

1. China's ambition is to emerge as a global science and technology power and Beijing is keenly aware that the next phase of the science and technology revolution will center on clean technology. While the term “indigenous innovation” has been interpreted in international policy circles as encompassing a very narrow group of government procurement policies, in fact, the policies are much more ambitious and involve the kinds of long-term support for RD&D that are detailed in these three case studies.
2. There are major opportunities for U.S. companies in China's clean technology deployment efforts. The success of Japanese and German companies in the wind and power sectors indicates that through joint venture, licensing, or joint design, foreign technology providers can benefit from China's financial resources, manufacturing capacity, and enormous market. While China's ambitious localization process for low-carbon technology has raised concerns about intellectual property rights in foreign governments and among OECD companies, major multinationals surveyed as part of the study did not view IPR as a major issue.



In the three case studies, the issue was somewhat more ambiguous. There did not appear to be any outright IPR violation, but instead different perceptions of ownership and contracts have colored some of the arrangements.

3. China's experience highlights the importance of effective domestic policy and long-term government commitment. Without clear and lasting signals from the government and a central role for government-funded R&D, the market will not automatically embrace low-carbon technology.

■ For technology providers

China's preference for domestically manufactured technologies can present a competitive risk for foreign companies seeking a foothold in China. However, in practice, depending on the technology investors' own conditions and needs, foreign technology providers can make a profit through various approaches:

1. **Joint venture:** Benefits include easy access to the Chinese market and freedom for foreign companies to use their own business model to sell products. One disadvantage is the possibility of leaking intellectual property rights to local partners. Because of this drawback, many joint-venture companies in China act as manufacturers or post-sale maintenance facilities instead of technology developers.
2. **Licensing:** Its benefit is guaranteed patent fees and royalties free of concerns about the technology users' business model. The disadvantage is that China's exports might swamp the marketplace and the patent owners only receive a small portion of the profit, usually from 3–6 percent of profits.
3. **Joint design:** If technology providers lack manufacturing capacity and financial resources, joint design offers good access to China's financial capital and enormous market. The drawback is that all patent rights are lost to the Chinese partner companies.
4. **Wholly foreign-owned investment:** Benefits include freedom for foreign investors to use their own business model and easy access to China's large skilled and relatively inexpensive labor force. For China this is a mechanism for training up a workforce in new technologies and related services. The disadvantage for the foreign company is that the Chinese government and scholars do not view wholly foreign-owned investment activities as a technology transfer mechanism. Therefore the foreign investors are less likely to receive administrative or financial support from the Chinese government.



■ For other countries who are adapting technology

Other countries might lack the tremendous scale of resources for domestic investment in R&D that China can bring to bear, but China's experience demonstrates some clear successes from which other countries can benefit. These include: the active role of the government in pursuing bilateral engagement internationally (in the case of steel); the importance of providing clear and lasting signals for low-carbon energy markets (in the case of wind); and the central role that government-funded R&D can play (as illustrated by the localization of all three technologies).

The detailed case studies in this report can also inform activities undertaken by the international climate technology mechanism. Technology transfer and diffusion throughout the developing world will be central tasks for the cooperative mechanism that is established.

However, when reflecting on the lessons that China's experience brings for technology transfer internationally, it is important not to lose sight of China's unique advantages. The size and growth of the Chinese market has meant that foreign companies are prepared to make concessions that they may be less willing to entertain in smaller markets. In addition, most developing countries lack the tremendous scale of resources for domestic investment in R&D that China can bring to bear. Nevertheless, the active role of the government in pursuing bilateral engagement internationally (in the case of steel), the importance of providing clear and lasting signals for low-carbon energy markets (in the case of wind) and the central role that government-funded R&D can play (as illustrated by progress on coal technology) give some clear instances of success from which other countries can benefit. Such learning will be critically important to efforts to scale-up low-carbon technology deployment around the world to counter climate change.

