Circular Economy in the Chinese Steel Industry: Case Studies of Two Pilot Enterprises

Made by ZHANG Chunxia and WANG Haifeng from CISRI

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ACKNOWLEDGEMENTS

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Notes:

① Financial data in the report are expressed in RMB (CNY). Exchange rate: 1 USD = 7.8 RMB (CNY) (People’s Bank of China, rate of December 31, 2006).

② 1 tce (1 ton coal equivalent) = 29.26 GJ
## GLOSSARY OF ABBREVIATIONS AND TERMS

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>APP</td>
<td>Asia Pacific Partnership. Initiated by the US, Japan, China, Australia, India and Korea in 2005, APP aims at developing economy, decreasing poverty, ensuring energy safety and reducing air pollution in the process of dealing with climate change. It is complementary to the Kyoto Protocol.</td>
</tr>
<tr>
<td>Baosteel</td>
<td>Baoshan Iron &amp; Steel Co., LTD.</td>
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<tr>
<td>BF</td>
<td>Blast Furnace</td>
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<tr>
<td>BFG</td>
<td>Blast Furnace Gas</td>
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<tr>
<td>BOF</td>
<td>Basic Oxygen Furnace = converter or LD</td>
</tr>
<tr>
<td>CC</td>
<td>Continuous Casting</td>
</tr>
<tr>
<td>CCPP</td>
<td>Combined Cycle of Power Plant</td>
</tr>
<tr>
<td>CDM</td>
<td>Clean Development Mechanism. One of the flexibility Mechanism defined in the Kyoto Protocol for dealing with air pollution by greenhouse gases.</td>
</tr>
<tr>
<td>CDQ</td>
<td>Coke Dry Quenching</td>
</tr>
<tr>
<td>Circular Economy</td>
<td>A generic term for (quantitative) reduction, reuse and recycle, and turning into resources in the process of production, circulation and consumption. (Draft of the &quot;P.R.C. Circular Economy Law&quot;).</td>
</tr>
<tr>
<td>CISA</td>
<td>China Iron &amp; Steel Association</td>
</tr>
<tr>
<td>CISRI</td>
<td>Central Iron &amp; Steel Research Institute</td>
</tr>
<tr>
<td>COD</td>
<td>Chemical Oxygen Demand. COD is a measure of the toxicity of waste water, measured by the amount of oxygen that is required to oxidize all of the organic and inorganic compounds in a particular waterbody.</td>
</tr>
<tr>
<td>COG</td>
<td>Coke Oven Gas</td>
</tr>
<tr>
<td>COREX</td>
<td>One of the technologies of smelting reduction process in ironmaking invented by Voest-Alpine Industrieanlagenbau (VAI)</td>
</tr>
<tr>
<td>EAF</td>
<td>Electric Arc Furnace</td>
</tr>
<tr>
<td>Four closed-circuits</td>
<td>Closed recycling of by-product gases, iron and steel slag, Fe-bearing dust and waste water</td>
</tr>
<tr>
<td>GDP</td>
<td>Gross Domestic Product. GDP means the total monetary value of the goods and services that are produced by a country, within that country, over a given year.</td>
</tr>
<tr>
<td>GHG</td>
<td>Greenhouse Gases</td>
</tr>
<tr>
<td>IISI</td>
<td>International Iron and Steel Institute</td>
</tr>
<tr>
<td>JFE</td>
<td>JFE Steel Corporation in Japan. In JFE, &quot;J&quot; for Japan, &quot;F&quot; for steel (as in Fe) and &quot;E&quot; for engineering. The acronym can also be thought of as standing for &quot;Japan Future Enterprise&quot;.</td>
</tr>
<tr>
<td>Jinan Steel</td>
<td>Jinan Iron &amp; Steel Group Corporation</td>
</tr>
<tr>
<td>JISF</td>
<td>Japan Iron Steel Federation</td>
</tr>
<tr>
<td>Kyoto Protocol</td>
<td>An international agreement that sets limits on the emission of greenhouse gases</td>
</tr>
</tbody>
</table>
gases into the atmosphere, in order to reduce the threat of global warming by air pollution. It was drawn up under the UNFCCC and agreed in Kyoto, Japan, on 11 December 1997 by the signatory countries to the UNFCCC.

- **LCA**  Life Cycle Assessment or Life Cycle Analysis
- **LCI**  Life Cycle Inventory
- **LD**  Linz Donarwitz
- **LDG**  LD Gas or converter gas or BOF gas
- **LT**  Method for recovering LDG invented by Lurgi and Thyssen in Germany
- **NDRC**  National Development and Reform Commission of China
- **NOx**  Nitrogen Oxides. Nitrogen Oxides (NOx) is a gas compound of nitrogen and oxygen (nitric oxide, nitrogen dioxide, and nitrous oxide) which are produced directly or indirectly from the combustion of fossil fuel and from the processes used in chemical plants.
- **NSC**  Nippon Steel Corporation (Japan)
- **NSFC**  Natural Science Foundation Committee of China
- **OG**  Oxygen Converter gas recovery
- **PCI**  Pulverized Coal Injection
- **POP**  Persistent Organic Pollutant. POP is a chemical substance that is persistent in the environment, bio-accumulates through the food web, and can damage human health and the environment.
- **POSCO**  Pohang Steel Corporation (South Korea)
- **PSA**  Pressure Swing Adsorption

**Renewable resources**  Renewable resources relative to natural resources, generally refers to the wastes generated in the process of society and life consumption, have lost their original value, and after recovery, classification, processing and finishing, will be re-value.

**Secondary resource**  So-called “discarded substances” are also resources, secondary resources generated from a production process. Under certain technical, economic and social conditions, these secondary resources can be recycled.

**SMEs**  small and medium enterprises

**SO₂**  Sulphur dioxide (SO₂) is a colourless and poisonous gas that formed by burning sulphur to create an oxide, most commonly by the burning of fossil fuels that contain sulphur in order to generate electricity in power stations.

**Three-full and two adjustments**  Full hot charge, full regenerative combustion and full multiple length rolling of plate; the adjustment of structure and calorific value of by-product gases.

**Three-high and two low**  High blast furnace temperature, high PCI, high productivity and low delay rate and low coke rate

**TRT**  Top gas pressure Recovery Turbine

**The 11th five-year plan**  Chinese government planning cycle from the year of 2006 to 2010

**UNFCCC**  United Nation Framework Convention on Climate Change

**USTB**  University of Science and Technology Beijing, China

**WSD**  World Steel Dynamic
Case Study on Implementation of Circular Economy at Pilot Steel Enterprises in China

ABSTRACT

As a pillar of China’s recent industrial growth, the rapid development of the steel industry in the last 20 years has been very important to the development of the country’s economy as a whole. Tremendous advances have been made by the Chinese steel industry since 1990 in energy savings and environmental protection. However, the industry is still in a mode of extensive and often reckless development. If this continues, resources and energy will be increasingly hard to come by, and the environment increasingly burdened by pollution. The development of circular economy is therefore an inevitable step toward realizing the sustainable development of the industry.

The Eleventh Five-year Plan (2006-2010) specifies that Jinan steel, Baosteel and a number of other enterprises are to be built up as model circular economy enterprises. In addition, on November 1st, 2005, a plan was issued by six commissions and ministries headed by National Development and Reform Commission (NDRC) to appoint more than eighty enterprises, including Jinan steel and other four steel enterprises, as pilot enterprises of circular economy.

Jinan Steel is a typical medium-large integrated steel group, which has grown from small size to large and in the process of shifting its production from long products to flat products. Baosteel is the biggest and most modern integrated steel group in China, and one of the biggest flat-steel manufacturers in the world. Baosteel is also the only domestic steel enterprise to publicly issue an environmental (or sustainability) report.

In the course of implementing circular economy, Baosteel and Jinan Steel have emphasized optimizing manufacturing efficiency, energy conversion, waste treatment and recycling. Remarkable improvements have been achieved in efficient energy conversion, development of green steel products, utilization and processing of solid “secondary resources” (formerly waste materials), and the expansion of “eco-supply chains” with other industries and with municipalities.

The following are some preliminary conclusions based on the experiences of Baosteel and Jinan Steel:

1) Conceptual guidance and the support of the leadership are important to developing circular economy. The strategic development of an enterprise is decided to a great extent by the understanding and coordinated actions of its leadership.

2) Innovations in organizational structure and management processes are needed to ensure the development of circular economy.

3) Technical innovation is the ‘key’ to the development of circular economy.

4) Some technologies used by Jinan Steel and Baosteel are suitable for replication by other steel enterprises, such as the ‘steel-slag treatment by rotating drum’ technology and ‘green’ steel products developed at Baosteel, or the high-pressure CDQ (coke dry quenching) and high-efficiency energy conversion at Jinan Steel.
Circular economy is still in its infancy in the Chinese steel industry. Some steel plants are just now accepting the concept of circular economy and using it to guide planning, reconstruction and construction, but most steel enterprises basically either haven’t considered, or have yet to start implementing recycling, whether in the industrial supply chain or with municipal waste. There are several important obstacles to the development of circular economy. First, the amount of technologically backward steel production is rather high, and eliminating this backwardness is difficult. Secondly, there is lack of policy support. Thirdly, more systematic research of enabling technologies for circular economy is needed. In addition, certain systems urgently need to be improved, including systems providing statistics on energy, as well as energy measurement and monitoring systems. China has a long way to go toward developing circular economy. For its steel industry, the current main tasks are saving energy, reducing emissions, and making production cleaner.

In a circular economy society there are two main kinds of steel plant that need to be considered: suburban steel plants, and those located in eco-industrial port zones.

Based on our analysis of the policy requirements, the following 5 major suggestions are put forward in this paper.

1) To provide a variety of new types policy support for pilot enterprises, particularly more long-term policy support.

2) To have the government coordinate the steel and power industries so that, after further economic analysis, reasonable policies and price systems can be put in place for connecting the power generated by steel enterprises to the state grid. Steel enterprises should be encouraged to build their own power plants to use residual heat and residual and secondary energies.

3) To promote the utilization of solid secondary resources, the import of scrap should be encouraged while restricting its export. For encouraging the use of metallurgical slag, new grades of cement need to be developed, and uses for slag found in other construction materials. At the same time, enterprises need to be charged higher fees for using natural resources rather than secondary resources such as slag. Government must also guide or organize the recovery, classification, treatment and supply of scrap and waste plastics, and give financial and policy support to this business.

4) To set up a “Steel Industry Circular Economy Technology R&D Center”, to share technologies for circular economy among enterprises, and to develop a comprehensive plan for the systematic optimization of the industry.

5) To stress strict enforcement of environmental laws. At the same time, government should encourage steel enterprises to apply advanced pollution-control technologies by giving them financial support or low-interest loans, as appropriate.
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Circular Economy in the Chinese Steel Industry:  
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1 Background of Circular Economy in the Chinese Steel Industry

1.1 General situation of the Chinese steel industry

The development of the Chinese steel industry has been marked by gradual advances, fluctuations, and very rapid growth in recent years (Figure 1.1). It produced only 160,000 tons in 1949, at the founding of New China, ranking 26th in the world, with 0.1% of total world steel production. But China’s steel industry has come to be of global importance, especially from 1990 onwards. China’s crude steel output was 65 million tons in 1990. By 2006, it had risen to 418 million tons, and accounted for about 34% of the world’s steel output. Its steel output increased 540% between 1990 and 2006, and the year 2006 was the 11th consecutive year that China’s crude steel output was the largest in the world.

![Figure 1.1 The crude steel output of China from 1949 to 2005](image)

The steel industry is a large consumer of resources and energy. Since 1990, the energy consumption of the Chinese steel industry has accounted for about 10%~13% of China’s total energy consumption, while consumption of fresh water stands at around 3.2~4.0 billion tons/a, accounting for about 3% of the total consumption of fresh water of all industrial sectors. The wastewater and exhaust gases of the steel industry accounted for about 14% of total industrial emissions, while solid waste accounted for 16%. Together with the power, chemical, building-materials and nonferrous industries, the steel industry ranks among the top polluting industries, at about No. 3 or 4 in overall pollution.
1.2 Progress in energy savings and environmental protection

1) Economic and technical improvements in steel production

The 1990s were a period of crucial developments in the Chinese steel industry. Driven by increasing domestic demand for steel products, especially for fixed assets, the steel industry has made breakthroughs in six key technologies guided by a strategy of technological advancement. They were, in chronological order: CC (continuous casting) technology; PCI (pulverized coal injection) technology; elongation of the BF (blast furnace); continuous bar and wire rolling technology; integrated energy savings through process adjustments; and slag splashing technology for the BOF (basic oxygen furnace). With these breakthroughs and their subsequent integration, accompanied by strategic capital investments, a huge increase in the use of overseas resources, and the domestication of equipment manufacture for the steel industry, great progress was made in lowering costs and improving product quality. Steel plants have become larger, more modern, and more widely distributed, which, along with adjustments to product structure, has led to dramatic technological and economical improvements in the industry (Table 1.1). The main indices are close to the international level, with some of the largest iron-and-steel enterprises, such as Baosteel, actually reaching that level. Gradual merging of steel enterprises and increasing profits have, along with the technological breakthroughs, established a stable foundation for the rapid development of the Chinese steel industry.

