Using External Finance to Foster a Technology-Transfer-Based CO2 Reduction Strategy in the Cement and Iron and Steel Industries in China

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Disclamer

This paper was produced as a reference paper to inform the discussion paper "New Mechanisms for Financing Mitigation: Transforming economies sector by sector." The views expressed in this paper do not represent the views of WWF nor the agencies that committed financial support to carry out this project.

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An Introduction to the Global Financial Mechanism Supporting Studies Series

Beginning in mid-2008, at the request of several European governments, WWF led an analysis and dialogue on international financing arrangements to address climate change in developing countries. That meant, on the one hand, advancing a technically strong proposal capable of mobilizing the considerable public and private funds that may be needed to attain the below 2 degrees centigrade goal for climate change stabilization and, on the other hand, advancing an equitable proposal that could garner the support of the parties at COP15.

The work approach is designed (a) to bring a bottom-up perspective to the to the current top-down discussion, based on a suit of developing countries' sectoral studies that focus on what it would actually take to move whole economic sectors towards a low emission trajectory; (b) to focus on the operational requirements of an international financing scheme; (c) to engage leading experts on a critical review of relevant experiences and government proposals; (d) to convene experts and negotiators from South and North to discuss these issues; and (e) to present the project findings to key stakeholders and forums in the run-up to COP15.

The program's main conclusions and proposals are in the document: "Global Financial Mechanism. The Institutional Architecture for Financing a Global Climate Deal" that can be downloaded from http://www.panda.org/what_we_do/how_we_work/policy/macro_economics/our_solutions/gfm/

In this Supporting Studies Series we are presenting a dozen reports that were used as inputs to the project. All these studies were commissioned to independent experts or institutions. Some are case studies of mitigation opportunities in different sectors of developing countries (e.g. cement and iron & steel in China and Mexico, coal based power generation in India, renewable energy opportunities in Morocco). Others are stock-taking reports focusing on critical issues for the global climate change financing (e.g. mapping new financing options for climate change, a review of sectoral mitigation proposals, a review of proposals to fund technology cooperation, etc.).

Some of the ideas and proposals in these support series have been carried over to the project recommendations and have been summarized in the main document (either as short summaries, theme boxes, or pull quotes). Still, these documents have much more to offer, and for that reason we present them here in full. As usual, opinions in each document are the sole responsibility of its author(s), and should in no way be considered representative of WWF positions.

Authors and titles in this GFM Supporting Studies Series include:

1. Michael Rock; (Bryn Mawr College) Using External Finance to Foster a Technology Transfer-Based CO_2 Reduction Strategy in the Cement and Iron and Steel Industries in China
2. Christine Woerlen (Arepo consult, Berlin) ; "Opportunities for renewable energy in Tunisia: A country Study
3. The Energy and Resources Institute (TERI, Delhi) "Strategies to reduce GHG emissions from India's coal-based power generation"
4. Britt Childs with Casey Freeman (WRI, Washington DC) "Tick Tech Tick Tech: Coming to Agreement on Technology in the Countdown to Copenhagen"
5. Energia, Tecnologia y Educacion, SC (ETE, Mexico DF) "Strategies to reduce Mexico's cement and iron & steel industry GHG emissions"
6. Charlotte Streck (Climate Focus, Brussels) "Sectoral Transformation Plans as Strategic Planning Tools"
7. Charlotte Streck (Climate Focus, Brussels) "Financing REDD a Review of Selected Policy Proposals

8. Charlotte Streck (Climate Focus, Brussels) “Financing Climate Change: Institutional Aspects of a Post-2012 Framework”
9. Silvia Magnoni “Review of the CDM and Other Existing and Proposed Financial Mechanisms to Transfer Funds from North to South for Mitigation and Adaptation Actions in Developing Countries”
10. Silvia Magnoni “Sectoral approaches to GHG mitigation and the post-2012 climate framework”
11. Weishuang Qu (Millennium Institute, Washington DC) “Using the T21 computing model to forecast production and emissions in China’s cement and steel sectors”
12. Neil Bird et al (ODI, London) “New financing for climate change. And the environment in the developing world”

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Abstract

Following the liberalization and opening up of China's economy to trade and investment in 1978, production in basic industries such as cement and iron and steel exploded. As a consequence, China is the world's largest producer of both, and those industries in China account for a disproportionate share of China's global CO_2 emissions. This paper addresses three questions: If China were to develop state-of-the-art technological capabilities in both of these industries, how large would the potential CO_2 savings be? Is there any evidence that the government of China is assisting firms in building their technological capabilities so that at least some of the firms in these industries have the technological capabilities to reduce CO_2 emissions over a baseline scenario? What role might international finance play in helping firms in these industries achieve a substantially lower CO_2 emissions trajectory? Findings show that potential reductions in CO_2 emissions in these industries are very large. They also show that China has been assisting at least some firms in these industries to build their technological capabilities. This suggests that at least some firms in this industry have the capability to adopt a range of new technologies and management practices that should enable them to achieve substantially lower emissions trajectories. But the cost of moving to lower emissions trajectories in both cement and steel is quite large, roughly US$124 billion, suggesting that international finance might well play a critical role in speeding such a transition.

I. Introduction

Reduction of CO_2 emissions on a large enough scale to affect global climate change will undoubtedly require significant emissions reduction from the world's developing economies, particularly large economies like Brazil, Russia, India, and China (BRIC). Since each of these economies is in the midst of its industrial revolution, each is expected to significantly increase its greenhouse gas (GHG) emissions as industrial development proceeds. Because real income per capita in the BRIC economies is a fraction of average incomes in the economies of the Organisation for Economic Co-operation and Development (OECD), it is unreasonable to expect that reduction in GHG emissions in these economies will occur as a result of policies designed to slow the rate of industrial or income growth. This means that strategies for reducing GHG emissions must focus on win-win opportunities[1] that lower the energy and CO_2 intensity of all economic activity, including that in industry.

The focus here is on demonstrating how an external financing mechanism might be used to achieve substantial reductions of CO_2 emissions from two large CO_2-emitting industries, cement and iron and steel, in China. Attention is centered on external finance because of interest in it in the international community and because finance is an important resource constraint in both industries in China. China is chosen for study because the government is using explicit industrial policies to restructure both industries (Cui 2006; Ligthart 2003; Wang et al. 2007). While the aim of those policies is to rationalize the size distribution of firms in each industry by closing small firms, encouraging consolidation of economic activity into a smaller number of very large firms, and pushing the remaining firms to the technological frontier, as is demonstrated herein, this industrial development strategy offers real and substantial opportunities for putting both industries on substantially lower CO_2 emissions trajectories. The cement and iron and steel industries are chosen because they are very large GHG emitters in China.[2] Taken together, the availability of external finance, the large share of CO_2 emissions occurring in these industries, and a set of industrial development policies aimed at a massive industrial restructuring project provide a unique opportunity to reap substantial reductions in GHG emissions in China. In fact, this combination is unique to China, as none of the governments in the other BRIC countries have articulated a set of industrial policies that provide such an amenable opportunity to lower CO_2 emissions. But this opportunity is also a short-lived one, one that will play out at the speed with which China achieves its industrial policy goals. Unless action is taken now, the country and world may find themselves locked in an unsustainable GHG emissions trajectory.

The argument is made in three steps. To begin with, profiles of both industries outline the current trajectory of output and GHG emissions in these industries. Following that, opportunities for reducing GHG emissions in both industries are outlined. Since the potential for emissions reduction depends on access to state-of-the-art technology and management practices in these industries in the OECD, the financing challenge is also described. The paper closes by considering how an external financing mechanism might be used to put cement and iron and steel production in China on a significantly lower CO_2 emissions trajectory.

[1] Win-win opportunities are ones that reduce GHG emissions without reducing industry or economic growth.

[2] Cement accounts for 15 percent of China's GHG emissions (Cui 2006), while iron and steel accounts for an additional 10 percent (Wang et al. 2007; World Resources Institute 2008).

II. GHG Emissions in Cement and Iron and Steel in China

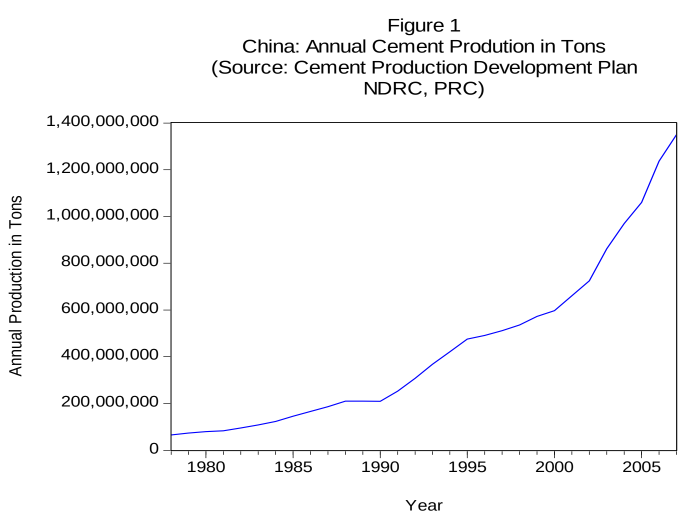
A. Economic and Industrial Growth Since 1978

Following a set of economic reforms first adopted in 1978, the Chinese economy has been growing at almost 10 percent per year, while industry has been growing at nearly 12 percent per year (World Bank 2008). The scale of the increase in the economy and in industry since reforms has been enormous. Real gross domestic product (GDP) in 2007 was more than 33 times larger than it was in 1978; real industrial value added was more than 67 times larger than it was in 1978 (World Bank 2008). Rapid expansion in GDP and industry went hand in hand with rapid urbanization as nearly 450 million people urbanized; 137 million of these live in cities with populations larger than 1 million (World Bank 2008). Similar expansions in the transport sector (roads, rails, and airports) and in power generation, particularly in hydropower (Three Gorges Dam), led to massive expansion in the production of cement and steel—the basic building blocks of urban-industrial economies.

