Efficiency in the steel sector

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Technology overview

The iron and steel sector consumes about 19% of global final energy use and accounts for a quarter of direct CO_2 emissions from industry and roughly 4.5% of global CO_2 emissions (WSA 2008a). Steel production is very energy intensive with 20% to 40% 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 CO_2 emissions in OECD countries (ArcelorMittal 2008). The energy efficiency of steelmaking 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 CO_2 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 CO_2 emissions are not possible using current technologies. A portfolio of breakthrough technologies will therefore be required to meet the CO_2 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 CO_2 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 CO_2 Steelmaking Project,[1] 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

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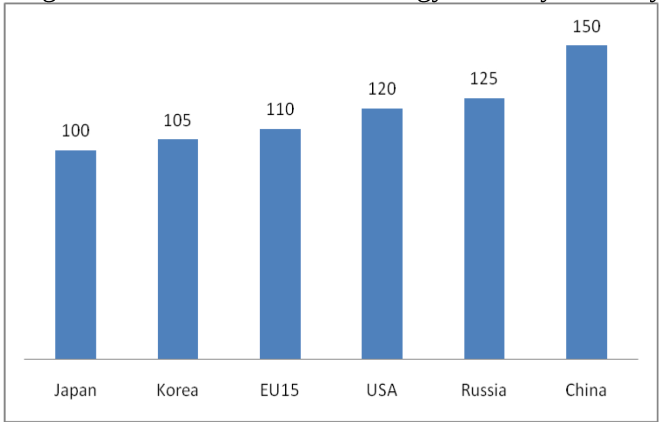
[1] The project was launched in 2004. It groups together all the major EU steel companies as well as several energy and engineering partners, research institutes, and universities in the search for new solutions to CO_2 reduction.

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?

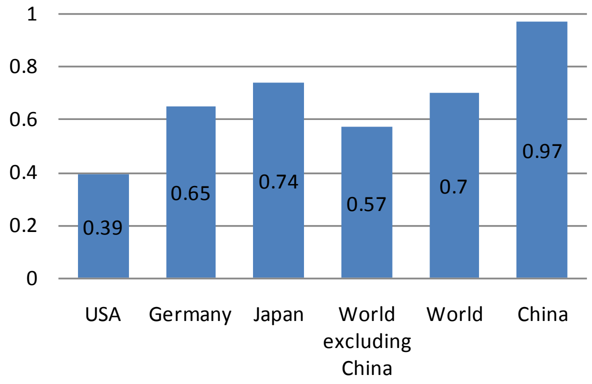
Steel production accounted for nearly 17% of China's primary energy use in 2008. Compared to developed countries' steel producers, China's steel sector has much higher primary energy intensity (Figure 11). This higher intensity can be explained by heavy reliance on coal, relatively higher iron alloy 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 show high pig-iron versus crude steel ratio in China. According to a Japanese study, in 2005 China could have reduced CO_2 emissions by 180 million tons per year by increasing its steel sector's national average energy efficiency to match Japan's (Yamaguchi 2005).

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



Source: Huang, 2008

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% between 2006 and 2010. From 2006 to 2008 the sector's per GDP energy consumption was respectively reduced by 1.8%, 3.7%, and 4.2%. 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.

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

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 steelmaking technologies were deeply influenced by the former Soviet Union where many Chinese leaders and technicians received training in running steel plants.

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 equipments 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.

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

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 200^0C 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 • Equipment only • Including construction cost	 1.4 years 1.8 years

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

equipped with TRT. This innovation partly explains why the Japanese steel sector boasts the best energy efficiency in the world.