Table 1.1 Changes in the technical and economic indices of the Chinese steel industry between 1990 and 2005

<table>
<thead>
<tr>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Output of steel (million tons/a)</td>
<td>65.35</td>
<td>80.93</td>
<td>92.61</td>
<td>101.24</td>
<td>114.59</td>
<td>128.50</td>
<td>151.63</td>
<td>182.25</td>
<td>222.34</td>
<td>282.80</td>
<td>352.39</td>
</tr>
<tr>
<td>CC ratio (%)</td>
<td>25.07</td>
<td>31.79</td>
<td>41.75</td>
<td>55.91</td>
<td>77.61</td>
<td>86.97</td>
<td>89.44</td>
<td>93.03</td>
<td>96.19</td>
<td>98.35</td>
<td>97.51</td>
</tr>
<tr>
<td>Specific energy consumption (tce/t)**</td>
<td>1.611</td>
<td>1.574</td>
<td>1.519</td>
<td>1.392</td>
<td>1.009</td>
<td>0.920</td>
<td>0.876</td>
<td>0.815</td>
<td>0.770</td>
<td>0.761</td>
<td>0.740</td>
</tr>
<tr>
<td>PCI rate (kg/t)</td>
<td>50.0</td>
<td>50.3</td>
<td>61.3</td>
<td>72.0</td>
<td>94.9</td>
<td>117.0</td>
<td>122.0</td>
<td>125.6</td>
<td>117.7</td>
<td>116.0</td>
<td>124</td>
</tr>
<tr>
<td>BF coke rate (kg/t)</td>
<td>557</td>
<td>551</td>
<td>566</td>
<td>495</td>
<td>496</td>
<td>437</td>
<td>422</td>
<td>417</td>
<td>430</td>
<td>427</td>
<td>412</td>
</tr>
<tr>
<td>BF productivity (t/ (m³ d))</td>
<td>1.73</td>
<td>1.81</td>
<td>1.81</td>
<td>1.75</td>
<td>2.02</td>
<td>2.15</td>
<td>2.34</td>
<td>2.46</td>
<td>2.47</td>
<td>2.52</td>
<td>2.62</td>
</tr>
<tr>
<td>BOF-utilization efficiency of key steel enterprises (t/(t d))</td>
<td>22.60</td>
<td>30.24</td>
<td>28.19</td>
<td>25.59</td>
<td>27.37</td>
<td>31.80</td>
<td>28.08</td>
<td>34.57</td>
<td>36.11</td>
<td>35.64</td>
<td>37.01</td>
</tr>
<tr>
<td>BOF campaign (heat)</td>
<td>438</td>
<td>487</td>
<td>592</td>
<td>1127</td>
<td>1858</td>
<td>3500</td>
<td>3526</td>
<td>4386</td>
<td>4631</td>
<td>5218</td>
<td>5647</td>
</tr>
<tr>
<td>Product yield rate of key steel enterprises (%)</td>
<td>83.21</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>89.81</td>
<td>92.48</td>
<td>94.01</td>
<td>94.19</td>
<td>94.92</td>
<td>95.60</td>
<td>95.61</td>
</tr>
</tbody>
</table>

*Data from 2000 and onwards are statistics from the key steel enterprises only, with the exception of steel output and CC ratio, which include the entire industry. Source: “China Iron and Steel Statistics”

**Specific energy consumption per ton of steel includes many procedures, such as mineral processing, sintering, coking, and auxiliary procedures. 1 tce = 29.26 GJ

2) Results of energy savings and emissions reductions

Progress has been made reducing the energy consumption of the Chinese steel industry, owing to the energy savings brought about by individual pieces of equipment installed in the 1980s, and energy saving procedures set up then, and the systematic energy savings brought about in the 1990s by optimization of processes. The high reduction of
energy consumption per ton of steel is mainly due to the latter (Table 1.2)

<table>
<thead>
<tr>
<th>No.</th>
<th>Category</th>
<th>Energy savings (in million tce*)</th>
<th>Energy savings (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Optimization of steel-manufacturing processes</td>
<td>18.7</td>
<td>40.7%</td>
</tr>
<tr>
<td>2</td>
<td>Adoption of energy-saving technologies and equipment</td>
<td>8.7</td>
<td>18.9%</td>
</tr>
<tr>
<td>3</td>
<td>Improvement of auxiliary steel-production material, etc.</td>
<td>7.1</td>
<td>15.4%</td>
</tr>
<tr>
<td>4</td>
<td>Energy management</td>
<td>11.5</td>
<td>25.0%</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>46.0</td>
<td>100%</td>
</tr>
</tbody>
</table>

*1 tce = 29.26 GJ

During the 1990s, China’s crude steel output nearly doubled, while total energy consumption only increased by about 31%. Between 2000 and 2005, the crude steel output increased by 175%, while total energy consumption grew by only 120.6%. Over the past 5 years, specific energy consumption per ton of steel at key steel enterprises has gone from 0.92tce/t in 2000 down to 0.741tce/t in 2005, a decrease of 19.5%.

As for environmental protection, the pollution situation has remained stable or improved at key steel enterprises, but has become worse in some cases, especially at smaller and more backward enterprises.

At key steel enterprises in China, comparing 2005 with 2000, fresh-water consumption per ton of steel decreased 66% due to technological improvements, the treatment rate of waste water increased from 98% to 99.6%, dust discharge decreased 37.5% on average, the utilization rate of waste residue increased by 41.3%, waste gas emissions per ton decreased by 12.27%, and percentage of plants reaching the waste gas treatment standard improved by 5 points. CO₂ emissions per ton fell somewhat because of the lower energy consumption per ton of steel. All of this came about as a result of technological progress since 2000.

### 1.3 Two main features of the Chinese steel industry

1) BOF steel makes up more than 80% of Chinese steel output

Steel manufacturing involves two kinds of process: the BF-BOF “long” process and the EAF “short” process [3] (Figure 1.2).

- BF-BOF: Hot rolling with iron ore, coal and other natural resources as its inputs.
- EAF: Hot rolling with scrap and other renewable resources as its major sources.

Since the long process involves sintering, coking, use of the BF, and other heavily-polluting procedures (Figure 1.3), the pollution it produces and energy it
consumes are much higher than for the short process. The resources and energy the two processes consume, and pollutants they emit, are compared in Table 1.3.

Figure 1.2 The two kinds of steel production: the BF-BOF “long” process & EAF “short” process

Figure 1.3 Schematic diagram of the main sources of pollution in the BF-BOF “long” process at integrated steel enterprises
Table 1.3  BF-BOF “long” process compared with EAF “short” process in terms of consumption and emissions\textsuperscript{[3-5]}

<table>
<thead>
<tr>
<th>Items</th>
<th>BF-BOF “long” process</th>
<th>EAF “short” process</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw material consumption</td>
<td>~3.7 t/t</td>
<td>~1.2 t/t</td>
</tr>
<tr>
<td>Energy consumption</td>
<td>19~26 GJ/t</td>
<td>8.8~11.7 GJ/t</td>
</tr>
<tr>
<td>Solid material discharge</td>
<td>~0.6 t/t</td>
<td>~0.2 t/t</td>
</tr>
<tr>
<td>Emissions of CO\textsubscript{2} and other gases</td>
<td>~2.3 t/t</td>
<td>~0.52 t/t</td>
</tr>
</tbody>
</table>

* Data for the EAF “short” process are based on the assumption that the process is based on scrap. Emissions from the production of purchased electricity are not included.

Table 1.3 shows that, since the EAF “short” process uses mainly renewable resources such as scrap, it consumes less raw material and energy and discharges less gas and solid material than the BF-BOF “long” process, which uses natural resources. The energy consumption of BF-BOF process is about twice that of the EAF process, while its CO\textsubscript{2} emissions are about 3.8 times as high\textsuperscript{[4]}.

However, with the steel industry in China developing so quickly, the scrap supply is limited, and the BF-BOF “long” process is forced to dominate now. Over the past 15 years, 80% to 88% of Chinese production has been of BOF steel. In developed countries, the proportion of EAF steel is higher, with the world average level at about 33% in 2005: in Japan 26% ~ 30%, in Germany 30%, in the USA 40% ~ 50%, in Italy 60%. China’s lack of scrap, and consequent low EAF ratio, is a major cause of the high energy consumption and heavy pollution of its steel industry.

At present, annual scrap production in China is about 30 ~ 60 million tons, while about 10 million tons are imported, and about 80% of scrap is used by the steel industry. We expect the proportion of EAF production to increase slower than before. Due to the shortage of scrap in China, about 30% liquid metal must be added in EAF steel production\textsuperscript{[5]}.

2) Coal is the primary source of energy of the Chinese steel industry

The leading energy sources in the world are oil, coal and natural gas, in that order (Figure 1.4(b)). But in China, as shown in Figure 1.4(a), oil and natural gas are deficient, while coal is relatively abundant. Coal is therefore the country’s primary energy source, at about 70% (Table 1.4 and Figure 1.4(a)), much higher than the world average (in 2005) of 26.5%. This picture has changed little in recent years.
Figure 1.4  Comparison of Chinese with world-average energy resources

Table 1.4  Percentage consumption of energy sources in China since 1990 [6]

<table>
<thead>
<tr>
<th>Year</th>
<th>1990</th>
<th>2000</th>
<th>2003</th>
<th>2004</th>
<th>2005*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>76.2</td>
<td>66.1</td>
<td>67.1</td>
<td>66.7</td>
<td>68.2</td>
</tr>
<tr>
<td>Oil</td>
<td>16.6</td>
<td>24.6</td>
<td>22.7</td>
<td>23.0</td>
<td>21.6</td>
</tr>
<tr>
<td>Natural gas</td>
<td>2.1</td>
<td>2.5</td>
<td>2.8</td>
<td>2.9</td>
<td>2.8</td>
</tr>
<tr>
<td>Other**</td>
<td>5.1</td>
<td>6.8</td>
<td>7.4</td>
<td>7.4</td>
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</tr>
</tbody>
</table>

** ‘Other’ including nuclear and hydro

Coal also supplies about 70% of the energy consumed by China’s steel industry (Figure 1.5). Coking coal, anthracite coal and steam coal are the main coals it uses, and the proportion it consumes, relative to natural gas and fuel oil, is much higher than that of other important steel-producing countries (Table 1.5). The problem for China is that coal has a lower utilization efficiency than other sources of energy (leading to higher energy costs), and heavier emissions, especially of dust and SO₂. Therefore, problems of energy utilization and environmental protection are more significant in the Chinese steel industry than in the rest of the world[5,7] - a defect inherent to China’s energy resource structure.

Figure 1.5  Energy consumption of the steel industry in China in 2004

Data from the “Chinese steel industry yearbook,” 2005 [8]

Table 1.5  Patterns of energy consumption of the steel industries of several steel-producing countries

<table>
<thead>
<tr>
<th></th>
<th>China (2004)</th>
<th>USA</th>
<th>Germany</th>
<th>Japan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>69.9 %</td>
<td>60 %</td>
<td>55.8 %</td>
<td>56.4 %</td>
</tr>
<tr>
<td>Oil</td>
<td>3.2 %</td>
<td>7.0 %</td>
<td>20.7 %</td>
<td>19.9 %</td>
</tr>
<tr>
<td>Natural gas</td>
<td>0.5 %</td>
<td>17.0%</td>
<td>8.2 %</td>
<td>———</td>
</tr>
<tr>
<td>Other</td>
<td>26.4 %</td>
<td>16.0%</td>
<td>15.3 %</td>
<td>23.7 %</td>
</tr>
</tbody>
</table>

1.4 Problems facing the Chinese steel industry

1.4.1 Lack of metallurgical resources

China is the world’s largest steel producer and consumer, and also its largest iron-ore
Circular Economy in Chinese Steel Industry

consumer. The developed countries, whose population accounts for less than 20% of the world’s, still consume about 60% of the energy and 50% of its ore. In the next 15 to 20 years the industrialization of China, the population of which is about a quarter of the world’s, will face unprecedented pressure on resources.

Relative to its steel output, and when compared to world resources, China has a serious shortage of metallurgical resources (see Table 1.6). Domestic iron ore production in China can only satisfy about half the country’s demands. A great deal of iron ore is imported every year (as much as 275 million tons in 2005), with the growth in China’s imports accounting for 90% of the growth in global iron ore output. Iron supply import dependence reached 53.6% in 2005, with the increase in imports becoming a threat to the safe supply of iron ore in China.

### Table 1.6 Steel-industry resources in the world and in China \(^{[5,8]}\)

<table>
<thead>
<tr>
<th>Resources</th>
<th>Years to be exploited worldwide</th>
<th>Years to be exploited in China</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron ore</td>
<td>156 years</td>
<td>(30+20) years*</td>
<td>China imported 275 million tons in 2005</td>
</tr>
<tr>
<td>Coking coal</td>
<td>40~60 years</td>
<td>(40+20) years</td>
<td>/</td>
</tr>
<tr>
<td>Manganese ore</td>
<td>81 years</td>
<td>Rich ore is imported</td>
<td>About 55% is imported</td>
</tr>
<tr>
<td>Chromium ore</td>
<td>155 years</td>
<td>Rich ore is imported</td>
<td>Almost all of China’s supply is imported</td>
</tr>
</tbody>
</table>

*Exploitation can be prolonged to 50 years (30+20) assuming rational exploitation at current rates.

Coal is abundant in China, but only about 25% of it is coking coal which can be used for steel production. Of this coal, more than half is gas coal, while only 19% of it is prime coking coal, and only 13% is fat coal. The distribution of coking-coal mines in China is very uneven, 66% of them concentrated in North China and about 15% in East China, a situation which matches poorly with the distribution of steel plants.

Along with ore, China also lacks water, with fresh-water resources per capita at just 1/5 of the world level. China has 300 cities short of water, 108 of them seriously, and 80% of steel output is concentrated around large and medium-sized cities \(^{[5]}\). At the same time, water wastage is a serious problem in the Chinese steel industry, even though fresh-water consumption per ton of steel has fallen greatly as a result of measures adopted in last 10 years. A gap of 3~5 m\(^3\)/t still exists between China and Germany, Korea and other advanced steel-producing countries. Fresh-water consumption per ton of steel at Baosteel is lower than 4 m\(^3\)/t, which matches the international level, but at some backward steel plants it is more than 5 times higher, over 20 m\(^3\)/t. The steel industry is a large water consumer, the amount of water held stands at about 100 m\(^3\)/t (at some plants as high as 200 m\(^3\)/t), while typical fresh-water consumption is about 8~15 m\(^3\)/t. The impact of the shortage of water on the sustainable development of the Chinese steel industry is probably larger than that of the shortage of ore.