References

- ArcelorMittal. 2008. Safe sustainable steel. Annual Report 2008. <http://www.arcelormittal.com/>
- Archibugi, D., and C. Pietrobelli. 2003. The globalization of technology and its implications for developing countries – Windows of opportunity or further burden? *Technological Forecasting & Social Change* 70: 861–883.
- Autonet. 2009. Made-in-China power generation equipment top the world market. <http://pv.autoooo.net/info/4/25451.html>. Viewed Feb. 16, 2010.
- Balling, L., and G. Rosenbauer. 2007. Power generating technology to meet European market requirements. Paper presented at the 2007 Power-Gen Europe conference, 26–28 June, Madrid, Spain.
- BCSE (Australian Business Council for Sustainable Development) and CREIA (Chinese Renewable Energy Industries Association). 2006. Pursuing renewable energy business with China. September. http://www.cleanenergycouncil.org.au/cec/resourcecentre/reports/Past-Reports/businchina/mainColumnParagraphs/0/text_files/file/China1.pdf
- Bergek, A., and S. Jacobsson. 2002. The emergence of a growth industry: A comparative analysis of the German, Dutch, and Swedish wind turbine industries. *Journal of Evolutionary Economics* 12(1–2): 197–227.
- Block, F., and M. Keller. 2008. Where do innovations come from: Transformations in the U.S. national innovation system, 1970–2006. The Information Technology & Innovation Foundation (July). <http://archive.itif.org/index.php?id=158>
- Bonvillian, W., and C. Weiss. 2009. Taking covered wagons east. *Innovations Journal* 4(4): 289–300.
- CAIT (Climate Analysis Indicators Tool). 2005. World Resources Institute. <http://cait.wri.org/>
- Caselli, F., and W. Coleman. 2001. Cross-country technology diffusion: The case of computers. *American Economic Review*, American Economic Association 91(2): 328–335.
- CBS News Online. 2010. Where America Stands: Green Energy. March 9. Video. <http://www.cbsnews.com/video/watch/?id=6283348n&tag=mncol;lst;3>
- CCCIN (China Climate Change Info-Net). 2008. China's first large-scale off-grid wind power project to start trial tests next year. July 24. <http://www.ccchina.gov.cn/en/NewsInfo.asp?NewsId=13620>
- Chen, E., and J. Dunning, eds. 1994. *Transnational corporations and technology transfer to developing countries*. The UN Library on Transnational Corporations. London: Routledge.
- China Bureau of Statistics. 2009. China science and technology statistics data book. Chinese. <http://www.sts.org.cn/>
- China Wind Power Center. 2009. Wind energy resource characteristics and development potential. <http://www.cwpc.cn/cwpc/en/node/6295>
- Christmas, I. 2008. A global steel sector approach. World Steel Association Presentation. December 8. <http://www.worldsteel.org/pictures/newsfiles/Global%20sector%20approach%20position%20paper%20and%20release.pdf>
- Comin, D., and B. Hobijn. 2003. Cross-country technology adoption: Making the theories face the facts. Economic research report, C.V. Starr Center for Applied Economics. http://www.newyorkfed.org/research/staff_reports/sr169.pdf
- Comin, D., and B. Hobijn. 2004. Cross-country technology adoption: Making the theories face the facts. *Journal of Monetary Economics* 51(1): 39–83.
- CREIA (China Renewable Energy Industries Association), Greenpeace, and GWEC (Global Wind Energy Council). 2006. A study on the pricing policy of wind power in China. October. <http://www.gwec.net/fileadmin/documents/Publications/Report%20wind-power-price-policy%20china.pdf>
- Diazanadon, L., K. Gallagher, M. Bunn, and C. Jones. 2009. Tackling U.S. energy challenges and opportunities: Preliminary policy recommendations for enhancing energy innovation in the U.S. Belfer Center for Science and International Affairs, Harvard Kennedy School. http://belfercenter.ksg.harvard.edu/files/ERD3_Energy_Report_Final.pdf
- Downs, E. 2007. The fact and fiction of Sino-African energy relations. *China Security* 3(3): 42–68.
- Dubois, P. 2007. Assessment of EU policies supporting wind power development. Paper presented at China Wind Power Research and Training, Beijing.
- EC (European Commission). 2008. Investing in European research: Towards 3% of GDP: Key figures 2008/2009. Belgium: European Communities. http://ec.europa.eu/invest-in-research/monitoring/statistical01_en.htm
- EIA (U.S. Energy Information Administration). 2009. Annual energy review 2008. June. <http://www.eia.doe.gov/aer/pdf/aer.pdf>
- EPRI (Electric Power Research Institute). 2008. Program on technology innovation: Integrated generation technology options. Technical update. November. <http://mydocs.epri.com/docs/public/000000000001018329.pdf>
- Evans, P. 1999. Japan's green aid plan: The limits of state-led technology transfer. *Asian Survey* 39(6): 825–844.
- Freeman, C., and C. Perez. 1988. Structural crises of adjustment: Business cycles and investment behavior. In *Technical change and economic theory*, ed. G. Dosi, 38–66. London: Francis Pinter.
- Gallagher, K.S. 2006. Limits to leapfrogging in energy technologies? Evidence from the Chinese automobile industry. *Energy Policy* 34(4): 383–394.