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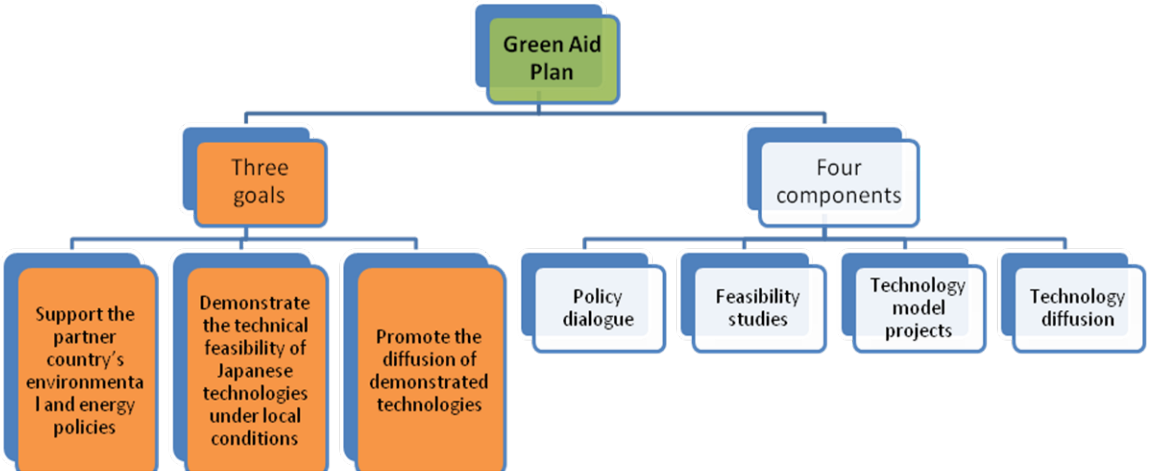
Feasibility studies are often the first step of technology import in China. China's National Science and Technology Plan—the Medium to Long-Term Plan for the Development of Science & Technology—for example, requires an assessment of all imported technologies to evaluate whether China has the capacity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

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.

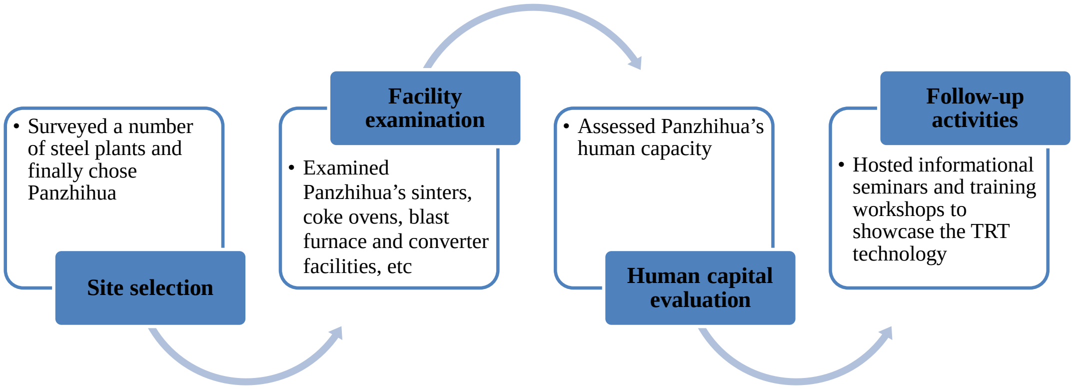


Source: Ohshita 2008; METI website

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.