### 1.4.2 Low centralization of production, high proportion of backward producers

At the end of 2005, there were 871 steel plants in China, producing only 400,000 tons per plant on average. The scale of Chinese steel plants is quite different from those in the rest of the world, with the majority being small and medium plants.
The total steel output of the 8 biggest steel groups, with a capacity of more than 10 million tons, was 105 million tons in 2005, about 30.2% of the total steel output of China. The steel output of the 69 ‘key’ steel plants in 2005 accounted for 79.8% of the total, a drop of 14.3% compared to the year 2000. The crude steel output of China in 2005 was 352 million tons, an increase of 174% over the output in 2000 of 129 million tons. In 2005, the steel output from 18 plants with a capacity of more than 5 million tons was about 47% of total output; in 2000, it was 64%. After 2002 especially, due to overheated investment, the Chinese industry has not only failed to become more centralized, in fact it has become more dispersed, in contrast to the worldwide trend of merging and reorganization.

The levels of industry concentration in the world’s more advanced steel producing countries are all quite high. In 2004 the output of the 4 largest Japanese steel enterprises accounted for 73% of Japan’s total crude steel output. The crude steel output of 3 steel enterprises in the USA accounted for 61%, of 5 steel enterprises in Russia for 79%, and of 2 steel enterprises in Korea for 82% of total crude steel output.

China’s steel output has increased rapidly in recent years, and been heavily characterized by blind investment and reckless development. The growth of large enterprises has been slower than that of small and medium-sized enterprises. Of the new capacity installed by small and medium enterprises, a significant share is still using backward equipment. Output by non-key (small and medium) enterprises grew faster than that of key enterprises.

In addition, the proportion of large equipment in the Chinese steel industry is low. The total number of BFs was up to more than 1000 in 2005, with pig-iron output at more than 400 million tons, but with fewer than 100 BFs having a volume of over 1000 m³, accounting for about 33% of capacity. In contrast, only 28 large BFs produce about 80 million tons of pig iron in Japan.

The concentration of the steel industry has been declining in China in recent years, then, while the proportion of backward technology has been growing. It is impossible to establish circular economy in an industry with so much backward equipment. So the most important step toward developing circular economy in the Chinese steel industry will be to take firm measures to eliminate outdated technology.

1.4.3 Problems of low energy-efficiency and high energy consumption

Using Japan’s index of energy consumption per ton of steel in 2004 as the international standard, the energy consumption of key Chinese steel enterprises is, on average, about 10% higher than the international level.

However, the crude steel output of key steel enterprises accounted for 80% of China’s total output in 2005, while the crude steel output of small and medium enterprises (SMEs) accounted for the remaining 20%. Incomplete statistics indicate there was a gap of more than 30% between the energy consumption of SMEs and the key steel enterprises. When SMEs are included, the total gap between the energy consumption of the Chinese steel industry and the world standard is about 15%.

It should be noted that the statistics concerning energy consumption supplied by the China Iron and Steel Association (CISA) in recent years are only for key steel enterprises, and don’t represent the industry as a whole. Attention should therefore be paid to finding
ways to save energy at SMEs, most of which are not members of CISA, and eliminating backwardness.

1.4.4 Low recycling rate

In 2005, the total amount of solid waste from steel production (not including tailings) was about 139 million tons (see Figure 1.6), or about 50% of the mass of crude steel output and about 16% of all industrial solid waste in China. Through years of efforts, recycling technology at steel enterprises has improved, and become more and more commercially viable; but the rate of use is still low, with the actual utilization rate of BF slag still only about 65%, that of steel slag at only 11%, and of dust and sludge, etc., at less than 80% in 2005, still lower than that in Japan. The separation of waste before utilization and the utilization of high value-added elements are also inadequate, and the treatment and utilization of Zn-containing dust and sludge have yet to be put on the agenda.

1.4.5 Heavy pollution

At present, through pollution control and end-of-pipe treatment at some key steel enterprises in China, the situation is gradually coming under control, and the environment at several enterprises has improved somewhat; but pollution at existing, and even newly built, small and medium steel enterprises is becoming more and more serious. Many such steel plants have no treatment whatsoever in place for smoke, dust, wastewater and the like, which is very worrying. Even at key enterprises, of which about 89% of output is in SO2 control areas (totaling about 249 million tons), problems of environmental protection are still extremely urgent.

In terms of environmental protection, the gap between Chinese steel enterprises and foreign ones is apparent from statistics, and shows from the following aspects:

1) Weak understanding and awareness of environmental issues, imperfect legislation, and inadequate law enforcement.

2) In general, low management level and technical expertise of those responsible for energy savings and environmental protection.

Emissions indices at Baosteel and some other key enterprises match the international
level, but the average level of the Chinese industry is much lower. Steel enterprises have been passive for years, only starting controls after pollution is observed, with end-of-pipe treatment (the treatment of visible dust, smoke, wastewater, etc.) being the main measure. They struggle to meet emissions goals, and their understanding of energy-saving and environmental-protection technology lags far behind the rest of the world’s. This is mainly due to the reckless expansion of the industry in recent years.

1.5 The importance of developing circular economy in the Chinese steel industry

As a fundamental industry, and a pillar of China’s recent industrial growth, the rapid development of the steel industry in the last 20 years has been very important to the country’s economy as a whole. But the traditional reckless development of the industry, with growth coming at the cost of a huge consumption of resources and environmental damage, is not sustainable. If the Chinese steel industry continues to develop on its present course, it will be difficult to establish circular economy. If resource and energy needs remain hard to satisfy, and the environment can’t continue to bear the burden of pollution, then the sustainable development and the competitive power of the Chinese steel industry will be heavily restricted, and in the end the economy as a whole will suffer.

A new type of development must be established to improve the competitive power of the Chinese steel industry and to attain sustainability. Historically, the responsibilities of the Chinese steel industry have been to improve product quality and increase profits, while supporting China’s industrialization by lowering its consumption of energy and resources, providing sufficient output and efficient production, and causing less pollution. In the future circular economy, after expanding its functions and through ecological reform, the steel industry will become an important link in the eco-industrial chain, playing an active role. To develop rationally, and in line with circular economy, is the inevitable path for steel enterprises and indeed their social responsibility, allowing them to remain competitive while facing the great challenges of adapting to the future.

At the same time, since steel production is a typical process industry, circular economy is in some ways uniquely suited to it.

1) Steel production involves serial processes that run in synergy (are integrated) and consume resources and energy in a concentrated manner; it involves large-scale production and input (modern steel plants include sizes of 8–10 million tons, 6–8 million tons, 3–4 million tons or 1–2 million tons); the manufacturing process is a complex structure of processes and interactions, involving huge exchanges of materials and energy between processes; the production process is coupled with large emissions of materials and energy, and makes for a complex interface with the environment. To produce one ton of crude steel at an advanced integrated steel plant, each ton of steel consumes about 0.6–0.8 tce (17.6–23.4GJ), 1.50–1.60 tons of iron ore and 3–8 tons of fresh water, while producing more than 2 tons of waste gas (CO, CO, SO, NOx, etc), and abundant secondary energy such as excess heat, excess pressure, and so on, along with waste slag, dust, sludge and other pollutants.

2) Steel production is a chemical and physical process involving the combination of iron and carbon. But not all the material and energy used ends up in the final product (this is especially true of carbon), and this leads to waste unless recycling is in place. Steel production also involves high-energy conversion processes, such as coking, which has the
highest efficiency of all the processes that turn coal into energy (at least 80%). The most important by-product of BF iron-making is BF gas, which has low sulfur content. It is possible, therefore, for the metallurgical production process to be an efficient and clean center of energy conversion.

3) Steel is vital to both economic competitiveness and national security. It is easy to recycle, and more of it is recycled than paper, plastic, glass, and aluminum combined. The steel industry is among the most productive, efficient, and technologically-sophisticated industries in the world, and provides challenging, well-paid jobs for a highly-skilled and diverse work force.

4) The steel industry has a very close relationship and interactive influence on the power, chemical, oil, building-materials, and nonferrous-metal industries, among others.

In traditional production, the BFG or LDG, slag, wastewater, dust, and other by-products are discharged directly or after simple treatment, or piled up without being recycled. The utilization rate of secondary resources (waste) is very low, leading to severe pollution. Air pollutants are formed in the quenching of cokes, sintering, the discharge of BFG and LDG, from dust discharged by reheating furnaces, and other processes. Wastewater comes mainly from the processes of coking, iron making, steel making, hot rolling, etc., especially from processes that demand washing or rapid cooling. Metallurgical slag is produced mainly in the processes of iron making and steel making. Before the 1980’s many utilizable by-products were simply released, which was both wasteful and polluting. However, if the steel industry were to form eco-industrial chains with its related industries mentioned in (4) above, then they could interact in such a way as to take advantage of one another’s resource and energy by-products. The following three types of interaction are possible:

1) Mutual energy supply. COG, BFG, LDG and so on, recycled in the steel production process, are clean sources of energy containing low levels of dust and sulfur, and are thus excellent fuels or gas raw-material sources for power generation and the chemical and petrochemical industries.

2) Mutual resource supply. Numerous interactions can be formed between by-products of the steel and other process industries, such as the chemical, building-materials, and nonferrous-metal industries, so as to optimally utilize resources. For example, steel slag can be used by the building-materials industry as a cheap resource to produce cement and concrete; Zinc-bearing dusts from steel plants can be used as raw material for Zinc-making in the non-ferrous metallurgical industry; while municipal waste, such as waste plastic or tires, can be used as a fuel and reductant in steel production.

3) As resources to promote novel industries. For example, H₂ can be extracted from the COG of steel plants and be supplied to petrochemical plants or used in fuel-cell production. Integrated steel enterprises may end up being the largest and most competitive suppliers of clean H₂ in the 21st century. Moreover, the large amount of CO₂ produced by the steel industry may become a useful raw material, after purification, for the agriculture and food industries, as well as in fire fighting and environmental protection.

With steel being the most recycled key material in a modern economy, steel production
has the potential to easily establish connections of material and energy exchange in many different directions with relevant industries. The steel industry can be the backbone of a circular economy, which underscores the importance of implementing the principles of circular economy in this industry.
2 Introduction of the Two Pilot Steel Enterprises

Circular economy has just started being implemented in China. Some large steel enterprises attach great importance to achieving energy savings and environmental protection, so the new concepts were likely to be well received.

Special column No. 11 of the government’s eleventh Five-year Plan states: “Jinan Steel, Baosteel, Anben Steel and Panzhihua Steel must be built to become pilot enterprises of the establishment of circular economy.” In November, 2005, more than eighty circular economy pilot enterprises were named by the National Development and Reform Commission (NDRC) and five other commissions and ministries. The steel enterprises among them included Jinan Steel, Anshan Steel, Laiwu Steel, Baotou Steel and Panzhihua Steel.

2.1 Background of Jinan Steel and its foundations for circular economy

The Jinan Iron & Steel Group (Jinan Steel) was built in 1958. It is a typical large-scale state-owned company, with 38,000 employees and 37.7 billion RMB in total assets. It is a large integrated steel enterprise that includes coking, sintering, pelletizing, iron making, steel making and hot rolling. Jinan Steel is one of China’s main medium-plate production bases, its major products being medium, thick, and hot-rolled plate. The plant’s output was 300,000 tons annually when it was founded; this had increased to 10.42 million tons in 2005 and 11.24 million tons in 2006. It is a typical Chinese medium-large integrated steel group, in that it has grown from small size to large, and it is in the process of shifting from the production of long steel products to flat steel products.

Before 1990, Jinan Steel used a good deal of backward equipment, such as cupola furnaces, ingot-casting facilities, and a blooming mill, to produce long steel of poor quality.

Since then, Jinan Steel has stressed cost and energy savings, environmental protection, and consumption reduction, laying a good foundation for establishing circular economy there.

In 1995, Jinan Steel began its own efforts to maximize profit, optimize its technology, and save energy. By imitating innovations in other countries, it adopted ‘fully beneficiated burden for iron-making,’ full steel refining, full continuous casting, full one-fire rolling, and increasing the pulverized-coal injection rate of the blast furnace (this set of improvements being conveniently abbreviated as ‘Four Fulls, One Injection’ in China). Some backward processes, such as smelting pig iron for steel making, mixer-ingot casting, and blooming were eliminated. Production was also re-organized to become more intensified.

Let’s take the ‘fully beneficiated burden for iron-making’ as an example. When the ninth Five-Year Plan was revealed, the average Fe content of blast-furnace burden was only about 53%. To increase agglomerate capacity and improve the burden, the raw-materials yard was expanded and two 90m² sintering machines and two shaft pelletizing machines were put in place. In November 1996, all 12 blast furnaces started operating on fully agglomerated burden.

With the Fe content of the burden thus increased, the ratio of hot metal slag obviously declined. By 2000, the raw Fe content of the burden had increased to 59.2%, and BF slag had fallen from more than 500 kg/t to 308 kg/t (Figure 2.1). This means that over 30 million tons per year of silica impurities did not enter the BFs, leading to a decrease in lime
consumption of more than 60 million tons annually, equivalent to 1.2 million tons of limestone. This resulted in a reduction in the coke rate and an increased output of hot pig iron, reducing waste at the source.

Since the year 2000 Jinan Steel has placed even more emphasis on developing cleaner production, and set out a cleaner production plan labeled “Reduction from the source, Process Control, and End-of-Pipe Treatment.” The key technological innovation has been “four closed circuits,” introducing the “three highs and two lows” and “three fulls and two adjustments”. Energy and resource consumption have been reduced at both the source and in the process (Figure 2.1), making progress in optimizing the energy structure of the process.