- GWEC (Global Wind Energy Council). 2008. Global wind energy outlook 2008. October. <http://www.gwec.net/index.php?id=92>
- GWEC. 2010. Wind power is crucial for combating climate change. Fact sheet. http://www.gwec.net/uploads/media/Wind__climate_fact_sheet_low_res.pdf
- Hargadon, A. 2003. The best practices of technology brokers. Harvard Business School Working Knowledge for Business Leaders. August 4. <http://hbswk.hbs.edu/archive/3613.html>
- Hogan L., R. Curtotti, and A. Austin. 2007. APEC energy security and sustainable development through efficiency and diversity: economic issues in technology R&D, adoption and transfer. Abare Research Project 07.12; prepared for the eighth meeting of APEC Energy Ministers, Darwin, May. http://www.abare.gov.au/publications_html/energy/energy_07/APEC_security.pdf
- Hu, X.L., D.G. Xin, and S. Qu. 1997. Comparative study on standard energy consumption in high energy using industries between China and other countries. Beijing: Center for Energy, Environment and Climate Change Research, Energy Research Institute.
- Huang, D. 2008. Energy efficiency in China's steel sector. Presentation at APP 5th Steel Task Force Meeting, Busan, Korea, 14–17 April.
- IEA (International Energy Agency). 2006. *Energy Technology Perspectives*. Paris: IEA.
- IEA. 2007. *Tracking industrial energy efficiency and CO₂ emissions*. Paris: IEA/OECD.
- IEA. 2009. *World Energy Outlook*. Paris: IEA: OECD.
- Japan Iron and Steel Federation. 2005. Japan Iron and Steel Federation. <http://www.jisf.or.jp/en/index.html>
- Jerzmanowski, M. 2002. Total factor productivity difference: Appropriate technology vs. efficiency. Brown University.
- Kim, L. 1997. *Imitation to innovation: The dynamics of Korea's technological learning*. Boston: Harvard Business School Press.
- Kim, L., and Y. Kim. 1985. Innovation in a newly industrializing country: a multiple discriminant analysis. *Management Science* 31(3), 312–322.
- Kim, L., and Y. Kim. 1988. Environment, generic strategies, and performance in a rapidly developing country: a taxonomic approach. *The Academy of Management Journal* 31(4): 802–827.
- Kim, L., and J. Utterback. 1983. The evolution of organizational structure and technology in a developing country. *Management Science* 29(10): 1185–1197.
- Kirkegaard, J., T. Hanemann, and L. Weischer. 2009. It should be a breeze: Harnessing the potential of open trade and investment flows in the wind energy industry. WRI Working Paper. <http://www.wri.org/publication/it-should-be-a-breeze>
- Klenow, P., and A. Rodriguez-Clare. 1997. The neoclassical revival in growth economics: Has it gone too far? In *NBER Macroeconomics Annual*, ed. B. Bernanke and J. Rotemberg, 73–102. Cambridge, Massachusetts: MIT Press.