B. Cement

Not surprisingly, given the pace and scale of industrial growth and urbanization in China, cement production has risen rapidly, from roughly 65 million tons in 1985 to more than 1.35 billion tons in 2007 (see figure 1). Production has grown at 11.2 percent per year since 1978. As a result, China currently accounts for about one-half of global cement production (Cui 2006). The next largest producers, India, the United States, and Japan, account for roughly 6 percent, 5 percent, and 3 percent of global production, respectively (China Environment Forum 2008).

Expansion of the cement industry in China since 1978 has been affected by past and present policies. Following the Sino-Soviet split in the 1950s and the isolation of the Chinese economy, the government of China adopted an industrial development strategy of disbursing industry away from its large population centers and its coast while it encouraged local self-sufficiency. The main outcome of this strategy was the growth of locally produced, small-scale vertical shaft cement kilns. Prior to the economic reforms of 1978, virtually all the cement produced in China was with these small-scale kilns. Unfortunately, these kilns are extremely polluting, and they use relatively large quantities of energy (186 kg of standard coal equivalent to produce a ton of cement versus 110 kg of standard coal equivalent to

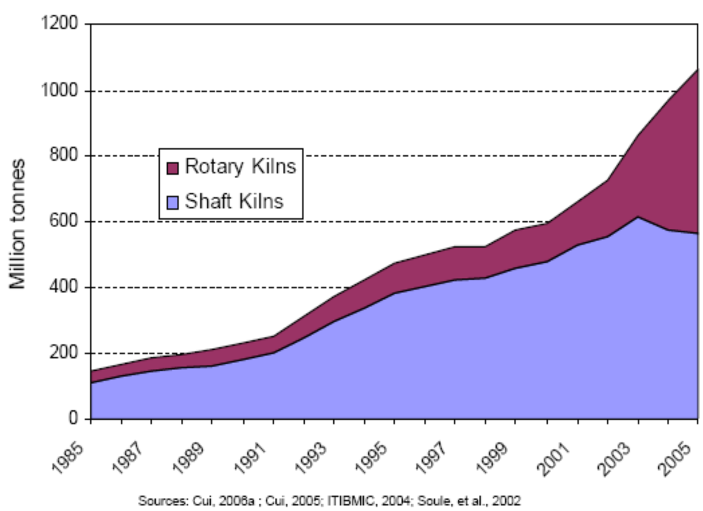


Source: Bureau of Statistics of China (2008) produce a ton of cement in new rotary kilns) to produce very low-quality cement (Cui 2006). Following the opening of the economy to trade and foreign investment, there was some shift away from vertical shaft kilns to more energy-efficient imported, modern, dry rotary kilns with preheaters and precalciners. Source: National

Domestic industry also began producing a Chinese version of these modern rotary kilns. This helped shift at least some of the industry's output away from vertical shaft kilns toward larger, more energy-efficient and less polluting rotary kilns. As a result, by 2000 new rotary kilns accounted for 9.6 percent of production (Kang 2007).

But this process of moving toward larger and more efficient kilns was interrupted by China's economic decentralization policies, which shifted power away from the center toward provinces and lower levels of government. Provincial, county, and township governments responded to decentralization by promoting local industry, including cement. Typically this meant that local government-owned banks extended credit to local governments to invest in a range of local industries to drive up the rate of growth and employment (Wang et al. 2006). In cement, this meant that local governments invested in small-scale vertical shaft kiln cement plants. Thus as a result of history and decentralization, the structure of the cement industry is extremely fragmented, and until the mid-1990s, as shown in figure 2, expansion of cement production by vertical shaft kilns kept pace with expansion by modern, dry rotary kilns.

Figure 2



Fragmentation in the industry is also reflected in the size distribution of firms and in ownership structures. It is also reflected in the low share of output produced in large, modern, dry rotary kilns with preheaters and precalciners (12 percent of production in 2002, Ligthart 2003).[3] As recently as 2002, there were 4,626 firms in the industry operating more than 13,000 kilns. Of these, 3,657 were small firms accounting for 52.7 percent of industry output, and 835 were medium-sized companies producing 26.1 percent of output; there were only 134 large-sized firms, accounting for 21.2 percent of output, capable of attracting foreign investment and/or investing in large, modern rotary kilns with preheaters and precalciners (Ligthart 2003). Of all these firms, only 4 percent had any foreign investment, only 17 percent were state owned with the capacity to attract foreign investment, while the rest were collective

[3] This is so even though rotary kilns now account for roughly 40 percent of output. Many of the rotary kilns in use are small and do not have preheaters or precalciners.

enterprises (26 percent), private enterprises (23 percent), or funded from other domestic sources (30 percent, Ligthart 2003).

The large number of cement firms operating vertical shaft kilns with very small production capacity (between 50 and 200 tons of cement per day compared with the large and more efficient rotary kilns that produce 10,000 tons per day) has created a significant number of problems for the government of China. To begin with, most of these firms suffer from a number of severe structural weaknesses.[4] All too frequently, they have unsecured debt from locally owned government banks. They face highly volatile prices for their product. They produce very poor-quality cement. They have huge unfunded social liabilities for their workers— in the form of housing, schooling, and unfunded pensions—and they have bloated workforces. This combination of factors makes it extremely difficult for these firms to routinely earn profits. To make matters worse, factories in this segment of the cement industry have poor safety records, they are heavy polluters of local environments, and, as noted above, they are extremely inefficient in their use of raw materials and energy (Rock and Angel 2005).

In 1990 the government of China began a program to restructure the cement industry. The aims of the restructuring program are to close small cement plants; shift to larger production lines using state-of-the-art equipment, technologies, and management practices; and consolidate the industry by encouraging the creation of a small number of very large firms in the state-owned enterprise sector that can compete with the small number of international cement conglomerates that dominate this global industry (Ligthart 2003).[5] To achieve these goals the government of China adopted a set of quantitative restructuring goals. By 2010 China expects to have reduced the number of cement firms by 40 percent by closing many of the small firms that use vertical shaft kilns to produce low-quality cement (Price and Galitsky 2007). When combined with planned new investment, large rotary kilns are expected to account for 70 percent of output by 2010 (Price and Galitsky 2007). In addition, the government plans to foster further consolidation in the industry by increasing the share of output by the top 10 firms to 35 percent (roughly 350 million tons) (Price and Galitsky 2007). And it is aiming to reduce integrated energy consumption by 20 percent. By 2020, China expects that energy efficiency across the cement industry will fall from 4.9 gigajoules (GJ) per ton of cement to an international best-practice level of 3.0 GJ per ton of cement (Price and Galitsky 2007). These are ambitious and very costly goals (see table 2).

To date, modest progress has been achieved by this restructuring program. Large, new dry process rotary kilns with capacity to produce more than 5,000 tons per day increased their share of cement production from 9.6 percent in 2000 to 34.2 percent in 2005 (Kang 2007). The top 10 firms in the industry increased their share of production from 4 percent in 2000 to 13.7 percent in 2005, while the top 25 publicly listed companies whose main line of business is cement now account for 25 percent of production (Kang 2007). At the same time, average energy consumption in cement plants has fallen from 4.9 GJ per ton of cement to 3.9 GJ per ton of cement (Cui 2006).[6] Despite these improvements, substantial problems remain. To begin with, the industry continues to be fragmented. Twenty-five percent of all the kilns in China continue to be small (production is less than 1,000 tons per day), 63 percent produce less than 2,000 tons per day, and only 6 percent have the capacity to produce more

[4] The discussion that follows on the structural problems in small locally owned cement plants is drawn from Ligthart 2003.

[5] Competition occurs within China and in the export trade as cement has become a tradable good. To cite one example, Siam City Cement LTD in Thailand can produce and ship cement from Thailand to the United States and sell it at a lower cost than it can be produced in the United States (Rock 2003).

[6] This has occurred by closing many of the small vertical shaft kilns in the industry, but as noted, above serious problems remain that will be more difficult to address.

than 6,000 tons per day.[7] To make matters worse, many of the smaller firms and kilns are owned by local governments that use them to prop up production and employment within their jurisdictions. Given the potential social disruption associated with the closing of many of these small-scale production units, the government is reluctant to move too quickly for fear of increasing social unrest. As a result, energy efficiency in cement production in China is currently 1.3 times international best-practice levels (3.9 GJ/ton of cement vs. 3.0 GJ/ton of cement, Cui 2006). Because of this, CO_2 emissions from cement production in China are roughly proportionate with production, and cement accounts for roughly 15 percent of China's GHG emissions (Cui 2006).[8]

Given the current structure of the cement industry in China and the government's ambitious restructuring goals, three questions need to be asked. First, what is the most likely trajectory of this industry through 2020? Second, given this trajectory, what opportunities exist to drive down the CO_2 intensity of cement production? And third, how might international finance speed such a transition? The first two questions are addressed here; the third is addressed after discussion of the opportunities for saving energy and reducing CO_2 emissions in China's iron and steel industry. Although no rigorous empirical and analytical studies of the trajectory of cement production in China exist, most researchers expect production to decline slowly from the 1.35 billion tons produced in 2007 to about 1 billion tons or less in 2020.[9] With respect to the second question, there are essentially four opportunities for improving energy efficiency in cement production in China (Hohne et al. 2008). They are (1) improving fuel efficiency of kilns by retrofitting existing kilns or replacing them with larger and more efficient kilns, (2) using alternative (waste) fuels in kilns, (3) decreasing electricity use in raw materials preparation and in the grinding of clinker, and (4) shifting to blended cement. Each of these activities along with their energy and CO_2 savings and cost (where available) is described below and summarized in tables 1 and 2.