![Figure 2.1 Results of improved burden and “Reduce from the Source” at Jinan Steel](image)

Jinan Steel has for a long time concentrated on achieving resource and energy savings and environmental protection. Jinan Steel has a good tradition, then, of accepting new ideas and developing new technologies. In the late 1990s, after the promotion of CC technology by the Ministry of Metallurgical Industries, Jinan Steel was the first steel plant in China to put in place 100% continuous casting.

### 2.2 Background of Baosteel and its foundations for circular economy

Baosteel, the largest and most modern integrated steel manufacturer in China, is located in the northeast of Shanghai, adjacent to the Yangtze River, to the north, and close to Wusong harbor to the east. It has its own dedicated port, providing it with logistical and transportation advantages. Baosteel covers an area of 19 km² and has 15,000 employees.

Baosteel began construction in December, 1978, and had witnessed completion of its first, second and third phases by the end of 2000. With its large, advanced equipment, capable of continuous and automatic operation, Baosteel has become one of the biggest integrated steel manufacturers in the world. According to a report by the magazine World Steel Dynamic (WSD) in 2005, Baosteel ranks third in general competitiveness among 23 “world-class steel companies.”

Baosteel has an annual capacity of 15 million tons of steel, with its major products being hot-rolled sheet, cold-rolled sheet, and pipeline steel. The growth of the steel output of Baosteel from 1985 to 2005 is shown in Figure 2.2.
Baosteel has a good tradition of coordinated construction and sustainable development. The company has steadily increased its level of environmental protection, vigorously promoted cleaner production, consistently adhered to a policy of green production and green management, and carried out environmental control according to its own standards, stricter than those of the government. Baosteel received ISO14001 Environment Management System Certification in January, 1998, and also BSI certification for integrated management systems in 2004. In January 2005, Baosteel was named the top environment-friendly enterprise in the Chinese steel industry.

Baosteel has followed worldwide energy-management trends since the late 1990’s and has developed an innovative energy-management system, Baosteel Energy Center, specifically suited to its own situation. It has set “safety, stability and economy” as its energy-management goals. Its energy conservation and management methodology, called “entire-process systematic energy-management,” is carried out in every aspect, from energy conversion, energy transfer and distribution, end-use of energy, to utilization and recovery of residual energy, among others. It has changed its energy-consumption indicators from quantitative to value-based, and has pioneered the emerging field of comprehensive utilization and systematic energy-management thinking in the steel industry. Baosteel has become a model of energy management in the Chinese steel industry, and is at an advanced energy-management level by international standards.

At the same time, Baosteel is continuously improving its energy savings by improving the management of individual pieces of equipment to lower their energy consumption. As part of efforts toward ‘zero’ gas output, Baosteel’s power station, as the end user of residual gas, contributes greatly to the efficiency of energy utilization at Baosteel. The station has three 350MW generators and one 150MW gas-steam turbine power unit (CCPP-Combined Cycle Power Plant) for a total capacity of 1200 MW. It is presently the biggest steel-enterprise-owned power station in China. Its BFG emission rate was about 20% before 1997. In 1999, when the first CCPP using BFG in the world came into operation there, the BFG emission rate fell to almost zero. The power station can use a mixture of BFG and converter gas (LDG) at a maximum ratio of 25%. Baosteel’s power station generates 7.9 billion kWh of electricity a year, meeting the demand of Baosteel, and allowing it to feed some power to the grid. The station consumes only 325 gce/kWh of coal. At this time, Baosteel is the only steel enterprise in China that generates surplus electricity.
In terms of efficient energy utilization, Baosteel puts great emphasis on residual-energy recovery, having adopted the recovery techniques TRT, CDQ, LT and OG, among others. The gas-utilization rate at Baosteel has been high for many years, with emissions near zero for each gas. Baosteel leads Chinese enterprises in use of converter gas (LDG), the use of it and of waste steam being the main ways of producing surplus energy in the course of steel making. At this time the average recovery rate in China is 55 Nm$^3$/t, while at Baosteel, it has been 95 ~100 Nm$^3$/t steel for many years because of its use of OG and LT to recover converter gas (LDG). Baosteel has made great breakthroughs in its energy-saving indices. Its energy consumption per ton of steel, and some of its processes, have reached or exceeded modern-day international standards (Figure 2.3). Compared with 1995, energy consumption per ton of steel had fallen by roughly 12% by 2005. The energy consumption of the BF iron-making process was below 400 kgce/ t, putting it at number one in the world. At Baosteel energy costs made up roughly 19% of total product costs in 2005, 5% less than in 1993. This figure was almost at the level of that at POSCO (Korea), China Steel (Taiwan, China) and JFE (Japan), among others, and 4 % lower than the average for domestic steel enterprises.

![Figure 2.3](image_url)  
**Figure 2.3**  Energy consumption per ton of steel at Baosteel, China Steel and POSCO from 1995 to 2005
3 Implementing Circular Economy at Two Pilot Steel Enterprises

3.1 Progress in developing circular economy at Jinan Steel

The energy savings and clean production practiced for many years at Jinan Steel have laid a good foundation for implementing circular economy at the final stage of the 11th Five-Year Plan. Over the years, Jinan Steel, guided by the principles of resource efficiency, has optimized resource use, energy conversion, and turning waste into resources. Process optimization at the enterprise has lead to technological progress and restructuring; huge reductions in energy and material consumption; and significant improvements in environmental indicators, increasing the enterprise’s ability to survive in the market, and the sustainability of society as a whole.

Jinan Steel recognizes that a steel company’s ability to attain cleaner production and protect the environment affect not only its economic efficiency but its image and, in the end, its very existence. As environmental concerns intensify in modern society, enterprises either eliminate pollution, or pollution eliminates them.

3.1.1 Developing circular economy, innovation in company culture and management

- Innovations in ideas and enterprise culture lead the changes in enterprise development.

Jinan Steel believes in innovation under the guidance of its enterprise culture; in taking advantage of market opportunities through the scientific decision-making of its leaders; in promoting innovations in technology by innovations in its management system; and in investing in technological innovation to ensure its implementation. The company has an incentive system that favors and promotes technological innovation.

Jinan Steel is guided by the view that “pollutants and wastes are resources in the wrong place” and the motto, “Unlimited Innovation, Unlimited Resources.” It considers savings and reductions to be the responsibility of enterprises and entrepreneurs, and consider environmental protection to be the greatest welfare of its workers. Jinan Steel believes "there is no waste, only backward technology," and that steel companies should not only achieve clean production within their company but become “processors of pollutants, suppliers of clean energy and clean products, and street cleaners for their cities,” aiming to reduce resource consumption and environmental costs as much as possible to gain the greatest possible economic and social benefits.

- Enhancing technological and management innovation

At Jinan Steel, a culture of "encouraging innovation, allowing failure, and tolerating mistakes" under the motto, "innovation is in your hands; anyone can innovate," encourages employees to think and express themselves freely in coming up with solutions to problems. Year by year, Jinan Steel has been awarding more and more to its employees for their technological innovations, with nearly 4 million RMB being awarded in 2004. During the commissioning of a gas-steam combined power-generation project, engineers and technicians successfully developed an intelligent control system based on the heat of mixed
gases; a key technical problem was solved this way, and now Jinan Steel possesses independent intellectual-property rights to the new technology. A substantial award of 500,000 RMB was given to key personnel.

Company management has increased investment in science and technology every year, stressing its support for independent innovation projects; more than 3% of turnover is used for R&D, maintaining a leading position among domestic steel enterprises. In 2005, Jinan Steel invested 84 million RMB in 61 technical-innovation projects, with expected benefits of 840 million RMB per year. About 14% of this consisted of contributions to cutting-edge technology, which illustrates the importance Jinan Steel assigns to independent innovation and the enhancement of its core competitiveness.

3.1.2 Steel plant energy conversion – a highlight of Jinan Steel

During its implementation of circular economy, Jinan Steel, on the basis of a conception of “efficient use of resources, conversion of energy, and regeneration of metabolites,” took measures to establish high-efficiency iron making, steel making, and rolling, and has perfected power generation with recovered gas. Its successes at energy conversion and water recycling have included an independently-developed CDQ for utilizing waste heat, which received a second-prize award for scientific and technological progress in 2004.

1) High-efficiency energy conversion and utilization

Jinan Steel’s unique achievements in energy conversion result from detailed study and analysis, and independent innovation.

Employees at Jinan Steel concluded that energy costs accounted for a large portion of production costs, and that therefore energy savings would be important for reducing costs and enhancing competitiveness. Five stages of the steel production process involve heating, including: coking, sintering, iron making, steel making, and rolling. Hot coke, hot sinter, hot metal, molten steel and the heated slab or billet are formed at these stages respectively. Each stage has its own cooling process, so that five cooling periods are involved. The repeated process of "heating – cooling" and accompanying processes of "water cooling-water treatment" are shown in Figure 3.1.

![Figure 3.1 Schematic of temperature changes during steel manufacture at an integrated steel enterprise](image-url)
This repeated "heating - cooling" process is energy intensive. A lot of energy is required for heating, but the heat efficiency of industrial furnaces is altogether lower than 70%. More than half of the insulating facilities at the five stages are simple, and a lot of heat is dissipated. Heat is also lost during cooling. The cooling process needs a large amount of cooling equipment and consumes a lot of cooling water, electricity and other resources. Four cooling processes are involved, and most of the heat is not recovered. Heat recovery for coke quenching is less than 30%, so that around 70% of the energy used in the process is lost, along with large amounts of cooling water.

Analysis of the recovery and energy-savings potential of steel enterprises shows that energy recovery in steel enterprises is still in a very early phase, and characterized by the following common problems.

1) Backward techniques and equipment, inefficient use of media, a low degree of centralization in process control, and many other issues make it difficult to adopt advanced energy-saving technologies. Backward techniques and equipment that are incompatible with energy saving technology should be made obsolete.

2) Energy systems at steel plants are considered only in terms of their application to steel production, not as important resources which deserve to be effectively utilized and for which careful management techniques should be developed.

3) The traditional over-emphasis of operational safety leads to “a big horse pulling a small carriage,” and higher-than-needed energy consumption in the operation of equipment.

4) Failure to timely recover and utilize. Recovery and utilization of energy and resources are traditionally carried out centrally, causing dissipation of energy, high energy costs for transportation, high transmission loss of energy and materials, and loss of by-product gases as a source of energy.

5) Too often the processes of recovering waste heat and energy operate without attention to their efficiency, actual use and actual results, leading to poor recovery or even overall negative effects.

In the past, most of the waste heat, residual energy and recoverable residual pressure, such as by-product gases, were not recovered at Jinan Steel. The waste heat of high-temperature flue gas from metallurgical furnaces, low-temperature furnace waste gas, and low-quality saturated steam and hot water produced during the cooling process came to about 1.35 million tce per year. If the energy-conversion efficiency is 30%, it could generate about 500 MW. This conclusion was obtained during an energy audit at Jinan Steel in 2004. Based on this analysis, it was realized that resource loss and environmental pollution result if waste heat and residual energy are not effectively recovered. The potential for energy conversion at Jinan Steel was thus established, and its difficulty also recognized.

The key to energy savings is to recover as much waste heat, residual energy, and other secondary energies as possible, and to make effective use of them. According to expert studies [9], and Jinan Steel’s own analysis, one way to achieve high-efficiency energy conversion, and effectively utilize energy, is to transform residual energy into electric energy. In line with China’s energy policies and the motto, "only buy coal, not electricity or oil," a new way of efficiently converting and comprehensively utilizing surplus energy was developed at Jinan Steel. The main idea of energy conversion there is to use rationally the waste heat of each production procedure, build a distributed power station, recycle, deliver, and use the energy as close to its source as possible. The focus is on optimizing the
entire structure of energy use, especially that of gas, with relatively stable and independent users of BFG, LDG, and COG being established respectively.

In the field of energy-saving technology, Jinan Steel has always stressed independent innovation. In 1999, the first domestic CDQ device with independent intellectual property rights was completed at the plant, leading to considerable benefits both in terms of power generation by the recovery of heat from hot coke and improved coke quality, as well as an improved operating and working environment. A high-pressure CDQ, producing steam at around 50kg/t, and with a power-generation efficiency 10% higher than that of a conventional CDQ, was first introduced to a new coke oven at Jinan Steel, and successfully operated.

Before 2004, there were only two sets of CCPP at domestic steel plants in the whole of China. The first was built in 1999, when a 150MW-capacity CCPP unit was installed at Baosteel using only BFG (calorific value less than 3000 kJ/m$^3$). However, because all the technology was imported, equipment maintenance and operating costs were very high, and due to a low and unstable calorific value for the gas, the power-generation efficiency of the equipment was less than 40%, far below the rated efficiency. Later, a 120-MW-capacity MW CCPP unit using a mixture of BFG and COG (calorific value between 4200 kJ/m$^3$ and 5500 kJ/m$^3$) was installed at Tonghua steel. However, its operation was unsatisfactory because of the calorific value of the mixed gas, lack of precision of flow rate control, and frequent gas-compressor malfunction. Jinan Steel learned from the mistakes and experiences of domestic and foreign companies in low efficiency power-generation when using pure or low calorific BFG boilers. In cooperation with the Nanjing Steam Turbine and Motor Company, a power-generation technology using low calorific mixed gas was developed, and has independent intellectual property rights. In 2004, the first new CCPP (gas-steam combined-cycle power-plant unit) using mixed gas (calorific value about 5400 kJ/m$^3$) was built at Jinan Steel, composed of two gas-turbine generators, one waste-heat boiler and one steam-turbine generator. Its installed capacity is 136 MW, and eight technologies were successfully patented in the course of its development, including the intelligent blast furnace, a control system for the coke-oven-gas mixing station, dynamic balance and stability control of mixed gas calorific values, gas compression and stabilization technology, a system for stable sweeping of N$_2$ of high flow rate and rapid pressure reduction of N$_2$, and a large-turbine self-diagnosis system. With these technologies the power generation runs smoothly, and annual power-generation capacity is 9.9 billion kilowatt-hours at an efficiency of 45%, reducing energy consumption per ton of steel by 50 kgce/t. Domestic technology content of the new equipment was 95%, reducing investment in overseas equipment. These new methods demonstrated by the successful operation of the CCPP at Jinan Steel gives other steel companies confidence in advanced CCPP techniques for energy cascading and generating power from gas, and provides them with a clear way to achieve this. Six CCPP generators will be built and operated in the second, third, and fourth phases, after 2006, at Jinan Steel.