- Kline, K., and N. Rosenberg. 1986. An overview of innovation. In *The Positive Sum Strategy*, ed. R. Landau and N. Rosenberg, 275–305. Washington DC: NAE, National Research Council.
- Lall, S. 1998. Technological capabilities in emerging Asia. *Oxford Development Studies* 26: 213–243.
- Lewis, J. 2006. A review of the potential international trade implications of key wind power industry policies in China. Paper prepared for the Energy Foundation China Sustainable Energy Program, October. http://www.resource-solutions.org/pub_pdfs/China.wind.policy.and.intl.trade.law.Oct.07.pdf
- Lewis, J. 2007. Technology acquisition and innovation in the developing world: Wind turbine development in China and India. *Studies in Comparative International Development* 42(3).
- Lewis, J., and R. Wiser. 2006. Supporting localization of wind technology manufacturing through large utility tenders in Québec: Lessons for China. Paper prepared for the Energy Foundation China Sustainable Energy Program, June.
- Lewis, J., and R. Wiser. 2007. Fostering a renewable energy technology industry: An international comparison of wind industry policy support mechanisms. *Energy Policy* 35(3): 1844–1857.
- Li, J. 2006. Renewable energy policy in China: Overview. Fact sheet by National Renewable Energy Laboratory International Program. www.nrel.gov/international
- Li, J., and G. Hu. 2007. China wind power report 2007. Beijing: China Environmental Science Press.
- Lundvall, B., ed. 1992. National systems of innovation: Towards a theory of innovation and interactive learning. London: Pinter.
- Lundvall, B. 1995. The social dimension of the learning economy. Danish Research Unit for Industrial Dynamics Working Paper No. 96-1. Aalborg University, Denmark.
- McIlvaine Company. 2007. Coal-fired boilers: world analysis and forecast. Northfield, Illinois: McIlvaine Company.
- McKinsey & Company. 2009. China's green revolution: Prioritizing technologies to achieve energy and environmental sustainability. http://www.mckinsey.com/clientservice/sustainability/pdf/china_green_revolution.pdf
- MOF (Ministry of Finance, China). 2009. Policy recommendations to China's wind industry. http://jjs.mof.gov.cn/zhengwuxinxi/diaochayanjiu/200806/t20080620_47472.html
- Mytelka, L., and K. Smith. 2001. Innovation theory and innovation policy: bridge the gap. Paper presented to DRUID Conference, Aalborg, June 12–15.
- Nalbandian, H. 2008. Performance and risks of advanced pulverized coal plant. IEA Clean Coal Center.
- NDRC (National Development and Reform Commission, China). 2009. Approval of the construction of GW-scale wind power base in Gansu Jiuquan during the 11th Five-Year Plan Period. NDRC Energy Approval Document # 1005.
- Nelson, R. 1993. *National innovation system: A comparative analysis*. New York: Oxford University Press.