Retrofitting vertical shaft kilns[10] can improve energy efficiency by reducing heat losses in the kiln, by adopting better process controls, and by installing variable-speed kiln fans. Vertical shaft kilns can be insulated (lined) to reduce heat loss in the range of 0.12 to 0.4 GJ per ton of clinker at a cost of roughly US$0.25 per ton of clinker. Adoption of better process controls can save between 2.5 percent and 10 percent (between 0.13 and 0.54 GJ per ton of clinker) of the energy used to heat kilns at between US$0.30 per ton of clinker and US$1.70 per ton of clinker. Adjustable-speed kiln fans can save roughly 6.1 kilowatt-hours (kWh) per ton of clinker, with unknown cost. Taken together, the energy and CO_2 savings from retrofitting vertical shaft kilns are quite large (see table 1). At the same time, the total costs per intervention (see table 2) vary from $25 million (to reduce kiln shell heat loss) to $100 million (to improve energy management and process control).[11]

The biggest question regarding retrofitting vertical shaft kilns is, does it make sense to retrofit kilns slated for closure? If government policy in this area is effective, virtually all of these kilns will be closed over the next decade. If this happens, retrofitting probably does not make sense. But if employment and social stability objectives outweigh the industrial policy objective of closing these small kilns, retrofitting may well make sense, particularly since the energy efficiency of these kilns is so low.

[7] By comparison, large, modern dry rotary kilns with preheaters and precalciners are capable of producing 10,000 tons per day (Rock and Angel 2005).

[8] Globally, cement accounts for roughly 5 percent of world CO_2 emissions (Cui 2006).

[9] This assumes China will not become a major exporter of cement. Current production is estimated at 1.35 billion tons per year, suggesting that there may be substantial excess capacity. It is not clear how this excess capacity of 350 million tons will be reduced. Some reduction, no doubt, will come from simply closing smaller vertical shaft kilns, but some may also result from exports, as China has begun exporting cement to other countries in Asia (Battelle Memorial Institute 2002).

[10] Unless otherwise noted, data in this section come from tables 1 and 2.

[11] This assumes about 100 million tons of cement will continue to be produced in vertical shaft kilns in 2020.

But given the severe budget constraints faced by the owners and operators of the large number of vertical shaft kilns extant in China, it is highly unlikely that owner-operators will invest in retrofits even if they have, as some do, short payback periods. Thus without some form of government support, retrofitting will, in all likelihood, not occur. Since the government of China plans to close virtually all small vertical shaft kilns, it is unlikely that it will support retrofits in the absence of international finance.

Table 1
Potential Reduction in CO_2 Emissions in Cement from Energy-Saving Interventions

Intervention	Costs (US$) per Ton	Fuel Savings (GJ/ton)	Electricity Savings (KWh/ Ton)	CO_2 Savings (Kg C/Ton)
Retrofitting all kiln types				
Kiln shell heat loss	$0.25	0.4-0.6		10.3-15.5
Energy management/process control	$0.30-$1.7	0.1-0.2	1.5-3.2	2.9-5.9
Adjustable-speed kiln fan	$0.23			
Upgrade rotary kilns by adding				
Precalciner to kiln with preheater	$9.40-$28	0.16-0.7		4.1-18.1
Preheater and precalciner	$8.60-$29	1.4		36
Multistage preheater	$28-$41	0.9		23
Reciprocating grate cooler	$0.40-$5.5	0.27		6.3
Improved kiln combustion system	$1	0.1-0.5		2.6-12.9
Optimize heat recovery/upgrade clinker cooler	$0.10-$0.30	.05-0.16		0.8-3.7
Heat recovery for power	$2.20-$4.40		20-35	4.6-8.1
Low pressure drop cyclone	$3		0.7-4.4	0.16-10
Energy savings in raw-materials processing				
Efficient transport system			3.4	0.78
Raw meal blending			1.7-4.3	0.4-1.0
Process control vertical mill			1.4-1.7	0.3-0.4
High-efficiency roller mill			10.2-11.9	2.3-2.7
High-efficiency classifiers			4.8-6.3	1.1-1.4
Slurry blending and homogenizing			0.5-.9	0.1-0.2
Wash mills with closed-circuit classifier			8.5-11.9	2.0-2.7
Roller mills for fuel preparation			0.7-1.1	0.2-0.3
Replace vertical shaft kiln with rotary kilns with preheaters and precalciners	$41	2.4		62

Source: Worrell et al. (2008)

Retrofitting existing rotary shaft kilns[12] can also yield substantial energy and CO_2 savings. Long, dry kilns can be upgraded with multistage preheaters and precalciners for between $8.60 and $29 per ton of clinker. Fuel savings from this kind of retrofit are potentially quite large (1.4 GJ/ton of cli`nker). Additional savings can be had by upgrading rotary kilns with preheaters and complementing them with precalciners. The cost of this retrofit varies from $9.40 per ton of clinker to $28 per ton of clinker. Fuel savings range from 0.16 to 0.7 GJ per ton of cement. Other opportunities for savings include converting to a reciprocating grate cooler, improving the kiln combustion system, shifting to indirect firing, optimizing heat recovery on the clinker cooler, shifting to more efficient kiln drives, and adopting a variety of heat recovery measures to generate electricity. The costs of adoption along with fuel, electricity, and CO_2 savings are presented in tables 1 and 2. Assuming these interventions are applied to roughly one-half of the rotary kilns in existence in 2005, total costs per intervention (see Table 2) will range from a low of $34 million (for optimizing heat recovery) to a high of $5.8 billion (adding preheaters and precalciners to rotary kilns without them).

As noted in table 2, the cost of a number of these upgrades is quite high. Even though the payback periods for some of these investments are not long—most are less than three years (Worrell et al. 2008)—it is not clear that firms in China are adopting them. In fact, limited available evidence suggests that except for the largest cement firms that are attempting to ratchet up to international best practice, adoption of these upgrades is quite slow. The literature on technological learning suggests why. That literature points out that adoption of new technologies is largely dependent on the willingness of firms to invest in the costly, difficult, and time-consuming process of technological learning associated with adopting, adapting, and operating new capital equipment. As we now know, some, but by no means all, or even a majority of, firms in any industry in any economy are willing to engage in the hard slog of building their technological capabilities. Because of this, there is enormous variability in economic and energy efficiencies across firms in most industries in most economies. What this means is that the speed and spread of adoption, adaptation, and effective operation of the energy-savings opportunities associated with retrofitting rotary kilns are unlikely to be tapped by firms in this industry unless there are strong incentives for them to do so. Supporting these shifts via international finance may well prove to be one of the most effective means to do so.

Replacing vertical shaft kilns with new suspension preheater, precalciner kilns[13] provides a very significant, and in fact the single largest, opportunity for saving energy and reducing CO_2 emissions. Existing evidence in China suggests that vertical shaft kilns consume roughly 5.4 GJ of energy to produce a ton of clinker. Evidence in China also suggests that at least some large, modern rotary kilns with preheaters and precalciners are operating at international best-practice levels by consuming 3.0 GJ of energy to produce a ton of clinker. Conversion of vertical shaft kilns to rotary kilns with preheaters and precalciners costs $41 per ton of clinker (table 2), and if it were applied to the replacement of vertical shaft kilns between 2005 and 2020, it would cost $29.9 billion (table 2). This shift saves 2.4 GJ of energy per ton of clinker and 62 kg of carbon per ton of clinker (table 1).

This kind of shift is also consistent with the government's attempt to rationalize and restructure the cement industry; but as can be seen, it is quite expensive, even though it has a reasonable payback period (five to seven years, Worrell et al. 2008). Despite these high capital costs, China has been moderately successful in shifting production away from vertical shaft kilns to modern rotary kilns with preheaters and precalciners. Between 2000 and 2005, 477 lines of new dry process kilns were added, expanding clinker capacity by 413 million tons, and the proportion of kiln lines producing more than 5,000 tons per day rose from 9.6 percent to 34.2 percent. That said, small vertical shaft kilns continue to account for roughly half of all cement production in China.

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12 Unless otherwise noted, data in this section come from tables 1 and 2.