But Jinan Steel has encountered many problems bringing CCPP into operation, including high costs, and difficulties getting approval for grid interconnection, leading to delays and further high costs. The operating costs of self-contained power plants at steel plants depend on generator (technology) costs, a restrictive factor throughout on the choice of technology for generating power from waste heat, residual energy, and other secondary energies. Also, the second to the fourth phase of the CCPP project were delayed because of delayed grid interconnection approval. In addition, no preference was given in determining the grid interconnection rates, that is, the fact that waste heat, residual energy and other secondary energies were being used was not taken into consideration, even though
the net cost of power generated by advanced CCPP technology (about 0.47 RMB/kWh, consisting of gas cleaning, compression, mixing, importing equipment and other costs) is much higher than that of power generated from pure BFG (about 0.26 RMB/kWh), and higher than the price, 0.35 RMB/kWh, of power from the Shandong grid. The CCPP power plant will operate at a loss if no policies are in place to support it. The return rate on CCPP investment is low, and the period of investment recovery long. The existing policies are not conducive to encouraging steel enterprises to adopt new energy-conversion technologies. Government departments should pay more attention to this.

Another innovation at Jinan Steel has been a technology of efficient heat transfer using heat-conductive oil as part of the coking process. Heat-conductive oil is an organic carrier. It has many advantages: good fluidity, heat-resistance, good heat stability, strong resistance to oxidization, and high thermal conductivity; it is tasteless, non-toxic and non-corrosive; and, above all, its heat-exchange efficiency is 20 times higher than that of steam. Heat-exchange technology with heat-conductive oil, and the metallurgical production process, were first combined at Jinan Steel by borrowing ideas from available technologies in the chemical industry. The technology for replacing steam with heat-conductive oil was applied to recover waste heat at the riser of the coking battery, completely superceding the traditional mode of heat exchange by steam, with steam (water) consumption and sewage markedly lower, heat-exchange efficiency significantly improved, lower energy consumption and flue-gas loss. The procedure energy consumption per ton of coke was reduced by 5.7kgce. The benefits in water savings, energy savings and environmental protection are very significant.

Since 2003, in the area of efficient energy conversion and utilization, many technologies have been successively implemented at Jinan Steel by continuously developing and integrating the energy-recycling techniques of metallurgical processes and analyzing the available technologies of other industries. Examples include BF TRT power generation, recycle power generation of mixed low to medium-calorific value gas / steam, BF dry dust collection, high pressure CDQ, coking with heat-conductive oil without using steam and ammonia, power generation from waste heat of circular coolers of 320m² sintering machines, and other technologies. Many other techniques are in the process of being implemented, including power generation using saturated steam heated by the waste heat of the converter flue, and steam power generation using the waste heat of the heating furnace, among others (Figure 3.2). In recent years, the proportion of Jinan Steel’s own power generation gradually increased from 1% in 2000 to 32% in 2005. It is estimated than when the four CCPP sets are all brought into operation, and steel output increases to about 10 million tons, the proportion of power generated by the company’s own power plant will reach 70%. Effective energy recovery and a high energy-utilization rate will contribute greatly to CO₂ emission reduction at metallurgical enterprises, along with lower pollution, and lower waste of secondary energy.

With the development of energy-saving technology and integration of energy-conversion systems at Jinan Steel, an energy center has been built to centrally manage energy supplies and schedule their use, with automatic coordination among processes and technologies adopted to cover both production and management, achieving integration of control and higher-level management of energy systems. However, the center is still in its initial stages, and only has the functions of measuring, monitoring and (partial) distribution, just enough to be called a ‘management center’. A sound and effective energy management mechanism will be established and improved in the future, and the functions of centralized energy management will be re-positioned, to establish unified management of energy.
Reduction and recycling of fresh water

The water problem at steel plants is, on the one hand, that of saving fresh water, while, on the other, treating sewage and reducing sewage discharge. Sewage involves not just pollution, but also waste and energy (heat) loss. Jinan Steel is located in a region of serious water shortages, so the importance of saving water is very high. The potential for water-savings is also large.

In 1990, Jinan Steel proposed that its steel output would reach 2 million tons by the end of the 8th Five-Year Plan, and 3 million by the end of 2000. According to the level of fresh-water consumption per ton of steel in 1999, for an annual steel output of 2 million tons, the total fresh-water consumption would have been 67 million cubic meters; for 3 million tons, more than 100 million cubic meters. These two figures amount to more than one third and one half respectively of the total water consumption of Jinan City. From the perspective of social sustainable development, this is clearly unacceptable. Jinan Steel had to reduce its water consumption or face being shut down. Saving water, then, became vital to the very survival of the company.

Through analyzing the system water balance, Jinan Steel estimated that more than 90% of the water consumed at steel enterprises was used for cooling, and for de-dusting to protect the environment. Water was used to remove heat and Fe-containing materials from the process, leading to loss of energy and other resources, and the generation of secondary pollution. For example, in the traditional coke-quenching process the coke was quenched with water (wet quenching), which wastes both water and heat, reduces the quality of the coke, and causes pollution. By contrast, in the CDQ process no water is consumed, the heat of the coke is recovered for power generation, the quality of the coke is improved, and
environmental harm is reduced. Replacing wet dust with dry dust in the blast furnace and converter is another typical example. Many such examples indicate that the more water is consumed at a steel plant, the more serious the problems with resource consumption, energy recovery and pollution are. At Jinan Steel, at first, water was consumed and wasted in large quantities, and directly discharged. In the second stage, water was cascade-used, and directly delivered and discharged. By the late 1990s, water quality had been stabilized, wastewater was being recycled, and detailed work had been done on structure optimization and efficient utilization of water. These days anhydrous or low water-consumption technologies have been developed, and a closed-circuit cycle has been realized at Jinan Steel.

A new model of water consumption has been developed by the water-saving practices at Jinan Steel. The model is "supply according to quality requirements, separate treatment, match temperatures, cascaded utilization, small radius circling and regional closed circuits." The water-allocation structure has been optimized. For different technologies with different water-quality and temperature requirements, different water treatments are used, and water is classified into six different grades – fresh water, soft water, clean circulating water, muddy circulating water, civil waste water and recovered water – in order to be allocated appropriately. The water is distributed in 17 small circuits and 13 regional closed circuits, such as the oxygen plant, steel making plant, rolling mill, and BF. Sewage is assimilated in the process as much as possible. At the same time, technologies using less water, or none, such as CDQ, BF dry de-dusting, replacement of steam with heat-conductive oil, and others, are vigorously promoted as efficient ways to use water resources.

In addition, price is being used as a way of promoting reduced consumption and efficient use and recycling of water. For example, the price gap between fresh and recycled water has been broadened, and quotas set for the amount of fresh water to be used, with water used in excess of the quota costing twice the standard rate. At the same time, the consumption of fresh water is being independently measured, and 10% of the value of the water saved is awarded if consumption remains within the quota. However, in the case of over-consumption, a fine of 100% of the total value of the water consumed is applied. Different prices are used for clean circulating water and muddy circulating water. Large differences in the internal value of water are used to guide the adjustment of the structure of water used, in order to rationally use water, and reduce its consumption.

The fresh-water consumption per ton of steel in the year 2005 was 60% less than that of the year 2000, and 81.9% less than that of the year 1995 (Figure 3.3). The industrial water reuse rate had greatly improved by 2005, standing 5 percentage points higher than that of the year 2000, and 7 percentage points higher than that of the year 1995, while sewage output was drastically reduced. The steel output in 2005 had increased over 5 times from that in 1995, but fresh-water consumption had increased by only 7%. Based on the level of fresh-water consumption per ton of steel in 1995, 183 million cubic meters of water were saved in 2005, equivalent to 32 million RMB (at four RMB per cubic meter of fresh water) in expenses on water, sewage discharge, power, labor and so on. The burden on water resources was also reduced, and room for development won for Jinan Steel.
3.1.3 Waste treatment and recycling

Jinan Steel has been concentrating on utilizing slag, dust, wastewater, waste gas, and other by-products of steel production. In order to increase the value of BF slag and extend the industrial chain, a slag-powder production line with a capacity of 600,000 tons per year and slag-wool production line using BF slag have been built, capable of disposing of 3.4 million tons of BF slag per year with a utilization rate of 98%, a turnover of 250 million RMB, and profits of 180 million RMB.

Waste treatment and recycling have been actively developed at Jinan Steel, along with implementation of clean production and recycling of secondary resources. Jinan Steel also actively accepts its social responsibilities, and extends the chain of circular economy to society. Based on its experience in the steel manufacturing process, it is actively studying the assimilation and treatment of municipal waste and the waste of surrounding enterprises.

Figure 3.3  Changes in fresh-water consumption per ton of steel during 1995~2005 at Jinan Steel

![Graph showing changes in fresh-water consumption per ton of steel during 1995~2005 at Jinan Steel.](image)

Figure 3.4  Civil sewage-treatment plant at Jinan Steel

(Annual treatment capacity is 2.6 million m³/a)
In 2004, a treatment plant with an annual capacity of 2.6 million m$^3$/a for civil sewage (Figure 3.4) was built at Jinan Steel, adopting advanced waste-water treatment technology to dispose of community sewage, and using the treated water for production, not only assimilating and treating community sewage and alleviating the burden of urban sewage treatment, but also reducing its own fresh-water consumption. This is a key example of how a steel enterprise can function to benefit the rest of society.

In April 2006, a technology for assimilating chromium slag from chemical factories by replacing some dolomite with it was developed at Jinan Steel. The hexavalent chromium in chromium slag is reduced to trivalent chromium and then further reduced to chromium by the strong reduction processes of high-temperature sintering and iron-making, not only rendering chromium slag nontoxic, but also giving full value to the recovered material. A technical scheme, "sintering for agglomeration and detoxification during iron-making," was proposed, with the harmful chromium slag abandoned at Jinan Yuxing chemical plant being treated by sintering and blast furnace processes. An environmental problem that had been puzzling Jinan City for 50 years was thus solved. The present chromium-slag treatment capacity reaches 600 tons/d, and 70,000 tons of chromium slag had been safely disposed of by the end of 2006 at Jinan Steel.

3.1.4 Main achievements of the implementation of circular economy at Jinan Steel

As a member of the first group of national experimental models of circular economy, and a key model of circular economy in the state 11th Five-Year Plan, Jinan Steel strives for new ways to use resources and energy. At Jinan Steel, in accordance with the "pilot plan of development of circular economy at Jinan Steel," gradual achievement of the plan’s targets of energy and resource efficiency is foreseen.

Main results

- Improved resource and energy-utilization efficiency. The specific energy consumption per ton in 2005 was 16.7% less than that in 2000, and 44% less than that in 1995 (Figure 3.5), with the amount of energy saved cumulatively reaching 18 million tce over the 10 years. The yield of rolled products in 2005 was 6.18% higher than that in 1995 and the steel output in 2005 was 5 times that in 1995, while total water consumption only increased 7%, and fresh-water consumption decreased 82%.

- Improved labor productivity. The productivity of physical labor in 2005 reached 414 tons/person, 5.2 times more than in 1995.

- Reduced environmental pollution. While steel output increased between 1995 and 2005, dust emissions fell by 86%. Slag, dust, wastewater, waste gas and other by-products began being treated, while the prospect of a clean construction-materials industry based on the use of metallurgical slag has been undergoing study. Above all, the goal of zero emissions of slag, wastewater, and waste gas has been realized.
Extended recycling of community waste. More than ten thousands tons of chromium slag have been treated and 2.6 million m³ of community sewage disposed of per year. It is estimated that the stock of chromium slag in 2006 may be more than 5 million tons in China. Chromate production has had to be stopped at some chemical plants because of the lack of a viable disposal scheme, and chromium slag is stacked in the open air. The successful development of chromium-slag disposal at Jinan Steel has provided a useful model for other steel plants, which can assimilate and dispose of chromium slag from nearby chemical enterprises, leading to a wide range of social and environmental benefits.

Reduction of greenhouse gas emissions through energy conversion. After more than three years of efforts, the CDM project, which uses a mixture of gas and steam for power generation, was approved by the UN Framework on Climate Change in April, 2007. This was the only approved CDM project in the Chinese steel industry by the end of September, 2007.

3.1.5 Strategy for further development of Jinan Steel

In 2006, the implementation of circular economy further accelerated at Jinan Steel. The second phase of the gas-steam combined-cycle power-generation project, was finished successfully, and the first domestic 150-ton high-pressure CDQ, among other projects, was successively completed. In 2007, many further projects were started, such as power generation using the waste heat of the circular cooler of the 320m² sintering machine, and power generation using the waste heat of saturation steam in the flue of the 120-ton BOF. Energy-savings, emission-reduction and utilization-efficiency measures are in a continuous process of development there.

A new material-recycling process, named “resource - product – new resource” (Figure 3.6), with steel manufacturing as its core, has been developed at Jinan Steel. It reflects the growing social role of steel enterprises, integrating the functions of steel-product manufacture, energy conversion, and municipal waste treatment and disposal.
3.2 Progress in developing circular economy at Baosteel

3.2.1 Striving for sustainable development and a world-class green steel enterprise

Since Baosteel is a leader in the Chinese steel industry, its leaders have always paid great attention to, and taken the lead in, sustainable development, and social and environment friendliness. Baosteel prides itself on keeping its promises to shareholders, customers, suppliers, employees and society in general, and regards integrity as a basic value. It strives constantly to improve and innovate. Baosteel was named one of China’s 2006 “High-Integrity Enterprises.”