- OECD. 1992. *Technology and the economy: the key relationships*. Paris: OECD.
- OECD. 2009. *Factoids from the new OECD book: The economics of climate change mitigation: policies and options for global action beyond 2012*. http://www.oecd.org/document/32/0,3343,en_2649_34361_41951200_1_1_1_1,00.html
- Ohshita, S. 2008. Japan-China energy efficiency cooperation: Review, international comparison, future outlook. Prepared for NEDO (New Energy Development and Industrial Technology Organization), Washington, DC.
- Pavitt, K. 1984. Patterns of technical change: towards a taxonomy and a theory. *Research Policy* 13(6): 343–373.
- Qin, Yining. 2010. Interview. March. Lawrence Berkeley National Laboratory.
- Reuters. 2008. HKE obtains approval for wind farm project at Siziwang Qi Region in Inner Mongolia. June 9. Viewed Dec. 7, 2008.
- Rosenberg, N. 1976. The direction of technological change: inducement mechanisms and focusing devices. In *Perspectives on Technology*, ed. N. Rosenberg, 108–125. Cambridge: Cambridge University Press.
- Rosenberg, N. 1990. Why do firms do basic research (with their own money)? *Research Policy* 19(2): 165–174.
- Sagar, A., and B. Zwaan. 2006. Technological innovation in the energy sector: R&D, deployment, and learning-by-doing. *Energy Policy* 34(17): 2601–2608.
- Sawyer, S. 2010. Global wind power sees large increase in investment. February 2. Viewed Feb. 24, 2010.
- Schumpeter, J.A. 1934. *The Theory of Economic Development*. Cambridge, Massachusetts: Harvard University Press.
- Schwartz, L., and R. Hodum. 2008. “China’s wind power industry: localizing equipment manufacturing.” July 18. *Renewable Energy World*. <http://www.renewableenergyworld.com/rea/news/story?id=53076>
- Shanghai Daily. 2009. Stimulus to help push renewable energy bid. May 5.
- Shi, P. 2008. Statistics on installed wind capacity in China. February 28. Chinese. <http://www.cwea.org.cn/upload/20080324.pdf>
- Sinovel News. 2010. Sinovel 3MW offshore wind turbine passes 240-hour test. <http://www.sinovel.com/Latestnews.aspx?id=60>
- Statistics on China’s Wind Energy Installation. 2008. Chinese. <http://www.windpower-china.cn/node/609>
- Tan, X. 2010. Clean technology R&D and innovation in emerging countries—Experience from China. *Energy Policy* 38(6): 2916–2926.
- Timken. 2007. Timken and XEMC Announce Chinese Wind Energy Joint Venture. Press release. December 9. <http://www.timken.com/en-us/about/NewsRoom/Stories/Pages/TimkenandXEMCAnnounceChineseWindEnergyJointVenture.aspx>
- Tsinghua Study. 2009. Case studies of SC/USC, wind energy, and TRT technologies in China. The study was led by Professor Zhang Xiliang and conducted by Yueli, Huo Molin and Zhang Jihong. For a copy of the study, please contact lead author at: XTan@wri.org
- UNEP/GEF. 2010. Blast furnace top-pressure recovery turbine (TRT). EET KB (Energy Efficiency Technologies Knowledge Base). <http://62.160.8.20/eetkb/technologies/details.aspx?id=41>
- Viswanathan, R., R. Purgert, S. Goodstine, J. Tanzosh, G. Stanko, J.P. Shingledecker, and B. Vitalis. 2008. U.S. Program on materials technology for ultrasupercritical coal-fired boilers. *Advances in Materials Technology for Fossil Power Plants: Proceedings for the 5th International Conference (#05226G)*.
- Walz, R. 2007. The role of regulation for sustainable infrastructure innovations: the case of wind energy. *International Journal of Public Policy* 2: 57–88.
- Weiss, C., and W. Bonvillian. 2009. *Structuring an energy technology revolution*. Cambridge, Massachusetts: MIT Press.
- World Bank. 2009. *Coal Power Technology Country Studies: China and India*.
- WSA (World Steel Association). 2008a. Steel and energy. Fact sheet. <http://www.worldsteel.org/index.php?action=programs&id=68&about=1>
- WSA. 2008b. Breaking through the technology barriers. Fact sheet. <http://www.worldsteel.org/index.php?action=programs&id=68&about=1>
- WWEA (World Wind Energy Association). 2009. Wind energy international 2009/2010. <http://www.wwindea.org/home/index.php>
- Xinhua. 2009. Installed but not generating – one third of China’s installed wind capacity is wasted. June 1. Chinese. http://news.xinhuanet.com/fortune/2009-06/01/content_11465237.htm
- Xinhua. 2010. China’s first large-scale offshore wind farm completed turbine installation. February 28. Chinese. http://news.xinhuanet.com/fortune/2010-02/27/content_13063805.htm
- Yamaguchi, M. 2005. Factors that affect innovation, deployment, and diffusion of energy-efficient technologies. Presentation at UNFCCC Workshop on Mitigation Bonn, Germany, May 23.
- Yiping, Z. 2008. *Sectoral study on the iron and steel industry*. London: Chatham House.
- Zhang, X., S. Chang, M. Huo, and R. Wang. 2009. China’s wind industry: policy lessons for domestic government interventions and international support. *Climate Policy* 9(5): 553–564.
- Zou, J., K.S. Wang, S. Fu, et al. 2009. Proposal on innovative mechanism for development and transfer of environmentally sound technologies (ESTs). Beijing: Economic Science Press (both in Chinese and English).