13 Unless otherwise noted, data in this section come from tables 1 and 2.

Table 2 **Cost in Millions of US$ of Reducing CO_2 Emissions in Cement in China through 2020**			
Intervention	**Cost per Ton of Clinker**	**Million Tons of Clinker**	**Total Cost in Millions of US$**
Vertical Shaft Kilns			
Kiln shell heat loss	$9.25	100	$25
Improved energy management/process control	$1	100	$100
Adjustable-speed drive for kiln fan	$0.23	100	$23
Rotary Kilns			
Kiln shell heat loss	$0.25	170	$42.50
Improved energy management/process control	$1	170	$170
Adjustable-speed drive for kiln fan	$0.23	170	$39.10
Add precalciner to kilns with preheaters	$18.70	170	$3,179
Add preheater and precalciner	$34.50	170	$5,865
Convert to reciprocating grate cooler	$2.95	170	$501.50
Kiln combustion improvement system	$1	170	$170
Indirect firing	$7.40	170	$1,258
Optimize heat recovery/upgrade clinker cooler	$0.20	170	$34
High temperature heat recovery for power	$3.30	170	$561
Low pressure drop cyclone	$3	170	$510
New rotary kilns with preheaters and precalciners	$41	730	$29,930
Shift to blended cement	$0.70	500	$350
Adopt aggressive alternative-fuels program	$3.70	200	$740
Total cost			$43,350

Source: Author's calculations based on the following assumptions and data in Wang et al. (2008) and Cui (2006).
Assumptions:
1. 100 million tons of cement will be produced by vertical shaft kilns in 2020.
2. Adaptations to existing rotary kilns applied to one-half of kilns in existence in 2005 (170 million tons of cement).
3. New rotary kilns with preheaters and precalciners will account for 73 percent of production in 2020 (730 million tons).
4. One-half of cement production (500 million tons) in 2020 will be made up of blended cement.
5. Assumes 20 percent of production (200 million tons) will be fueled by waste materials.

Given the high capital costs of new, large imported kilns with preheaters and precalciners, the only way to speed the importation, adoption, adaptation, and operation of these kilns is to defray at least some of the cost by providing support to firms to make these investments. This is important because China has the capability to produce lower-quality, lower-cost, rotary kilns, but domestically produced kilns have shorter life spans and are smaller.[14]

China can also save energy and reduce CO_2 emissions from cement by **replacing traditional fuels, particularly coal burned in kilns, with waste fuels.**[15] Waste fuels are increasingly used in cement kilns in the United States, Western Europe, Japan, and developing economies such as Thailand (Rock and Angel 2005). In 1999, waste fuels in the cement industry in the United States accounted for 17 percent of fuel inputs. Waste fuels include tires, carpet and plastic waste, dewatered sewage sludge, wooden pallets, rice husks and other agricultural wastes, waste or spent oils, greases, paints, and other hazardous wastes. Assuming these wastes are otherwise and incinerated, burning them in cement kilns can result in net energy and CO_2 savings.[16] There are examples in the cement industry where wastes have constituted as much as 20 percent of energy use, thereby reducing traditional energy use by 0.6 GJ of energy per ton of clinker. Worrell et al. (2008) suggest that it can cost as much as $3.70 per ton of clinker to adapt kilns and feedstock lines and manage the burning of waste fuels in kilns.

Cui (2006) argues that China has ample waste to replace 20 percent of the coal consumed in cement kilns. Assuming this could be done, he estimates that it could reduce CO_2 emissions by 200 million tons or roughly 20 percent of total emissions from cement production. Moving in this direction would cost about $740 million just to adapt kilns and feedstock lines (see table 2). But this is a **lower boundary** cost estimate, as it does not consider the costs of mobilizing a collection, transport, and delivery system that replaces the coal used in cement kilns with waste fuels, nor does it consider the costs of retraining plant engineers and outfitting kilns with state-of-the-art pollution control technology to monitor the pollutants arising from burning waste fuels. As Holcim's experience in Thailand (Rock and Angel 2006) suggests, developing an aggressive and successful alternative (waste) fuels program is neither cheap nor easy. Many technical challenges have to be overcome, plant engineers have to be retrained, and extreme care must be taken to control burning and emissions so as not to undermine the quality of clinker produced or emit known carcinogens associated with the burning of some wastes.

Significant energy can also be saved by **shifting to blended cement.**[17] Blended cements are made by grinding clinker with a variety of additives. Blending cement is relatively inexpensive ($.070 per ton of clinker), and it can yield large energy savings (0.9 GJ/ton of clinker to 3.4 GJ/ton of clinker) and relatively large CO_2 savings (21 kg to 85 kg of carbon per ton of cement). Blended cements are common in Europe and are becoming more common in the United States, particularly because they reduce production costs, expand capacity without high capital costs, and reduce cement kiln emissions. Blended cements also have higher long-term strength and are more resistant to decay (Worrell et al. 2008, p. 27). Assuming China is able to shift roughly one-half of cement production to blended cements, this would cost about $350 million (see table 2).

In sum, table 2 provides a lower boundary estimate of the cumulative cost through 2020 of adopting the energy savings interventions outlined in table 1—those cumulative costs are $43.35 billion. But the interventions they would underwrite are substantial, as CO_2 emissions from cement production would be 450 million tons lower than what they might otherwise have been. This represents a saving of

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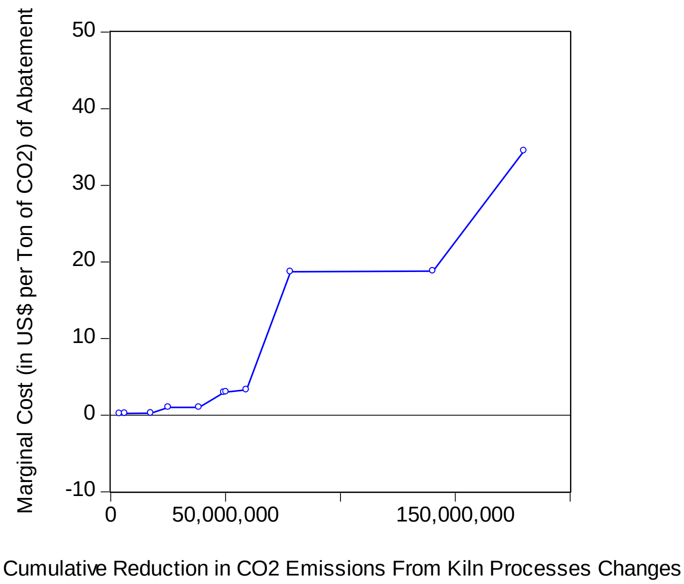
[14] They are not available in kiln sizes above 5,000 tons per day (Wang 2006).
[15] Unless otherwise noted, data in this section come from tables 1 and 2.
[16] Of course if these wastes end up in landfills or are otherwise recycled, CO_2 savings will be substantially less. Unfortunately, too little is known about how these wastes are used or disposed of in China.
[17] Unless otherwise noted, data in this section come from tables 1 and 2.

45 percent. But as table 2 shows, the cost of a number of the interventions is quite high. This can be seen more clearly in figure 3, which describes the marginal cost of abating CO_2. Note that it rises quite rapidly after the abatement of roughly 50 million tons of CO_2.[18]

Figure 3
Marginal Cost (US$ per Ton) of Abating CO2
From Kiln Process Changes Through 2020

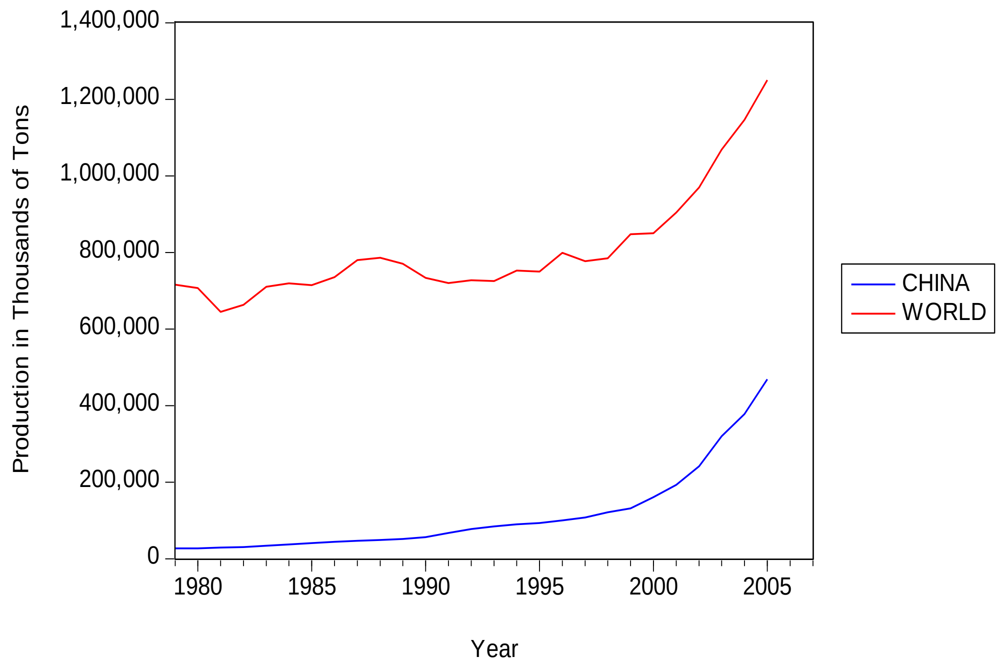


C. Iron and Steel

Following the liberalization of the Chinese economy after 1978, growth in the iron and steel industry, hereafter referred to as the steel industry, has been quite rapid, particularly since the mid-1990s (see figure 4). Crude steel production grew at an annual average rate of 8.1 percent between 1980 and 1995 and rose to 17.8 percent per year between 1996 and 2006. As a result, China became the largest producer of crude steel in the world as its share of world production rose from 3.7 percent in 1980 to 37.4 percent in 2006 (Iron and Steel Institute 2008).