Although Baosteel matches the international standard of energy efficiency, it continues to strive to improve its energy savings. It has successfully transferred advanced energy-management techniques to many domestic steel enterprises. Recently, Baosteel has devoted itself to developing circular economy. This began with its R&D department establishing the Baosteel Environment & Resources Department Committee. Under this Committee, the Environment & Resources Department and Environment & Resources Research Institute were founded to research, practice and manage circular economy.

Baosteel published an environmental report for the first time in 2003[11]. It is the only domestic steel enterprise to publish such a report. It is also the only Chinese member of the International Iron and Steel Institute, which periodically reports a number of related statistics and indices. Baosteel added economic, environmental and social duties to the report in 2005, and renamed it the ‘sustainable development report’. Baosteel published a
Baosteel works hard at being respected by the public and society. It accepts its social responsibilities and shows concern for global warming. Baosteel is performing preliminary research related to using the nutrition in converter slag as ‘food’ to grow ocean phytoplankton, which in turn are known to have the ability to absorb CO₂ from the atmosphere faster than any other living organism. Baosteel has participated in the APP steel-enterprise energy-consumption and greenhouse-gas emission benchmark research, held by China. It has contributed manpower and money to the study of POPs, a field other domestic enterprises have yet to start paying attention to.

Baosteel pays great attention to energy efficiency and energy recovery in the steel manufacturing process. Through practice and exploration, Baosteel has formed a unique energy-management method tailored to its needs, with good results. In terms of energy consumption per ton of steel, Baosteel reached 687 kgce/t in 2005, matching the international level. Compared with 1995, energy consumption per ton of steel had fallen roughly 12%. In terms of environmental protection, Baosteel also attempts to reach the international level. It continuously invests in environmental protection and has set up an emissions standard that is stricter than the national standard, focusing on de-dusting, elimination of SO₂, NOₓ, COD, and so on. It has independently developed desulphurization equipment for large sintering machines. Baosteel devotes roughly 400 million RMB to environmental protection every year. Its environmental-control standards for dust and gas emissions, wastewater, noise, and so on, are stricter than the national standards. It practices environment management strictly and is gradually perfecting a real-time environment-monitoring system for the whole company. **Baosteel’s environment-monitoring station is currently able to monitor over 200 items in ten categories. It is able to publicize authoritative and fair environment-monitoring reports.**

Although Baosteel is located near the Yangtze River, and has abundant water resources, for the purposes of national resource savings and environmental protection, aiming at the international level, Baosteel has brought management of water resources into the scope of energy management. Based on the quality-based distribution of water resources, control of the water-flow rate, and increasing re-circulation within each system, with cascade and serial utilization, waste-water recycling, and intermediate water-reuse technologies in place, by 2005 the fresh-water consumption per ton of steel was reduced to 3.77 m³/t from the designed 9 m³/t, and the water re-circulation rate was 97.6%, matching the international level. **Baosteel was the first domestic steel enterprise to reuse intermediate water in the industrial system.**

As part of the development of circular economy in the 11th Five-Year Plan (2006 – 2010), Baosteel is further developing green steel production, as well as studying and developing treatment and utilization of solid secondary resources, with distinct achievements having already been made.
3.2.2 Development of green steel products

The development and promotion of new products is the key to the sustainable development of a company, the essence of steel manufacturing, and the source of a company’s competitiveness. Baosteel dedicates itself to minimizing GHG (Greenhouse Gas) emissions, reducing environmental risks during the use and extended lifetime of its steel products, and reducing waste by recycling.

Baosteel not only emphasizes low environmental impact during its manufacturing processes, it also emphasizes, for its products, the low environmental impact of their use, their long life and high usage-efficiency, and the ease of recovering and recycling them. To achieve this, it is constantly innovating, with an emphasis on environment-friendly products. To adapt to the energy-reduction and environmental requirements of the automobile industry, it has successfully developed the following high-quality steels: hot-rolled high-strength steel plate, cold-rolled high-strength IF steel, cold-rolled high-strength low-alloy steel, cold-rolled TRIP steel, and cold-rolled dual-phase steel, among others. Lighter, higher-strength sheet metal for automobiles can save energy by reducing the weight of cars. Baosteel’s “Study on Types, Production Methods and Application Technology of Quality Automobile Sheet Metal” won a national prize in Scientific Technology Advancement. Baosteel has supplied over 50% of the domestic automobile sheet-metal market for many years.

Other green products with large market potential include chromium-free post-treated galvanized plate, electrical steel with a highly effective underwater self-adhesive coating, color-coated electrical sheet steel for household appliances, thin Tin Plate (DI Plate), pipeline steel, and so on. The T91 high-temperature and high-pressure boiler pipes Baosteel has developed are mainly substitutes for imported products, and can be used to manufacture supercritical and super-supercritical boilers with large capacities and excellent parameters. These save energy and alleviate environmental pollution. Many high value-added green products made by Baosteel have leading positions in the domestic market.

Baosteel does LCA (Life Cycle Assessment) of typical steel products in cooperation with the International Iron and Steel Institute (IISI). In 2004, Baosteel launched LCA of electro-galvanized products to provide a basis of information for decision-making on improvement of the environmental performance of the product. As part of this research an LCL (Life Cycle List) and related software for electro-galvanized products was created for the first time in China. The research not only quantified the environmental burden and the resource consumption of producing 1 kg of electro-galvanized product, and related products, but also gave a quantitative analysis of those aspects of production with important environmental impacts, that is, analyzed the distribution of environmental impact over the production process. It clearly shows where the best opportunities for reducing pollutant emission during production lie. Through the research, one patented technical discovery was made and 3 software copyrights were obtained.

3.2.3 Recycling techniques for solid ‘secondary resources’

Baosteel replaced the term “waste” with “secondary resource” in 2005. Baosteel’s sustainable-development report advocates awareness and action with regard to saving and protecting resources. The change in nomenclature reflects Baosteel’s attitude toward comprehensive utilization of resources.

1) Utilization of solid secondary-resource by-products of steel production
The effective utilization of solid ‘secondary resources’ at a steel plant can economize resources and avoid pollution. It has obvious social, environmental and economic benefits.

Baosteel devotes great attention to the development of recycling techniques for solid wastes. It was the first Chinese steel enterprise to develop powdering technology for granulated BF slag. In recent years, it has successfully patented a number of techniques, including grid treatment of casting slag, treatment of steel slag with a rotating drum, and the use of steel slag as a grinding material, among others. Its treatment of steel slag with a rotating drum, and refinement of steel and powdering granulated BF slag, rank at the top in China.

Baosteel is also working hard to resolve the tricky pollution issue of treatment of zinc-containing dust and sludge. It has started studying the methods and equipment for the comprehensive utilization of zinc slag, the recycling of zinc-containing dust, and the production and utilization of long-term effective silicon-cilium fertilizer made of de-siliconized slag.

- High value-added use of blast-furnace slag

Most BF slags are treated with water-quenching technology, and the milled granulated slag is used as a raw material in making Portland cement. Only a small part of BF slag is used for road building (Figure 3.7). Using BF slag to produce cement can significantly reduce limestone use, and reduces the CO₂ discharge of cement production by 40%.

![Figure 3.7 Usage of BF slag, and a slag-powder production facility with a capacity of 120 ton/a](image)

In order to promote the use of BF slag, Baosteel has developed a technique for using milled granulated slag as a substitute for cement in concrete. Such concrete is considered a new green construction material. Research shows that the grade of concrete made with blast furnace slag powder is over C80, is resistant to shrinkage and to chlorine and alkali corrosion, has strong coherence if used with reinforcing bar, and has high anaphase strength. At the same time, Baosteel is actively pushing the establishment of standards for concrete containing BF slag powder. In cooperation with domestic research institutions, it has worked out a national standard for such products. The proportion of BF slag powder in concrete can range from 20% to 70%. Baosteel’s BF slag powder has been widely used in major government projects such as the Shanghai magnetic-suspension railway, the Lupu Bridge, the Shanghai Science and Technology Museum, and Dayangshan and Xiaoyangshan harbors. Baosteel has built a blast-furnace slag-powder production line with a capacity of 1.2 million tons annually. (Figure 3.7)
Figure 3.8  Process of treating steel slag using a rotating drum

- Steel-slag treatment with rotating drum

Based on a Russian patent it purchased, and after ten years of study, a new method to treat molten steel slag was developed by Baosteel, as shown in Figure 3.8. The technology and equipment for treating molten slag with multiple-media cooling, crushing, and separation of iron from a slag with a closed vessel at the core was tested in 1998, and 35 patents were set up. Recently this technology has been put into use at Baosteel.

By now the fourth generation of this technology has been developed, and the equipment has demonstrated short treatment time, small investment, good environmental protection, low cost, and high slag stability. The technology has been transferred or exported to more than 10 domestic and foreign steel enterprises, including Nanchang Steel, Xuanhua Steel, Ma’anshan Steel, and JSW Steel of India. Japanese and Korean steel enterprises are also interested.

Steel slag treated this way is used for sintering, road engineering, cement production, and as milled steel-slag powder in concrete (Figure 3.9). New building-material engineering applications for BF and steel-slag powders are being developed, and steel slag is used for foundation fill and as reinforcement of soft foundations. Baosteel slag was successfully used in Baosteel’s third phase of construction and in the construction of Pudong International Airport in Shanghai.
After many years of continuous endeavor, the treatment of Baosteel’s solid ‘secondary resources’ has changed from storage or simple relocation to use in production, high value-added uses and recycled municipal use, leading to prevention of secondary pollution. From bulk use to specialized management and utilization, Baosteel has instilled systematic thinking about the comprehensive utilization of these ‘secondary resources’ as a way of reducing manufacturing costs as well as protecting the environment. In 2005, 13 solid “secondary resources” made in recycling, including steel slag, slag iron, scale, secondary BF ash, lime-washed mud cake, chemically active slurry, de-dusted coke powder and tar slag, have been recycled in the iron-making process. These amounted in total to 1.87 million tons, and the recycling rate in the plant was 25% in 2005 (Figure 3.10). 100% of coal powder, BF slag, converter slag and EAF slag are recycled for municipal use.
2) Assimilation and treatment of general municipal waste

For the assimilation and treatment of municipal waste, Baosteel started a preliminary study in 2001 on use of waste plastic in the BF, and the recycling of waste plastic by coking. The processing, transport and combustion characteristics of waste plastics were studied. A preliminary plan for experimentally injecting waste plastic into the BF has been started, process design is under way, and 3 patents are being approved. In 2003, Baosteel started research on joint coking of coking coal and waste plastic, and started experimenting with adding waste plastic to coking batteries.

But there are difficulties in promoting the use of waste plastic. The first is an unstable supply of such waste. Presently, the Chinese garbage-classification system for recycling is far from perfect, and the company finds it difficult to get a stable waste-plastics supply without establishing its own special waste-plastics collection operations. The second is high cost. If steel companies are not supported by relevant laws or policies, they will hardly be able to bear the large investment costs of waste-plastics recycling. In Japan, companies can get about 40,000 yen from the government for every ton of waste plastic they treat, giving steel companies an incentive to treat waste plastic and develop relevant technologies.

Mass production of hydrogen is presently based on reacting natural gas, petroleum and coal with steam at high temperatures, or partially oxidizing them. The COG by-product of steel production contains 50%–60% H\(_2\) and 20%–30% CH\(_4\)\(_4\), making it a good raw material for hydrogen production. High purity (99.99%) hydrogen can be produced from coking gas purified with existing treatment methods, using the PSA technique. PSA has been used to produce hydrogen from COG at Baosteel, with some of the H\(_2\) being supplied to the community and to fuel-cell manufacturers. The process has the potential of becoming an effective low-cost large-scale hydrogen-production technology in the future.

3.2.4 Main achievements of implementing circular economy at Baosteel

Baosteel has attained the following significant achievements promoting clean production, reducing raw-material consumption and emissions, and promoting the development of circular economy:

- Promotion of energy-saving technologies. Although Baosteel has continued further downstream processing of its products, and has completed more environmental-protection facilities, Baosteel’s energy consumption per ton of steel remained flat, at an advanced level by international standards. In 2005, fresh-water consumption per ton of steel at Baosteel was 3.77 m\(^3\)/t, while the re-circulation rate of industrial water was 97.6%, the highest in China. The SO\(_2\) emissions per ton of steel in 2005 fell by 20%, and dust by 37%, compared with 2000. CO\(_2\) emissions were 2.1 t/t in 2006\(^{[13]}\), advanced by Chinese standards.

- Baosteel successfully developed steel-slag treatment using a rotating drum. Treated converter slag has been used for construction in and near Shanghai to both save on limestone and reduce CO\(_2\) emissions.

With blast-furnace slag powdering and refractory materials recycling as examples, Baosteel’s promotion of ‘secondary resource’ recycling has put its utilization rate of solid ‘secondary resources’ as high as 98.11% in 2005. In the same year, 25.48% of solid secondary resources were used in the steel production process, the best level in recent years, with savings of about 1 billion RMB.

- By improving its production processes, Baosteel has actively reduced and continues
to reduce CO₂ emissions to reduce its contribution to global warming.

- Baosteel is actively developing eco-links with other industries and the community by providing hydrogen from COG and by recycling waste plastic. Such activities lay a good foundation for future developments of circular economy.

### 3.2.5 New challenges and opportunities

In 2005, Baosteel Co. Ltd. acquired several subsidiaries from Baosteel Group Corporation, including Stainless Steel Co., Meishan Steel, and Special Steel. The original Baosteel became a branch of the new Baosteel. The “Baosteel Circular Economy Program, 2007 to 2012,” and its detailed action plan, were completed in 2006. Through its Environment & Resources Department, Baosteel circulated this plan internally, along with related management and coordination regulations and information about circular economy, as a reference for each branch on how to develop circular economy.