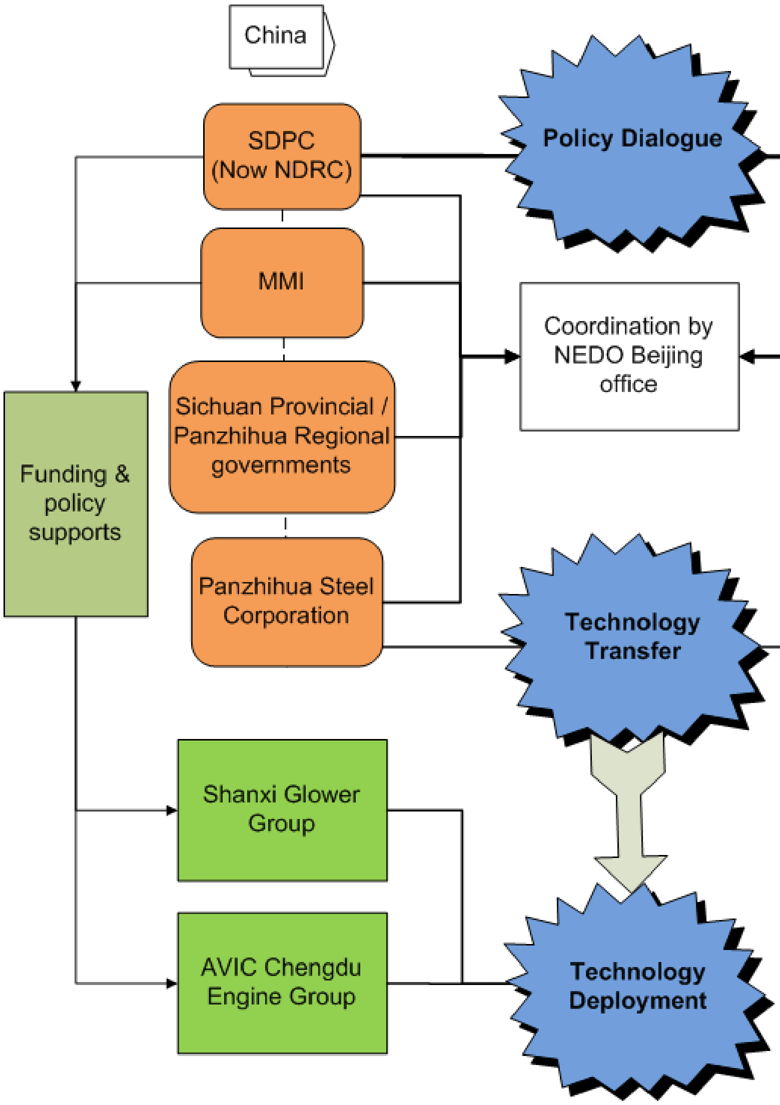
The collaboration between the two governments played a key role in the technology transfer. On the Japanese end, the government made two key contributions: (1) It directly provided funding to Kawasaki to cover the cost of equipment and trainings; and (2) It carried out a series of preparation steps and follow-up activities to insure the success of 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.

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



Source: Ohshita 2008

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 furnace smaller than 1000 m^3 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% 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% installation rate among all the large blast furnaces (≥3000 m^3). 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.

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

Blast furnace	**Volume**	**≥3000m^3**	**2000–2999 m^3**	**1000–1999 m^3**	**300–999 m^3**	**<300m^3**	**Total**
	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

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 m^3 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

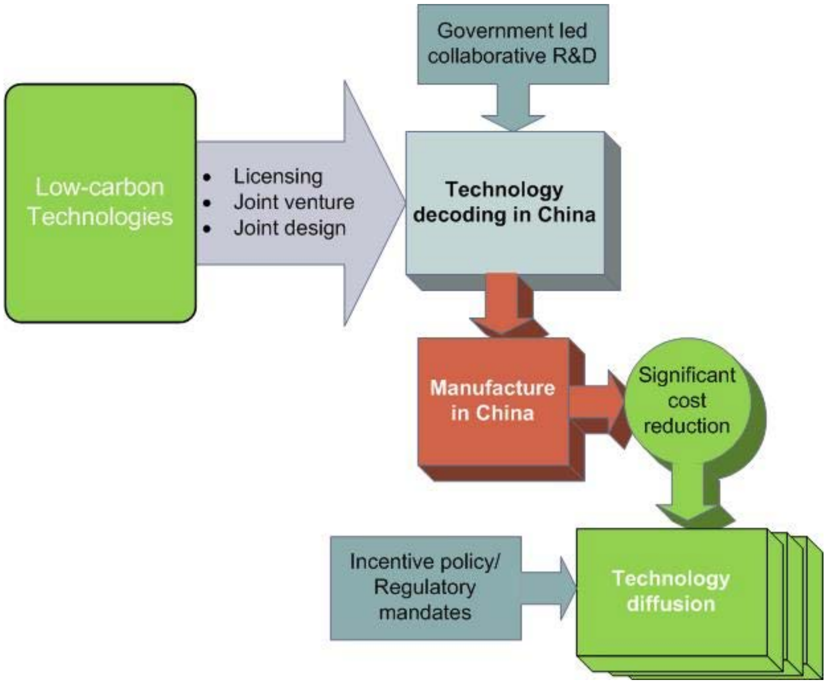
The transfer and deployment of TRT technologies for steel manufacturing in China has been a joint effort by the Chinese and Japanese. The TRT case draws attention to the significance of international cooperation. Through technology demonstration, especially hands-on training and dissemination workshops, 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 equipments and laying out a national TRT diffusion blueprint.

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 below.

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.

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



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 thirty 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% of profits.

3. **Joint design:** If technology providers lack manufacturing capacity and financial resources, joint design offers good access to China's financial capitals 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.

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