[18] Energy can also be saved by adopting one or more of a large number of **energy efficiency improvements associated with the handling and preparation of raw materials and the grinding of clinker to make cement.** Worrell et al. (2008) describe a wide range of opportunities to save electricity, which appear in table 1. Electricity savings range from a low of 0.5 kWh per ton of clinker to a high of 11.9 kWh per ton of clinker, while CO_2 savings range from 0.1 kg carbon per ton of clinker to 2.7 kg of carbon per ton of clinker. For the most part payback periods are quite long (more than 10 years) and energy savings low. Unfortunately, too little is known about what these interventions might cost; therefore no attempt is made here to calculate either the costs or the savings from these kinds of interventions.

Figure 4
Crude Steel Production (Th Tons)
China and the World

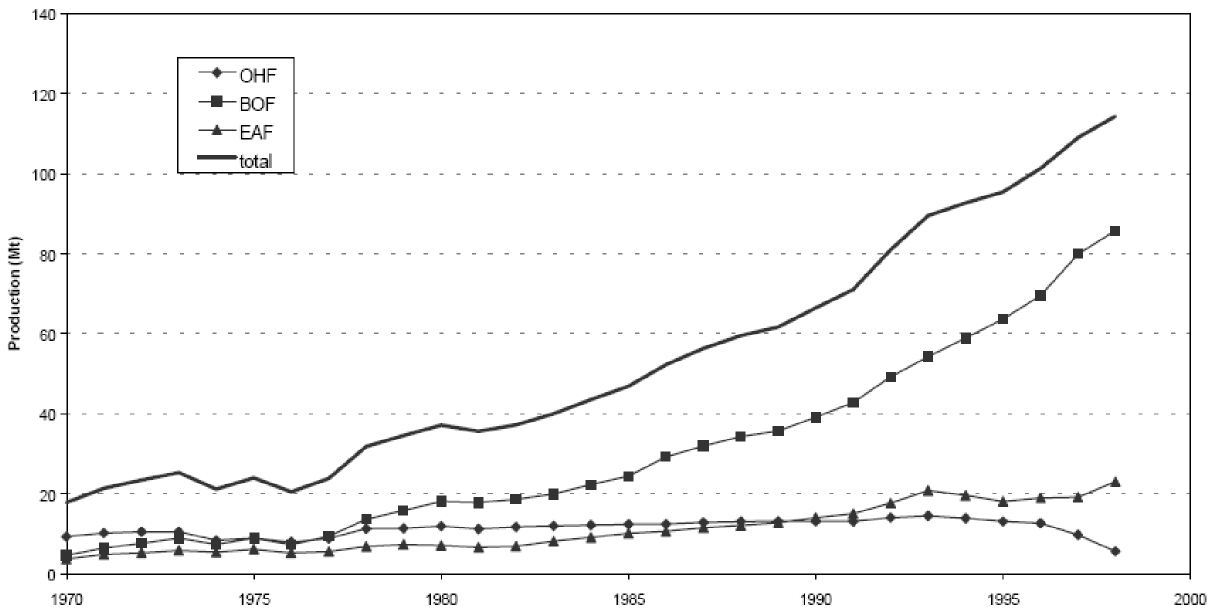


The rapid growth and the emerging structure of the steel industry in China have been affected by the same set of policies that affected the structure of the cement industry. Following the Sino-Soviet split in the 1950s and the isolation of China from the global economy, policy-makers in China set out to disburse iron- and steelmaking away from its coasts and large urban areas. The government also set out to promote local self-sufficiency in steel production. The worst mistake in this policy occurred during the Great Leap Forward, when steel was made in a large number of exceedingly small backyard furnaces. Not surprisingly, this policy promoted proliferation of small-scale iron- and steelmaking facilities throughout China. More recently, policies toward this industry have focused on rationalization and structural adjustment (Wang et al. 2007). Main elements of policy include closing older open-hearth furnaces, shifting production toward larger and more efficient plant sizes, and reducing the number of firms by promoting the emergence of several very large iron and steel conglomerates that can compete in the world economy.

As a consequence of policies during the period of central planning and of more recent decentralization policies, as late as 2004 small-scale blast furnaces for making pig iron accounted for 55 percent of production, while large furnaces (those with capacity greater than 1,000 m^3) accounted for only 17 percent of production (Wang et al. 2007). Similar production structures exist in the size of furnaces used to make crude steel. Only 4 percent of the steel produced in basic oxygen furnaces is produced in large furnaces (capacity greater than 300 tons), while 67 percent is produced in small furnaces (capacity less than 100 tons) (Wang et al. 2007). Similarly, only 30 percent of the steel produced in electric arc furnaces is produced in large furnaces (capacity greater than 100 tons), while 70 percent is produced in small furnaces (capacity less than 100 tons) (Wang et al. 2007). One other characteristic of the Chinese steel industry deserves mention. Because of China's ample supply of admittedly poor-quality iron ore and a limited supply of scrap steel, China is one of the few countries in the world that has been building new, integrated primary steel plants that require production of pig iron to make steel. As a consequence, a large share of crude steel (83 percent) is produced in basic oxygen rather than in more energy-efficient electric arc furnaces (see figure 5) (Price et al. 2001). This means that China may be forgoing an important opportunity to shift to a lower CO_2 trajectory in this industry by shifting production technology toward electric arc furnaces.[19]

Figure 5

Production Process Structure of the Chinese Steel Industry



Source: Price et al. (2001)
Note: OHF = open hearth furnace; BOF = basic oxygen furnace; EAF = electric arc furnace.

Three important consequences flow from past and current policies toward this industry. On the one hand, China has a small number of medium- and large-scale state-of-the-art and energy- efficient steel mills. The largest of these mills operate close to international best practice. By 2003, the 10 largest mills produced about one-third of industry output, while the top four produced 20 percent of output (Wang et al. 2007). Average energy consumption in those mills in 2004 was 705 kg of standard coal equivalent per ton of steel (Wang et al. 2007). This is only 7.5 percent higher than the energy efficiency of medium-sized and large mills in Japan (Wang et al. 2007). On the other hand, the average energy efficiency in China's small mills is 1,045 kg per ton of standard coal equivalent (Wang et al. 2007). This is nearly 50 percent higher than the average of medium and large mills in China and nearly 60 percent larger than those mills in Japan.

Another consequence of the growth in the share of steel output produced in large energy-efficient steel mills is that energy intensity in this industry has fallen quite dramatically from a best-practice index of roughly 250 (where best practice = 100) in 1980 to roughly 180 in 1998 (Price et al. 2001). Not surprisingly, the trend of carbon intensity of steel production in China follows this same pattern (Price and Galitsky 2007). A second consequence is that large technical opportunities remain for

[19] This assumes that China could significantly increase its imports of scrap steel and recover more scrap steel at home. The demand for scrap steel was 75 million tons in 2007, of which all but 10 million tons was provided locally (Wang 2008).

reducing the energy and CO_2 intensity of steel production in China. But tapping those opportunities will require China to close the large number of small, inefficient, and energy-intensive mills and replace them with imported, larger, and more energy-efficient mills. The potential gains from doing so appear quite large—for example, a shift from small to large blast furnaces could save 0.28 tons of CO_2 per ton of steel, while a shift from small to large electric arc furnaces could save 0.16 tons of CO_2 per ton of steel (Wang et al. 2007). Finally, even larger savings in CO_2 could be achieved if China were able to shift production away from integrated steel mills that produce pig iron to electric arc furnaces that rely on scrap, as opposed to pig iron, as the basic raw material for making steel. Such a shift could save 0.61 tons of CO_2 per ton of steel (Wang et al. 2007).[20]

Given the potential for saving energy and reducing CO_2 emissions in the steel industry described above, what might an actual CO_2 mitigation program look like? Wang et al. (2007) provide a good answer to this question. They demonstrate how energy use and CO_2 emissions might be reduced by comparing energy and CO_2 outcomes under three scenarios—a status quo program, a modest energy savings program that reflects policy changes introduced between 2000 and 2005, and a more aggressive CO_2 mitigation program. They also estimate the added costs of reducing emissions via the modest and aggressive CO_2 mitigation program through 2030. They begin by projecting crude steel production in China between 2000 and 2030. As they say, while it is difficult to project steel production that far into the future, conventional wisdom suggests that production will rise at a decreasing rate until 2020, when it will begin a slow decline (Wang et al. 2007).

Assuming crude steel production follows the path they suggest, they then turn to identify a range of technology and management changes in each scenario to reduce CO_2 emissions by 2010, 2020, and 2030. The main differences in the three scenarios are described in table 3 below. As can be seen, the main difference is the speed with which China adopts international best-practice technologies in a range of iron- and steelmaking activities and operates those new technologies at international best levels. For example, under scenario 2, the share of plants adopting dry coke quenching rises from 7.9 percent in 2000 to 18 percent in 2010, 19 percent in 2020, and 23 percent in 2030, while in scenario 3 it rises to 22 percent in 2010, 25 percent in 2020, and 28 percent in 2030. Similarly, in scenario 2, the share of steelmaking with advanced electric arc furnaces rises from 9 percent in 2000 to 22 percent in 2010, 25 percent in 2020, and 32 percent in 2030, while in scenario 3 it rises to 35 percent in 2010, 42 percent in 2020, and 51 percent in 2030. Obviously, the cost of these differences is quite dramatic, so as China shifts from scenario 1 to scenario 3, the cost of the shift from the status quo to scenario 2 rises by \$9.34 billion,[21] while the cost of the shift to scenario 3 is a dramatic \$80.95 billion (Wang et al. 2007).

[20] But this shift assumes that China could significantly increase the use of scrap iron and steel. Available evidence suggests that scrap iron and steel are in short supply in China and in the world. This may well constrain China's ability to save CO_2 by shifting to electric arc furnaces.