The advantages of the new structure of Baosteel are that the technologies and experience of the original Baosteel can be diffused to branch companies, giving a boost to technical expansion. But serious challenges are also being faced.

- Some new or revamped domestic steel companies have late-comer advantages with new equipment, integration of techniques, and product structure. They are also making great headway in the field of energy saving and environmental protection, adding competitive pressure for Baosteel. Especially in the case of Capital steel’s move to Caofeidian, they start at a high level, and have thoroughly considered the concept of circular economy. The design indices for environmental protection and energy consumption are all at the advanced international levels. This kind of competitive pressure is forcing Baosteel to pay even more attention to being socially responsible company.

- Although some effective technology transfer from the Baosteel branch (the original Baosteel) to other branches has already taken place, the management system and capabilities need to be cultivated gradually to eventually make the new Baosteel as strong as, or even stronger than, the original Baosteel.

The new Baosteel aims to become a globally top-ranking “green” steel company. Based on analyzing the current level of production cleanliness at each branch, testing indices, and making comparisons with the advanced level in both China and the rest of the world, the sum of the company’s advantages and disadvantages was analyzed, and a program for developing circular economy in terms of technology, management and scientific research was worked out. Among technical measures emphasis is put on elimination of backward technologies and techniques, and steadily increasing the utilization rate of resources and energy by implementation of smelting-reduction ironmaking, thin-slab continuous casting and rolling, and other new technologies. Baosteel has set 2012 as the target date for turning itself into a ‘green’ steel company; with low consumption of energy and resources; energy conversion, waste treatment, and recycling in place – as a pioneer and leader among steel companies in technologies for developing circular economy.
4 Developing Circular Economy in the Chinese Steel Industry

4.1 Positioning of the Chinese steel industry

In order to support the doubling of China’s GDP by 2020, meeting the demands of both the national economy, sustainable development of the steel industry, and adapting to competition from the world steel industry, the Chinese steel industry should be positioned in the following ways [14]:

- The steel industry, as an important basis of the national economy and of industrialization in general, should support the building of a comfortable society with steel-product consumption per unit of GDP as low as possible, and refrain from developing overcapacity.
- The Chinese steel industry should be oriented to the domestic market. Steel products are imported and exported, but, on the whole, China should not become an exporter of steel.
- The steel industry is a cut-in point and important link in promoting circular economy. Development and investment in the steel industry should be guided by the goal of building a resource-saving and environment-friendly steel industry.

4.2 The vision of implementing circular economy in the Chinese steel industry

There are three types of recycling (‘circles’) involved in the steel industry:

1) The recycling of self-produced materials and energy.

In steel plants, materials flow from process to process. Each process passes its products on to the next, and expels its waste. But materials are also recycled among processes. The object of steel manufacturing is the flow of iron-containing materials. The product is steel products (or billets, slabs). In the course of this process, some of the iron-containing materials are transformed into scrap, dust, mud, slag, and so on; but all of these materials can be recycled among the processes.

Solid non-iron-containing materials exist mainly in the form of slag. Some of this slag can also be recycled. When a heat is released from the energy medium (coke), gas is produced that can be used as fuel for steel plants. A lot of water is consumed in the manufacturing process, but this can be recycled in the plant itself. Internal recycling is necessary in steel plants to enhance the utilization rate of resources.

2) Recycling of steel-plant by-products of other industries and of the community

Other residual materials and energy, such as part of the slag and residual gas, and solid waste that is hard to use in the steel plant, can be integrated in the supply chain with other industries.

3) Treatment and utilization of community waste (secondary resources)

With growing wealth and increased consumption, waste produced by communities is quickly increasing in China. Some such waste, such as wastewater, steel scrap, waste plastic and old tires, can be treated and utilized at steel plants using metallurgical technology.
4.3 Functions of steel plants in a circular economy society

Steel production connects readily with the overall circular economy in terms of both materials and energy, and has an interactive influence on related industries. Steel manufacturing should have three functions (Figure 4.1), those of manufacturing steel products, energy conversion, and waste treatment and recycling[9].

This new conception of steel manufacturing is in accordance with the requirements of developing circular economy. Realizing the three functions of a steel plant allows it to form an eco-industrial chain with the power, construction-material and petrochemical industries [9, 15]. By becoming an important member of the environment-friendly circular economy society, the steel industry can achieve green production. Two kinds of steel plant and their place in a circular economy society are introduced below.

![Figure 4.1 Three functions of steel manufacturing][9]

1) Suburban steel plants

There are steel plants in 26 provincial capitals. China is rapidly urbanizing, and cities, especially industrial and commercial cities, are centers of production, consumption and waste treatment. Therefore the recycling of basic materials such as steel, plastic, glass, aluminum, copper, lead, zinc and so on has to be considered. Moreover, the urban consumption of electricity, gas, water, and hot water is enormous and growing. Obviously, the reform of suburban steel plants already finds, in a number of cities, favorable conditions for economic and ecological improvement. Scrap, waste plastic[16,17], garbage, wastewater and other urban wastes[18] can be used and recycled conveniently and effectively by a steel plant; examples are the civil sewage-treatment plant at Jinan Steel and the supply of H2 to the community by Baosteel. In addition to supplying steel, steel plants can supply hot water and even power to communities (the way the Swedish steel company SSAB does).

Therefore, a number of suburban and industrial-ecological steel plants near cities have great potential for positive development. The philosophy of developing these plants is shown in Figure 4.2.
2) Steel plants in eco-industrial port zones

With the acceleration of economic globalization, international trade in minerals and energy is expanding. Demand for steel as a basic material and oil as the principal source of energy will naturally grow in the process. The global sea-borne iron-ore trade has reached 450 ~ 670 million tons/a in recent years. In 2005, China's iron-ore imports reached 275 million tons. The development of large integrated steel enterprises at harbors will lead some harbor cities with other basic conditions to gradually turn into eco-industrial zones. Under such conditions, large integrated steel enterprises can rely on their logistics, material, financial, technological and expertise advantages to expand their manufacturing and management chains. In turn, an eco-industrial chain can be formed by linking with shipbuilding, container manufacturing, cement manufacturing, and even the construction industry. At the same time, large integrated steel enterprises have abundant hydrogen-producing potential. If this hydrogen is used by adjacent petrochemical enterprises, the competitiveness of both industries can increase. In such eco-industrial zones, resources, energy, and funds can be used fully and effectively, with a lower environmental burden per unit of output. Such zones can involve steel, power, cement and petrochemicals with a large integrated steel enterprise at its center. The functions of steel plants in such zones and their relationships with other industries and nearby areas are shown in Figure 4.3.
As a link in the eco-industrial chain, iron resources are important to the circular economy. At the same time, the socio-economic functions of steel plants are increased through their ecological transformation.

Jingtang Steel at Caofeidian, based on the relocation there of Capital Steel, will be built as a new-generation steel plant, the conceptual basis of which is shown in Figure 4.4. As Figure 4.4 shows, in the ecological chain of circular economy formed by the steel-production processes of large integrated new-generation steel enterprises, about 13.5 million tons of iron ore and 6.3 million tons of coal are consumed and 9 million tons of steel produced annually. At the same time, about 1.2 million tons of scrap and 0.14~0.28 million tons of waste plastic are taken from the community and utilized, and 4.3 million tons of slag cement and 660 million m$^3$ of hydrogen are supplied to the community and the petroleum industry each year. It is difficult to accurately estimate the economic, social and environmental benefits of such an operation, but it is clear that they are vast.
In summary, there will be two main kinds of ecologically-reformed steel plant in the future: suburban, and those located in harbor eco-industrial parks.

The socio-economic functions such plants can be expected to undertake are as follows.

1) Producing (as the starting point of the iron and coal-chemicals industries) better and cheaper steel, clean energy, and large quantities of relatively affordable hydrogen gas.

2) Being the cores of harbor eco-industrial parks.

3) Municipal waste recycling and community heat supply.

4) Being coordination and treatment points of industrial-waste recycling, energy cascading, and neutralization of hazardous waste.
5 Preliminary Experiences and Problems Developing Circular Economy in the Chinese Steel Industry

5.1 Preliminary experiences developing circular economy at steel plants

Jinan Steel and Baosteel are integrated steel enterprises with typical BF-BOF “long” processes using iron ores and coal as the main raw materials. They are resource and energy intensive, and produce a lot of pollution. But through years of practice, independent innovation, persistently adopting suitable, effective, and economical technologies and equipment, the important role of technological innovation in developing circular economy has been clearly demonstrated. These unique experiences contribute to exploring circular economy at a regional scale. All of these will undoubtedly prove very meaningful for the further development of circular economy in the steel industry, and useful as a model for other steel enterprises and other industries.

1) Conceptual guidance and attention of leadership are crucial to developing circular economy.

The direction of strategic development of an enterprise is decided to a great extent by the perceptions and actions of its leadership.

The leaderships of Baosteel and Jinan Steel have recognized that “development is determined by profit and survival is determined by the environment,” and that the only way forward is to establish positive relations with the environment and the community. The leadership has changed its thinking, and considers social and environmental factors when setting targets and making important decisions related to increasing scale and profit.

The following mottos have been established at Jinan Steel: “pollutants are resources in wrong locations,” “unlimited innovation, unlimited resources,” and “technical innovation is the key to efficient utilization of resources.” The core values of “respectability, credibility, creating together and winning together” have been cultivated. An enterprise culture of “human harmony, material harmony, harmony of interests, harmony of hearts” has been emphasized, instilling the concepts of applicable scientific development, and paving the way to a new type of resource-saving and environment-friendly industrialization.

Baosteel has always paid great attention to sustainable development. With “Honesty” as its basic value, the company actively takes on the social responsibilities of promoting economic development, social progress and environmental protection, has built a developmental frame that involves sharing results with other enterprises and related bodies, made its management more unified, and pursued building a world class “green” steel enterprise.

2) Structural innovation and effective management are the basis for developing circular economy.

A management department promoting innovation and R&D has been established at Baosteel. A quarterly meeting on environment and resources is organized as a platform to promote unified management of environment and resources, and help with coordination. Innovation and incentive mechanisms have been established to promote circular economy at Jinan Steel. All the measures mentioned in this report are steps toward implementing circular economy.
3) Technical innovation is the ‘golden key’ to developing circular economy

Experimenting with open methods of technological innovation which combine production with study and research, Jinan Steel cooperates with famous universities and research institutes, including Tsinghua University, the University of Science and Technology Beijing (USTB), Northeastern University, the Chinese Academy of Sciences, the Central Iron & Steel Research institute (CISRI), Research Institute No.703 of the China Shipbuilding Heavy Industry Group Co., the Nanjing Turbine Motor Group Co., the Shenyang Blower Group Co. and the Shenyang Consultation Institute of Electrical Power, gradually forming a unique system of independent innovation. These organizations give strong support to Jinan Steel’s prospects of achieving its targets set for pilot enterprises of circular economy.

Jinan Steel had the courage to install CDQ in China, then be the first to use high pressure CDQ, and install CCPP at a time when there were negative opinions about it in China. It is not the first time Jinan Steel has dared do something never done before in China, and use techniques other Chinese steel enterprises would not. Such courage comes from the farsightedness and correct decision-making of the leadership, but also the technical knowledge related to energy conversion accumulated over many years, and confidence in the ability of the workforce.

Technical innovation is not easy. Baosteel has a very good tradition of technical innovation, and was the first enterprise to do steel research in cooperation with the Natural Science Foundation Committee (NSFC) of China. In recent years it has cooperated with domestic and foreign organizations in carrying out research, with significant results.

4) Jinan Steel has summarized, based on its own practices, how to develop circular economy: “it is based on creating value, guided by conceptual innovation, supported by technical innovation, guaranteed by management innovation; involves implementing administration of resources, distribution and systems; realizing efficient utilization of resources, efficient conversion of energy, and regeneration of metabolites; pursuing the harmony of profit with environmental and social benefits in order to build an enterprise that economizes resources and is environmentally friendly and independently innovative.”

5.2 Existing problems developing circular economy at steel plants

Driven by market demands and the need to continue expanding, many domestic steel enterprises find themselves pulled between expanding capacity and reducing energy consumption and pollutants. The promotion of cleaner production and end-of-pipe treatment to provide a more solid foundation for circular economy still faces many obstacles.

1) Elimination of backward technology: a necessary condition for developing circular economy.

At Jinan Steel, six 350m$^3$ BF s, cupola furnaces, and other backward equipment are still being used, with high energy consumption and serious pollution. It is difficult to use advanced techniques on such facilities, and the efficiency of the whole process is compromised. The task of eliminating such backward technology is difficult, and demands complete rearrangement of the company’s production processes.

Baosteel, in its plan for circular economy, has made elimination of backward technology its priority.

2) Lack of deeper understanding of circular economy
For the time being, the conception of circular economy at many enterprises is quite superficial. Some enterprises take cleaner production along with end-of-pipe treatment as amounting to circular economy.

At this time, the circular economy implemented at enterprises is small-scale recycling within the enterprise itself, leading to energy savings and cleaner production. The utilization of solid waste is still primitive, but should be improved by learning from the experiences of energy conversion at Baosteel and Jinan Steel. At the same time, investment and optimization are required to improve environmental protection, and the circular economy of intermediate and large-scale recycling with related industries and the community has just started. The recycling and treatment of community waste at steel plants should be supported and promoted by appropriate policies.

3) Lack of systematic research for guiding circular economy

During investigations of research into optimizing power generation from residual heat, residual energy and other secondary resources, the vice president of Jinan Steel, Mr. WEN said that, in fact, enterprises need systematic study, carried out by relevant research institutes, the results of which can be used as guidelines for the industry. At present Chinese enterprises lack support for such research. Because most R&D is focused on individual technologies, and often even lags behind actual practice, there is rarely any applied fundamental study of the integration and optimization of energy-conversion techniques based on optimized technologies; therefore enterprises lack guidance in the development of circular economy. The process of implementing projects at enterprises is preceded by unsatisfactory study and planning, decisions are made in a hurry, problems are observed late, and sometimes the completion of a project needs to be followed by a technical overhaul.