Endnotes

- ¹ R&D intensity is R&D expenditure as a percentage of GDP.
- ² These reductions are based on a 700 MW, 30-year operation, 7,000 full-load hours operation and control technology to reduce emissions of particulate matter to 50 mg/m³, NO_x to 2 mg/m³, and SO₂ to 200 mg/m³.
- ³ Same assumptions as above.
- ⁴ The average cost of wind turbine is 8,500 Yuan/kw. This is based on an interview with the CEO of China Guodian Corporation. Available at: http://news.xinhuanet.com/fortune/2009-06/25/content_11598999.htm
- ⁵ The project was launched in 2004. It groups together all the major EU steel companies as well as several energy and engineering partners, research institutes, and universities in the search for new solutions to CO₂ reduction.

About the Authors

XIAOMEI TAN is the project manager of the China Climate and Energy Program at WRI. Her research focuses on China's climate/energy policy and actions. Ms. Tan's areas of expertise include clean energy technologies, low-carbon technology R&D and innovation, power sector climate policy, and US-China climate and energy communication. Ms. Tan received a Ph.D. in Public Policy, MA in Economics, and BA in Political Science. Her climate and energy related publications include:

- Clean Technology R&D and Innovation in Emerging Countries – Experience from China. *Energy Policy* 38(6) 2010;
- An Emerging Revolution: Clean Technology Research, Development, and Innovation in China. *WRI Working Paper 2009*;
- Policies for Wind Energy Deployment: Challenges and Opportunities for Low Carbon Society in China. 2009. *Low Carbon Society in Asia*. London: Earthscan;
- Renewable Energy – the Path to Sustainability. *Ecological Economy*, Vol. 4, 2008.

Xiaomei Tan can be reached at xtan@wri.org.

DEBORAH SELIGSOHN is the Principal Advisor of the China Climate and Energy Program at WRI. She can be reached at dseligsohn@wri.org.

ZHANG XILIANG is a professor and deputy director of the Institute of Energy, Environment, and Economy, Tsinghua University. He can be reached at zhang_xl@tsinghua.edu.cn.

HUO MOLIN is a doctoral student at Tsinghua University. She can be reached at molin.huo@gmail.com.

ZHANG JIHONG is a post-doctoral student at Tsinghua University. He can be reached at zhuohuo@gmail.com.

YUE LI is a post-doctoral student at Tsinghua University. He can be reached at yueli00@mails.tsinghua.edu.cn.

LETHA TAWNEY is a Senior Associate of International Technology Policy at WRI. She can be reached at ltawney@wri.org.

ROB BRADLEY is a Senior Policy Adviser of Climate Change in the Ministry of Foreign Affairs in UAE. He can be reached at r_bradley@mofa.gov.ae.

About World Resources Institute

The World Resources Institute (WRI) is an environmental think tank that goes beyond research to find practical ways to protect the earth and improve people's lives. Our mission is to move human society to live in ways that protect Earth's environment and its capacity to provide for the needs and aspirations of current and future generations.

Because people are inspired by ideas, empowered by knowledge, and moved to change by greater understanding, WRI provides—and helps other institutions provide—objective information and practical proposals for policy and institutional change that will foster environmentally sound, socially equitable development.

WRI organizes its work around four key goals:

People & Ecosystems: Reverse rapid degradation of ecosystems and assure their capacity to provide humans with needed goods and services.

Governance: Empower people and strengthen institutions to foster environmentally sound and socially equitable decision-making.

Climate Protection: Protect the global climate system from further harm due to emissions of greenhouse gases and help humanity and the natural world adapt to unavoidable climate change.

Markets & Enterprise: Harness markets and enterprise to expand economic opportunity and protect the environment.

In all its policy research and work with institutions, WRI tries to build bridges between ideas and action, meshing the insights of scientific research, economic and institutional analyses, and practical experience with the need for open and participatory decision making.



WORLD
RESOURCES
INSTITUTE

World Resources Institute
10 G Street, NE
Washington, DC 20002 USA

w w w . w r i . o r g