[21] The low cost of the shift to scenario 2 is largely due to very large energy savings, which are significantly larger than the costs associated with a series of managerial (establishing an energy management center) and technical (the shift to powder coal injection) changes.

Table 3

Comparison of CO_2 Savings Scenarios										
Intervention: Adopt International Best Practice Technology (IBPT)	Base Year 2000 Share of Plants Adop-ting IBPT	Scenario1 Share of Plants Adopting IBPT			Scenario 2 Share of Plants Adopting IBPT			Scenario 3 Share of Plants Adopting IBPT		
		2010	2020	2030	2010	2020	2030	2010	2020	2030
Coke Making	7.9	18	19	21.8	18	19	23	22	25	28
Dry Coke Quenching	6	25	42	67	40	65	91	45	80	100
Iron-making in Blast Furnaces	8.6	12	18	23	15	23	30	24	34	40
Steel-making in BOF	9.4	23	24	25	18	23	35	27	35	51
Steel-making in EAF	9	18	19	21	22	25	32	35	42	51
Continuous Casting	15	23	28	35	25	31	38	29	38	56
Direct Steel Rolling	13	19	23	26	21	25	29	37	42	49
Cool Rolling	57.1	63	68	72	73	80	71	80	88	

Source: Wang et al. (2007)

How large is the potential reduction in CO_2 associated with the most aggressive reduction scenario (scenario 3), and what is the incremental cost of increasing reductions in CO_2 in that scenario? Table 4 identifies the CO_2 savings associated with each intervention in scenario 3, while figure 6 provides evidence of the marginal cost of abatement. Several findings stand out in table 4 and figure 6. To begin with, the largest annual savings (117 million tons of CO_2) come from reducing the iron-to-steel ratio and shifting to larger and more efficient blast furnaces (90 million tons of CO_2). These two changes alone account for 49 percent of the total savings Wang et al. 2007 project (207 million tons out of 418 million tons).

Table 4

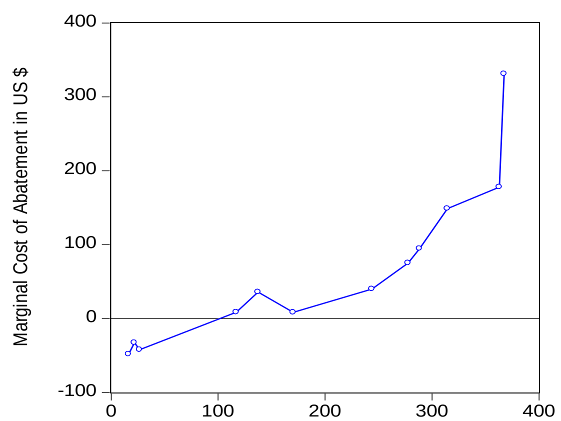
Potential Cumulative Reduction in CO_2 Emissions in Millions of Tons from an Aggressive Emissions Reduction Program in the Iron and Steel Industry								
CO_2 Savings Intervention	**Reductions by 2010**	**Percent Savings**	**Reductions by 2020**	**Percent Savings**	**Reductions by 2030**	**Percent Savings**	**Total**	**Percent Savings**
Energy management center	6.75	4.89	5.89	4.15	3.64	2.62	16.28	3.89
Powder coal injection	4.67	3.38	0.71	0.01			5.38	1.28
Advanced continuous casting	4.14	2.99	0.85	0.01			4.99	1.19
Advanced blast furnace	34.51	25.0	31.24	22.0	24.63	17.78	90.38	21.6
Reduce ratio of iron to steel	33.13	24.0	40.46	28.53	43.55	31.44	117.14	28.00
Dry coke quenching	8.28	5.99	8.52	6.00	3.52	2.54	20.32	4.85
Advanced coke oven	10.72	7.76	7.71	5.43	7.59	5.47	26.02	6.22
Advanced sintering machine	11.73	8.49	11.4	8.00	10.78	7.78	33.91	8.10
Advanced direct steel rolling	1.92	1.39	4.17	2.94	4.43	3.19	10.52	2.51
Advanced converter	10.72	7.76	7.71	5.43	7.59	5.47	26.02	6.22
Advanced EAF	1.75	1.26	4.45	3.14	5.68	4.10	11.88	2.83
Total CO_2 Saved	**138.03**	**100**	**141.78**	**100**	**138.52**	**100**	**418.33**	**100**

Source: Wang et al. (2007)

Table 4 details the remaining CO_2 savings achievable in 2030 under scenario 3. As previously noted, if all of the interventions in the table were adopted, CO_2 emissions from iron and steel in 2030 would be 418.3 million tons, or 18 percent, less than in status quo scenario 1. By comparison, CO_2 emissions would fall by 196.8 million tons under scenario 2, or be 8 percent less than in status quo scenario 1. As is obvious, most of the reduction in emissions occurs under scenario 3.

Interestingly enough, a number of the proposed interventions (establishing an energy management center, using powder coal injection, and shifting to advanced continuous casting) pay for themselves as energy savings exceed the costs of the intervention.[22] At the same time, the cost per ton of CO_2 saved by shifting to large, advanced, and imported blast furnaces is $8.67 per ton of CO_2 saved, that for lowering the iron-to-steel ratio in steel production is $33.56 per ton of CO_2 saved, while that from shifting to advanced and imported smelt reduction technologies is $177.86 per ton of CO_2 saved (Wang et al. 2007). This trend in costs is important because these three interventions alone account for nearly 60 percent of the total reduction in CO_2 emissions under scenario 3. Because of this trend, as figure 6 shows, the marginal cost of CO_2 abatement rises quite rapidly after an annual abatement of about 250 million tons.

Figure 6
Marginal Cost of Reducing CO2
Through 2030



III. Using External Finance to Speed the Transition to a Lower CO_2 Emissions Trajectory

The technological and management interventions described above have the potential to significantly reduce CO_2 emissions from both the cement and the iron and steel industries in China. But these interventions are not cheap, as a lower-bound estimate of those costs is $124.3 billion. Moreover, these CO_2 saving interventions will not occur automatically, nor are they particularly easy to implement. Three basic factors will affect the extent and the speed with which China is able to put both industries on significantly lower CO_2 emissions trajectories. To begin with, the largest savings in both cement and iron and steel come from policies designed to rationalize and restructure both industries—particularly those policies aimed at closing small and inefficient plants and shifting production to larger and more efficient plants. The biggest constraint on this shift is the loss of production, income, and employment to

[22] The cost per ton of CO_2 saved from establishing an energy management center is estimated at -$105.42 per ton of CO_2 (Wang et al. 2007). This suggests an energy saving above the cost of the intervention of $105.42 per ton of CO_2.

those local levels of government (provinces, counties, and townships) that have invested in small-scale cement and steel production following the central government's decentralization policies.

Several aspects of this problem are potentially troubling. To begin with, decentralization means that the central government may not have sufficient authority to implement these changes even if it wanted to. The best evidence available on how difficult it is for the central government to rationalize and restructure an industry following the decentralization of economic policy comes from the country's experience with an attempt to rationalize and restructure the automobile industry.[23] Despite the central government's best efforts to reduce the number of automakers and encourage consolidation within the industry, the industry remains characterized by a large number of small producers, while efforts at consolidation failed because local governments balked at transferring ownership rights to larger political entities (provincial governments and the central government). But even if the central government has the authority to make these changes, it may not be willing to push for full implementation if that risks local social stability. There is enough evidence to suggest that the central government is acutely aware of this problem. Finally, the extent of the shift to larger production units in cement and steel depends on the technical difficulties associated with eliminating a large number of small firms and consolidating their production in a smaller number of larger and more technologically and managerially sophisticated firms. Said another way, it may simply not be technically feasible to eliminate all of the small firms in both industries across China. To the degree to which this is the case, CO_2 savings will be smaller than suggested here.

The second important factor affecting the extent to which and the speed with which the cement and iron and steel industries in China can shift to significantly lower CO_2 emissions trajectories revolves around the willingness of firms in both industries to invest in the hard slog of building their technological capabilities so they can reap the CO_2 savings from adopting and adapting new capital equipment and adopting new management practices. A wide range of evidence suggests that building firm-level technological capabilities is costly, difficult, time-consuming, and fraught with uncertainty.[24] It is also a task that only firms can undertake (Lall 1992). As is now known, there are significant differences in the willingness of firms to undertake and succeed in this task. If this were not the case, productivity and efficiency differences between firms using the same technology in the same industry, within and between countries, would be less than observed (Tybout 1996). If international best practices in particular industries diffused quickly and cheaply, differences in the degree to which firms in those industries in the same country adapted and improved existing industrial technologies would also be smaller than observed (Bell and Pavitt 1992).

In developing countries like China, building firm-level technological capabilities is an imitative not an innovative process. It happens when firms import and adapt existing technologies for local use. Since firms in developing economies often start this process with limited technological capabilities, they face a particularly daunting set of problems. To begin with, they must match their choice of foreign technology to local needs, conditions, and constraints (Dahlman et al. 1987). This requires them to scan the technological horizon to identify and assess the technological possibilities open to them. This is a time-consuming and costly endeavor. Firms must assess the costs and benefits of each possible technological choice. Because different technologies offer substantially different opportunities for adaptation and improvement, initial technology choices tend to limit the capabilities firms can acquire. Because it is difficult for firms to learn across diverse technological dimensions, particular technology choices also tend to move firms along particular technological trajectories. This means that initial

[23] What follows is drawn from Eun and Lee (2002).