4) Overoptimistic analysis of energy-savings potential and the necessity of improving energy-monitoring and statistics system.

At most enterprises, the positive effects of implementing energy-saving technologies are considered fully during the analysis of energy-savings potential, but the increase of energy consumption due to prolonged processing, and the energy consumption of the environment-protection equipment itself are considered inadequately, giving overoptimistic energy-savings targets. For example, the energy consumption of the de-dusting system at Jinan Steel has increased a lot in recent years, and now 25% of total electricity consumption is for de-dusting.

Jinan Steel has recognized the importance of energy measuring, and will install instruments to measure energy, institutionalizing the testing of the calorific value of coal, coke and other fuels, and further improving the monitoring and management of the main energy-consuming equipment.

5) Inadequate policy support by government

As mentioned earlier, the metallurgical manufacturing process is a clean, efficient energy-conversion center, of which the by-product gases are clean energy resources low in dust and sulfur. These energy resources, as regenerated resources, may more reasonably be called “quasi-renewable energy resources” than “secondary energy resources.”

The utilization of quasi-renewable energy resources, such as residual heat and residual energy (including by-product gases) for power generation, and community waste, are for now restricted by inadequate policy support. For example, the schedule of the No.2, No.3 and No.4 CCPP projects at Jinan Steel is influenced by approval of connection to the state grid, and the price of power. This is a common problem in the process of promoting energy
savings in the steel industry and other large energy-consuming industries.

6) Inadequate knowledge of emissions of greenhouse gases (GHG)

At this time most Chinese steel enterprises give little thought to greenhouse gas (GHG) emissions \[^{[18]}\]. At most enterprises, there are no data concerning CO$_2$ emissions, and no suitable methods of evaluating them and gathering statistics. This situation should be changed.
6 Analysis of Needs for Policy Support

Tremendous progress has been made by the Chinese steel industry since 1990 in the fields of energy saving and environmental protection, through on-going efforts to save energy, install end-of-pipe treatment, and promote cleaner production. For the time being, the amount of backward steel production is still rather high in China, and the recycling of resources among enterprises and with the community either not considered or not implemented; the Chinese steel industry, then, is only just starting to establish circular economy. Some steel plants have accepted the concept of circular economy and use it to guide planning, reconstruction and construction. But there are many steel enterprises in China, they have huge discrepancies in their technical levels, and eliminating backward enterprises is very difficult. There is a long way to go toward developing circular economy.

6.1 Analysis of policy needs

Based on analysis of difficulties encountered in implementing circular economy at the two pilot enterprises and anecdotal evidence of the industry as a whole, the following policy suggestions are analyzed: favorable taxation to encourage adoption of specific technologies, allowing power generated by utilization of residual heat and secondary energy into the grid, allowing and promoting the treatment of community waste, and encouraging the utilization of by-products while discouraging the use of primary raw materials.

1) Favorable taxation for enterprises adopting advanced circular economy technologies

At this time there are no clear policies to encourage pilot enterprises of circular economy. As the results of implementation at Jinan Steel, Baosteel and others show, enterprises need to be encouraged by a variety of policies, such as tax breaks related to the investment in technologies (possibly after successful evaluation of the implemented projects). Alternatively, enterprises adopting circular economy could be offered favorable terms for the purchase of iron ore and other resources.

According to the document: “Notice regarding the State Council ratification of suggestions of developing comprehensive utilization of resources given by former State Economy and Trade Commission and other Departments” (State Council [1996] No. 36), and related advantageous tax policies, the direct profits of projects listed in “The Catalogue of Comprehensive Utilization of Resources” issued by the Chinese government can be exempted from corporate profit tax.

However, in the process of resource recycling, the scope of projects is far more than what is included in the catalogue, and many projects don’t lead to direct profits. For example, the reuse of water is 97% at Baosteel, worth hundreds of millions of RMB in environmental protection, but with no policy in place to support it financially. Since 1994, Baosteel has invested around 400 million RMB per year in energy-savings and environmental-protection projects, but in the entire five-year period of 1999~2004 received a total of only 230 million RMB in tax reductions for its waste-treatment projects. We suggest that the scope of “The Catalogue of Comprehensive Utilization of Resources” be widened, and that financial and taxation policy be studied with the goal of supporting enterprises in gaining indirect economic and social benefits from recycling.

Although there is some temporary support for projects, there is a lack of fixed
long-term policy support.

2) Allowing power generated from residual heat and energy into the grid

Power generated from residual heat, and from energy such as ‘quasi-renewable energy,’ is used at steel plants, but to stabilize the voltage, and for more effective utilization, the power should be allowed to enter the national grid. The obstacles are as follows:

- Difficulty gaining approval to enter the grid. Although the central government has issued a policy document, in practice the approaches differ from region to region, and time-consuming formalities can make entry difficult and very time-consuming. Steel enterprises have made several requests to local governments and the grid companies to coordinate a solution, but the problems remain. The major reason may be that grid companies want to maximize profits. It is predicted that once power supply is saturated, grid companies will start to discriminate against power generated from residual heat or residual energy, and the difficulties that steel companies face in supplying power to the grid will become even more serious.

- Unreasonable price of power supplied by steel plants. The price grid companies pay for power from steel plants is lower than that at which they sell it back to them, the difference being about 0.15~0.3 RMB/kWh. In principle, a management fee is reasonable, but grid companies have monopolies, and steel plants have no means to negotiate. Therefore, first, power stations working on secondary energy should be encouraged by the government. Secondly, the price of the power supplied by the steel plants should be fixed, since it is impractical to ask steel plants to negotiate with grid companies to fix it. Thirdly, the price of power generated by power stations working on residual heat or energy should be favorable compared with that of power generated by coal-power stations, and in general the power stations working on secondary energy shouldn’t be restricted by peak-time regulations, and be able to work at full capacity all the time.

In short, because power stations powered by ‘quasi-renewable energy’ are clean sources of energy, they should be encouraged by the government, the way wind-power stations are. It is suggested that the Chinese government learn from the experience of developed countries, giving grid companies subsidies, and not letting grid companies charge fees for grid access, so as to support steel plants in saving energy and reducing emissions.

3) Encouraging and allowing steel plants to use community waste

At this time, steel plants utilize community waste based on considerations of becoming environmentally friendly and contributing to society. For example, Jinan Steel recycles the chromium slag from Jinan Yuxing Chemical Plant at only 20 RMB/t, paid by the latter in the form of an employee health allowance, while the actual cost of treatment is much higher (200~300 RMB/t). Though steel plants have a duty to contribute, from a long term point of view allowances should be made to encourage their utilization of community waste and make it easier for them to start practicing principles of circular economy.

Abroad, Germany and Japan have implemented circular economy more successfully. For example, the Japanese government certifies steel plants for utilizing waste plastics and pays them 300-500 USD/t, while in Germany the sum is around 300 Euro/t. Not surprisingly,
the total quantities of waste treated are much higher in these countries. In 2004, the Nippon Steel Corporation (NSC) treated 140,000 t of waste plastic \cite{16}, while the Japan Iron and Steel Federation (JISF) has a plan to treat 1 million tons/a of waste plastic until 2010.

In addition, a collection and classification system along with a pricing system should be established (and regularly updated) for the treatment of municipal waste (or waste from other industries) for steel plants. As Jinan Steel has demonstrated, waste-fluids from paper pulp making can be used for pelletizing at steel plants. This technology is difficult to realize now because of the lack of suitable pretreatment and transport systems. Also, some kinds of plastics, which can be used as fuel, can be used in coking and iron making. But due to the lack of collection and classification systems, difficulty of accurately estimating cost, and lack of management at different stages, steel plants cannot practically utilize such plastics. The authorities concerned should guide and manage such activities.

4) Natural raw materials used to manufacture cement should be taxed, while the use of blast furnace slag should be encouraged by favorable pricing

- At present, the price of granulated blast-furnace slag is low, about 30–40 RMB/t and sometimes only 10–20 RMB/t. When market circumstances are poor, steel companies sometimes have to pay for removal. The savings to be gained from replacing limestone with blast-furnace slag to manufacture cement are much higher. A reasonable pricing system should be put in place.

- Due to the fact that blast-furnace slag is difficult to transport long distances, it is sold to cement factories or construction sites nearby. But not all the slag can be sold. Some cement factories are accustomed to using limestone, which they can get quite cheaply. Also, only a few cement (or concrete) grades can be manufactured with blast-furnace slag, and the amount of slag that can be added is limited. Given this, one can expect a greater and greater surplus of blast-furnace slag as the output of hot metal increases.

Policy guidance needs to be strengthened, use of metallurgical slag (blast-furnace slag and steel slag) encouraged, and cement-industry use of blast-furnace slag promoted. At the same time, studies should be carried out on using metallurgical slag rationally and standardizing the processes involved.

6.2 Suggestions for developing circular economy in the Chinese steel industry

6.2.1 Main measures needed to develop circular economy in the Chinese steel industry

1) Elimination of backward equipment is a basic requirement.

2) Effective utilization of scrap must be emphasized.

To some extent, the EAF “short” process of using scrap is in itself an example of circular economy. In 2004, the world crude steel output was 1057 million tons, with a scrap consumption of 420 million tons, accounting for 35.2% of the total charge. However, due to the rapid development of the Chinese steel industry, and the relative lack of scrap, the EAF ratio is under 15% here, and in 2005 fell to 11.6%.

A smooth supply of scrap (including recycled scrap and scrap from manufacture) is the
only raw material for EAF production. Increasing the application of the EAF process helps reduce energy consumption and the burden the steel industry as a whole puts on the environment, and hence promotes circular economy. In the first 20 years of the 21st century, the output of scrap in China will markedly increase, the supply to electric steel making will also gradually increase. The import and use of scrap should be encouraged along with the development of the EAF process.

3) Strengthening the ability of enterprises to innovate

A new system of market-oriented technical innovation should be formed. Steel enterprises should cooperate with state and professional research institutes to develop circular economy technologies for the steel industry. Enterprises should be the main investors in research projects, with a view to enhancing their own innovative capabilities.

Circular economy technologies should be developed on three levels and with three functions in mind:

a) Popularization of existing high-efficiency energy-saving technology and equipment

b) Development and promotion of industrialization of technologies that support circular economy

c) R&D of cutting-edge steel-manufacturing technologies and techniques

6.2.2. Policy suggestions

1) To provide a variety of new types policy support for pilot enterprises, particularly more long-term policy support.

2) The steel industry and power industry should be coordinated under the government to formulate reasonable policies and pricing for connecting power generated by steel enterprises to state grids, and the building of steel-enterprise power plants working on secondary energy such as residual heat, residual energy and by-product gases should be encouraged.

- Regulations should be established that provide subsidies to grid companies to cover fees for the connection of power generated from ‘quasi-renewable energy’, to encourage steel plants and power companies to take responsibility together for energy savings and emissions reductions.

- The power generated by steel-enterprise power stations should be given preference and should not be influenced by the controls put on power generation at peak-demand times. In order to reduce gas loss and save energy, the construction by steel companies of large generators operating on coal and gas, with good ability to control gas, should not be restricted; they are quite different from generators that operate on coal only, and should not be regarded in the same way.

- In addition, steel enterprises should be encouraged to generate power together with local power companies. Steel enterprises can supply residual gas to local power plants that can generate power from coal and gas, making a win-win partnership.
3) Comprehensive policy should be established that covers resource savings, recovery and utilization as a basis for developing circular economy.

Utilization of scrap, waste plastic, slag, dust and sludge, tailings, and used tires needs to be encouraged. The import of scrap should be encouraged, its export restricted. The government should guide or organize a new business sector covering the recovery, classification, treatment and supply of scrap and waste plastic, with financial and policy support.

In addition, guided by policy, investment in the demolition and separation of discarded automobiles, ships and steel equipment should be encouraged, both taking advantage China’s large labor force, and helping resolve the problem of limited supply of scrap to the steel industry.

When it comes to utilization of metallurgical slag, there should be regulations according to which enterprises which use natural resources are charged high resource fees, while enterprises which use tailings or slag receive tax reductions. This will lead cement (concrete) factories to use BF slag more actively. At the same time, new cement grades need to be developed, along with other construction materials to which BF slag can be added.

The scope of the “Catalogue of Comprehensive Utilization of Resources” should be broadened, and regulations supporting tax breaks on the indirect profits and social benefits (not only direct profits) enterprises achieve by recycling resources should be studied and established.

4) A “Steel Industry Circular Economy Technology R&D Center” should be established.

The government should support and guide the establishment of a “Steel Industry Circular Economy Technology R&D Center” as a platform for unifying enterprises in implementing circular economy, with technologies and integrated solutions shared among them. At the same time an information system and technical-consultation center should be set up to share methods and experience, to carry out further research, and to evaluate the systems of implementing circular economy at steel enterprises. It should carry out research on the policies needed by the steel industry for developing circular economy, and make suggestions to the authorities for establishing strategic targets and implementing plans.

5) Strict enforcement of environmental laws should be stressed. At the same time, the government should encourage steel enterprises to apply advanced technologies for pollution control by giving financial incentives such as subsidies and low-interest loans.

6) Symposiums on circular economy should be organized to train leaders of steel enterprises and eventually form a scientific performance-evaluation mechanism.

At present, the quality of the development of an enterprise is often mainly determined by the qualities of its president. The development of circular economy is guided by scientific development, changing the idea of growth, and also presenting a major shift in the focus of technological development. Whereas technologies used to focus only on product
mix and quality, they now need to turn to efficient utilization of resources and product-quality improvement. What we face is a need to change perspectives, targets, and ways of thinking. It is very important, therefore, to train the leaders of enterprises, while developing new systems for the evaluation of their performance.
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