[24] Unless otherwise noted, what follows draws on Rock and Angel (2005).

technology choices and subsequent technological activities are path dependent. Because of this it is critical that CO_2 reduction interventions be aimed at getting industries and economies onto cleaner and more efficient development paths as early as possible. This may well require training the engineers and entrepreneurs who make technology choices to look for greener technologies by, for example, exposing them to the rapidly growing literature in industrial ecology.

Once firms narrow their choice to particular technologies, they must decide how to acquire all the elements—information, means, and understanding—associated with their technological choices (Dahlman et al. 1987). Options include relying on foreign direct investment, technological licensing agreements, joint ventures, turnkey projects, purchase of individual pieces of capital equipment, and/or acquiring technological capabilities through technical assistance. Each of these options has advantages and disadvantages. Once having settled on technology choices and the option for acquiring all the elements associated with a particular technology, firms must invest in the arduous task of acquiring the investment, production, and linkage capabilities associated with the technologies they have chosen.

With respect to investment capabilities, firms must learn how to organize and oversee all the activities associated with establishing or expanding a given factory (Lall 1992). This requires the carrying out of feasibility studies, developing training programs to impart particular skills, and learning how to make the technology work in a particular setting. Once the technology is installed, emphasis shifts to acquiring production capabilities—or the capability to operate factories efficiently by optimizing raw material flows and production scheduling while maintaining quality control, troubleshooting problems as they occur, and adapting production processes and products to changing circumstances. Firms must also develop linkage capabilities that enable them to transmit information, skills, and technologies to others, including their suppliers and customers, while they receive information, skills, and technologies from both their suppliers and their customers. None of this is automatic, easy, or cheap. Moreover, this is most likely to happen when firms face incentives that push them to engage in the difficult, costly, and time-consuming process of upgrading their technological capabilities.

This perspective on technological learning within firms has several important implications for the design and implementation of CO_2 mitigation programs in the cement and iron and steel industries in China. To begin with, mitigation programs are not likely to be very successful unless the underlying policy framework in the economy and in industry encourages firms in targeted industries to invest in building their technological capabilities. Absent long-term investments by firms in technological capabilities-building activities, firms are not likely to adopt new technologies or management practices to reduce their CO_2 emissions, even if doing so reduces costs and/or increases profits. Said another way, even if payback periods for the interventions described above are short, many firms are likely to forgo them. While this appears to be irrational, there is ample evidence that firms do in fact behave this way—that is, they often fail to adopt cost-saving and profit-increasing activities.

Two particularly useful environmental examples should suffice. Following passage of the Pollution Prevention Act in the United States in 1990, the U.S. Environmental Protection Agency (EPA) along with a number of consulting firms undertook a large number of industry-specific workshops to demonstrate to firms that many pollution prevention activities pay—that is, they yield net economic benefits while also lowering the environmental burden of economic activity by preventing pollution.[25] Despite this demonstration, the adoption rate of pollution prevention activities that pay has been all too slow as many firms have simply failed to adopt them. Several studies have linked low adoption rates to technological learning problems. On the one hand, some firms do not substitute less toxic inputs for more toxic ones because the switch may be perceived to change, or may actually change, the quality of

[25] What follows draws on Rock et al. (2000)

the final product being supplied (Laughlin and Corson 1995). Thus, although it may pay to make this substitution, firms may be unwilling to take the risk of a negative customer reaction to this new product. They also may not want to take the time and resources necessary to educate customers about the "new" final product. On the other hand, before firms make these switches, they may have to invest scarce managerial and engineering time and even scarcer capital to identify pollution prevention production expenditures (Kiesling 1994). Unless these expenditures have known payoffs better than the alternatives, firms may simply be reluctant to make them (Panayotou and Zinnes 1994). That is, unless the high learning costs of adopting new pollution prevention activities can be overcome and the payoffs from learning are larger than the next best use of scarce managerial and engineering time and scarce capital, firms may simply find it prudent to stick with well-known end-of-pipe abatement alternatives.

A similar logic appears to characterize the reaction of firms in the United States to the EPA's Toxic Release Inventory (TRI) program. TRI requires firms that produce, use, or dispose of a significant amount of a wide range of toxic chemicals to annually report to the EPA on their emissions of those chemicals. Since few of these chemicals were or are subject to environmental regulation, disclosure is not backed by any regulatory action (fines). Despite the lack of regulatory consequences associated with disclosure, following implementation of the disclosure of TRI emissions by the emitters of identified toxic chemicals, emissions fell substantially as firms substituted cheaper and less toxic inputs for their TRI chemicals (Hamilton 1995). In numerous instances, this kind of input substitution substantially reduced costs. This raises an interesting question: Given the large economic gains associated with input substitution, why did many firms not make these substitutions prior to TRI? While there is no definitive answer to this question, it appears that the learning costs and risks of customer loss associated with such shifts prior to TRI reporting discouraged firms from making them. But once public disclosure of emissions occurred and stock markets reacted to differences in emissions across firms by punishing firms with larger than average emissions, senior managers became alarmed that high levels of emissions might undermine the reputations of their firms (Hamilton 1995). Said another way, public disclosure of firms' TRI emissions tilted firm-level incentives toward emissions reduction. This suggests that educating the public about the need to reduce greenhouse gas emissions alongside a program to publicly disclose individual firms' emissions may be an important part of an effective CO_2 reduction program. In the United States, nongovernmental organizations (NGOs) played a critical role in making firm-level TRI emissions data widely available to the public.[26] This suggests that they may have a similar role to play in publicly disclosing the CO_2 emissions of firms in China.

The logic of the literature on firm-level technological learning and the examples cited above suggest that unless firms in cement and steel in China are enticed to invest in building their technological capabilities, they may not be very likely to adopt many of the CO_2 savings interventions cited above. Fortunately, as noted earlier, there is substantial evidence that the government of China has put in place a set of policies designed to entice at least some of the firms in cement and iron and steel to invest in the hard slog of building their technological capabilities. Those policies have contributed to a shift in both industries to larger plant sizes, to lower energy intensities, and to significant technological learning as some plants in both industries operate at international best-practice levels of CO_2 emissions per ton of final product.

The challenge, of course, is to speed the diffusion of international best practices throughout both industries before China completes its industrial transformation in those industries. Unless this happens, China may get locked into a higher CO_2 emissions trajectory than desirable. One way to speed diffusion is to use international finance as a carrot to entice firms to increase their investments in technological learning, particularly in technological learning associated with reducing their CO_2

[26] See the Environmental Defense Fund's TRI Web site (www.scorecard.org).

emissions per unit of product. A carrot is likely to be critical to the speed of diffusion simply because implementation of most of the interventions described above would require expending substantial resources on the import of foreign capital equipment and foreign management know-how. Assuming that roughly 90 percent of the lower boundary estimate of the diffusion costs goes to purchase foreign capital and foreign management know-how, China would have to annually allocate 15 percent of its net export earnings each year between 2011 and 2020 to meet the diffusion demands of these two sectors, or it would have to increase its net foreign direct investment (FDI) flows by 22 percent per year.[27] Given the other needs for hard currency and the high share of FDI that China currently attracts, neither outcome seems particularly likely in the absence of a significant influx of concessional international finance.

Evidence from the newly industrializing economies in East Asia—particularly South Korea (Amsden 1989), China Taipei (Wade 1990), and Singapore (Huff 1999)—suggests a set of principles that might be used to allocate international finance to achieve this outcome. To begin with, international finance should be used to structure strategic collaboration between the public and private sector in the cement and iron and steel industries in China.[28] The aim of this collaboration should be to uncover or discover the real and most significant opportunities for and obstacles to firm-level adoption of technologies and management practices that will drive firms to lower their CO_2 emissions trajectories. This kind of collaboration is needed simply because markets alone will not reveal the opportunities for CO_2 savings. Both information externalities (the underlying cost structure associated with new CO_2 savings activities) and coordination failures (the requirement that simultaneous large-scale investments may be needed, for example, in mobilizing waste fuels in cement making and scrap metal in steelmaking) may have to be overcome before CO_2 savings can be realized.

Viewed this way, the first best policy regarding international finance is to provide financial incentives to new CO_2 savings activities in cement and iron and steel, particularly those activities subject to information and coordination failures. The problem, of course, is that it is extremely difficult to identify information and coordination failures and equally difficult to monitor how the finance is used. One way around this problem is to only finance new CO_2 savings activities, not copycat activities. In addition, provision of finance should be subject to performance requirements. That is, a firm's access to finance and its access to additional finance should be contingent on the level of CO_2 savings. It should also be recognized that some investment activities designed to reduce the CO_2 intensity of cement and steel production will in all probability fail. Because of this, those overseeing the international finance mechanism must be able to weed out bad investments by eliminating finance when they turn out to fail. What all this means is that an international finance program will have to be experimentalist by nature.

Evidence from East Asia suggests that such experimentalist programs have a higher chance of success when there is a policy champion near the top of the political system who supports the program and holds those responsible for implementing it accountable for outcomes. Successful programs also need effective deliberation councils between the public and the private sector. That is, the public sector agency implementing an international finance program for new CO_2 reduction activities must have embeddedness with the private sector so it understands the real problems private sector firms face (Evans 1995). But that agency also needs autonomy from the firms and industry it works with so it is not captured by the industry it is trying to help (Evans 1995). It may also help to publicly disclose both firms'

[27] China's average trade surplus between 2000 and 2006 was US$7.3 billion, while foreign direct investment inflows averaged US$5 billion (World Bank 2008). Assuming the annual trade surplus and FDI inflows do not substantially change, the import costs of the savings in CO_2 in cement and iron and steel would be about 15 percent of China's trade balance and 22 percent of its FDI inflows. If either the trade surplus or FDI flows fall, the costs could be substantially higher.

[28] Much of what follows draws on Rodrik (2004).

initial CO_2 emissions and the success of their attempts to reduce CO_2 emissions. This may impart a critical role to NGOs and the public.

Once a public sector agency has a policy champion in the higher reaches of government and embedded autonomy with the private sector it is attempting to help, it should adopt the following principles of action. It should only finance new activities, not copycat activities. It should use clear quantitative benchmarks to measure success and failure. The agency should operate under a sunset clause that leads to its demise once it has accomplished what it set out to do. It should finance those activities with the greatest potential reduction in CO_2 per dollar of subsidy and with the greatest spillover effects. The agency charged with implementing the finance program must also have clear and visible bureaucratic competence to carry out its task (Evans and Rauch 1999). Activities financed should, where possible, be self-renewing, so they foster continuous improvement. Finally, governments and NGOs should publicly report firm-level successes and failure. While meeting these requirements is difficult, unless one does so there is a very real danger that any international finance program designed to put China's cement and steel industries on lower CO_2 emissions trajectories will simply fail. Given the potential reduction of CO_2 emissions identified above, this failure would be extremely unfortunate.

References

Amsden, A. (1989). *Asia's Next Giant.* New York: Oxford University Press.

Battelle Memorial Institute. (2002) Trends, Challenges and Opportunities in China's Cement Industry. Study commissioned by the World Business Council for Sustainable Development.

Bell, M., and K. Pavitt. (1992). "Accumulating Technological Capability in Developing Countries." *Proceeding of the World Bank Annual Conference in Development Economics:* 257–281. Washington, DC: World Bank. China Environmental Forum. (2008). *Cleaning Up One of China's Building Block Industries*. Washington, DC: Woodrow Wilson Center.

Collins, S. M., and Bosworth, B. (1996). "Economic Growth in East Asia: Accumulation versus Assimilation." *Brookings Papers on Economic Activity* 2: 135–203.
Cui, Yuan-Sheng. (2006). *Potential and Major Strategies for Energy Saving and CO_2 Emission Reduction in the Chinese Cement Industry*. Paris.

Dahlman, C., Bruce Ross-Larson, and Larry Westphal. (1987). "Managing Technological Development: Lessons from the Newly Industrializing Economies (NICs)." *World Development* 15 (6): 759–775.

Eun, Jong-Hak, and Keun Lee. (2002). "Is an Industrial Policy Possible in China? The Case of the Automobile Industry." *Journal of International and Area Studies* 9 (2): 1–21.

Evans, P. (1995) *Embedded Autonomy: States and Industrial Transformation*. Princeton, NJ: Princeton University Press.

Evans, P., and J. E. Rauch. (1999). "Bureaucracy and Growth: A Cross National Analysis of the Effects of Weberian State Structures on Economic Growth." *American Sociological Review* 64 (5): 748–765.

Feng, L. (1994). "China's Steel Industry." *Resources Policy* 20 (4): 219–234.

Fisher-Vanden, Karen, Gary Jefferson, Hongmei Liu, and Quan Tao. (2004). "What Is Driving China's Decline in Energy Intensity?" *Resource and Energy Economics* 26: 77–97.

Goldstein, A. (2005). *The Political Economy of Industrial Policy in China: The Case of Aircraft Manufacture.* William Davidson Institute Working Paper No. 779. Ann Arbor: University of Michigan.

Hamilton, T. (1995). "Pollution as News: Media and Stock Market Reaction to the Toxics Release Inventory Data." *Journal of Environmental Economics and Management* 28: 98–113.

Hohne, N., Ernst Worrell, Christian Ellerman, Marion Vieweg, and Markus Hageman. (2008). *Sector Approach and Development: Input for Workshop—Where Development Meets climate—Development Related Mitigation Options for a Global Climate Change Agreement*. ECOFYS for Netherlands Environmental Assessment Agency.

Huang, C., Celeste Amorim Varum, and Joaquim Borges Gouveia. (2006). "Scientific Productivity Paradox: The Case of China's S & T System." *Scietometrics* 69 (2): 449–473.

Huff, W. G. (1999). "Singapore's Economic Development: Four Lessons and Some Doubts." *Oxford Development Studies* 21: 33–55.

Kang, Xiiangzhang. (2007). *Overview of China's Cement Industry*. Beijing: China Cement Association.

Kiesling, F. (1994). *Minnesota P2 Planning Survey: Results and Technical Report*. Minneapolis: Minnesota Survey Research Center, University of Minnesota.

Kim, L. (1997). *Imitation to Innovation: The Dynamics of Korea's Technological Learning.* Cambridge, MA: Harvard University Press.

Kim, Yeinbae, and Ernst Worrell. (2002). "International Comparison of CO_2 Emission Trends in the Iron and Steel Industry." *Energy Policy* 30: 827–838 (2002).

Lall, S. (1992). "Technological Capabilities and Industrialization." *World Development* 20 (2): 165–186.

Lawrence Berkeley National Laboratory and Energy Research Institute, Beijing. (2008). *Guidebook for Using the Tool BEST Cement: Benchmarking and Energy Savings Tool for the Cement Industry*. Beijing: Author.

Ligthart, A. "The Cement Industry in China: Present Structure, Restructuring Programme, Opportunities." Power Point presentation, London, June 25, 2003.

Linden, G. (2004). "China Standard Time: A Study in Strategic Industrial Policy." *Business and Politics* 6 (3): 1–26.

Nolan, P. (1996). "Large Firms and Industrial Reform in Former Planned Economies: The Case of China." *Cambridge Journal of Economics* 20: 1–29.

Panayotou, T., and C. Zinnes. (1994). "Free Lunch Economics for Industrial Ecologists." In R. Scolow, F. Berkhout, and V. Thomas (eds.), *Industrial Ecology and Global Change:* 383–397. Cambridge: Cambridge University Press.

Price, L., Dian Phylipsen, and Ernst Worrell. (2001). *Energy Use and Carbon Dioxide Emissions in the Steel Sector in Key Developing Countries*. Paper No. LBNL-46987.Berkeley, CA: Lawrence Berkeley National Laboratory.

Price, L., and C. Galitsky. (2007). "Opportunities for Improving Energy Efficiency and Increasing Economic Output in Chinese Cement Kilns." ACEEE summer study on energy efficiency in industry, Berkeley, CA: Lawrence Berkeley National Laboratory.

Rhee, Y. H., et al. (1984). *Korea's Competitive Edge: Managing Entry into World Markets*. Baltimore: Johns Hopkins University Press.

Rock, Michael T., and David P. Angel. (2005). *Industrial Transformation in the Developing World:* 127–149. Oxford: Oxford University Press.

Rock, Michael T., Ooi Giok Ling, and Victor Kimm. (2000). "Public Policies to Promote Cleaner Shared Growth in East Asia." In David P. Angel and Michael T. Rock (eds.), *Asia's Clean Revolution: Industry, Growth and the Environment:* 88–103.

Rodrik, D. (2004). *Industrial Policy for the 21st Century*. Faculty Research Working Paper Series No. RWP04-047. Cambridge, MA: Harvard University, Kennedy School of Government.

Tezuka, Hiroyuki. (2006). "Global Steel Sector Approach." PowerPoint presentation, American Iron and Steel Institute, June 20.

Tybout, J. R. (1996). "Heterogeneity and Productivity Growth: Assessing the Evidence." In M. J. Roberts and J. R. Tybout (eds.), *Industrial Evolution in Developing Countries:* 43–72. New York: Oxford University Press.

Sakamoto, Toshi. (2005). "Case study of technology transfer between Japan and China in iron/steel industry." PowerPoint presentation, Climate Technology Initiative, May 19.

Wade, R. (1990). *Governing the Market*. Princeton, NJ: Princeton University Press.

Wang, Jenn-hwan. (2006). "China's Dualist Model on Technological Catching Up: A Comparative Perspective." *The Pacific Review* 19 (3): 385–403.

Wang, K., Can Wang, Xuedu Lu, and Jining Chen. (2007). “Scenario Analysis on CO_2 Emissions Reduction Potential in China’s Iron and Steel Industry.” *Energy Policy:* 2320–2335.

Wang, L. (2008). “The Energy Management and Emission Control with Chinese Cement Industry: Cleaning Up China’s Cement Sector.” PowerPoint presentation, China Environment Forum, Woodrow Wilson Center, May 16.

World Bank. (2008). “World Development Indicators Online.” Washington, DC: Author.

World Bank. (1993). *The East Asian Miracle.* New York: Oxford University Press.

World Resources Institute. *Earthtrends*. At earthtrends.wri.org/pdf_library/country_profiles/cli_cou_156.pdf. Washington, DC: Author. .

Worrell, E., Lynn Price, Maarten Neelis, Christina Galitsky, and Zho Nan. (2008). *World Best Practice Energy Intensity Values for Selected Industrial Sectors*. Paper No. LBNL-62806. Berkeley, CA: Lawrence Berkeley National Laboratory, University of California.

Worrell, Ernst, Christina Galitsky, and Lynn Price. (2008). *Energy Efficiency Improvement Opportunities for the Cement Industry*. Paper No. LBNL-72E. Berkeley, CA: Lawrence Berkeley National Laboratory, University of California.

Zhang, Qun. (n.d.). Talk about the Chinese iron and steel industry development and environment protection.

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