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The Chinese nonferrous metals industry—energy use and CO_2 emissions

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ABSTRACT

China is the largest nonferrous metals producer in the world and largest consumer for six kinds of common nonferrous metals including copper, aluminum, zinc, lead, nickel and tin. This paper provides an overview of the nonferrous metals industry in China, from a CO_2 emissions reduction perspective. It addresses energy use disaggregated by energy carrier and by province. It focuses on an analysis of energy efficiency in the production of aluminum, copper and nickel. A few large-scale enterprises produce most of the aluminum, copper and nickel in China, and use manufacturing facilities that were built within the last 20 years or have recently upgraded their main production equipment and processes. The energy efficiency of these operations is not particularly low compared to international practice. A large number of small and medium-sized enterprises (SME) operate nonferrous metals production facilities which rank low in energy efficiency and therefore are highly energy intensive per unit of physical output. Backward production capacity would be phased out continuously by enforcing the energy intensity norms.

1. Introduction

1.1. Growing production and energy demand

China is the largest nonferrous metals producer in the world[1] and largest consumer for six kinds of common nonferrous metals including copper, aluminum, zinc, lead, nickel and tin. High domestic demand and prices on the international market drives the nonferrous metals output to grow quickly, along with associated energy consumption.

- From 1990 through 2006, the output of ten nonferrous metals[2] increased eight-fold, of which, nickel, copper, and primary aluminum nickel increased three, five, and eleven fold, respectively.
- From 1990 through 2006, energy consumption grew 450% for the nonferrous metals sector in general, 700% in electricity, and 370% in coal.
- The nonferrous metallurgy sector absorbed huge investments to expand production capacity, and significantly increased the requirement for ore imports. The investment in the sector in 2006 was 118 billion RMB or US$ 15 billion, six times more than in 2002. Only one-third of the copper was derived from domestically produced minerals.

The Chinese nonferrous metals industry is in many ways a typical energy-intensive sector. It consumed 43.2 million tons of coal equivalent (tce,[3] or 1267 million GJ[4]) in 2006,[5] 3.65% of national industrial final consumption or 85.8 million tce[6] (2514 million GJ), 3.48% of national consumption while it contributed 1.5% of GDP only. Due to widespread energy shortages in China during this time, the sector received considerable attention from the government regarding energy-efficiency improvement. Some 71 nonferrous metals enterprises are listed in the “Top One Thousand Enterprises” program, which authorities use to keep close watch on energy consumption and efficiency.

China has a national target of reducing the energy intensity of its GDP by 20% during the 11th five-year planning period (2006–2010), taking 2005 as the base year. The nonferrous metals industrial association has developed and adopted a similar target under this policy, as have other industrial associations and provincial governments. Rapidly rising metal prices can distort measurement of this goal because the ratio of energy used in production to the

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[1] Account for ten kinds of nonferrous metals which are copper, primary aluminum, lead, zinc, nickel, tin, antimony, mercury, magnesium and titanium.

[2] Including copper, primary aluminum, lead, zinc, nickel, tin, antimony, mercury, magnesium and titanium.

[3] Ton of coal equivalent.

[4] 1 tce = 29.3 GJ.

[5] China Energy Statistical Yearbook 2007, calorific value calculation (1 kWh = 3596 kJ).

[6] China Energy Statistical Yearbook 2007, coal equivalent calculation (1 kWh = 10050 kJ).

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Table 1
Non-ferrous metals output in China, 1990–2006.

Metals	1990	1995	2000	2004	2005	2006
Copper (000 ton)	561.6	1079.7	1371.1	2198.7	2600.4	3003.2
Aluminum (000 ton)	847.1	1676.1	2794.1	6688.8	7806.0	9358.4
Lead (000 ton)	296.5	607.9	1099.9	1934.5	2391.4	2714.9
Zinc (000 ton)	551.8	1076.7	1957.0	2719.5	2776.1	3162.7
Nickel (000 ton)	27.5	38.9	50.9	75.8	95.1	101.9
Tin (000 ton)	35.8	67.7	112.4	115.3	121.8	132.1
Antimony (000 ton)	60.0	129.5	113.3	125.3	138.3	140.4
Mercury (ton)	930	779	203	1140	1094	759
Magnesium (000 ton)	5.4	93.6	142.1	442.4	450.8	519.7
Titanium (ton)	1913	1723	1905	4809	9161	18,037
Ten non-ferrous metals (000 ton)	2393.2	4966.2	7838.1	14,306.2	16,390.2	19,152.1
Absolute annual increase		1990–1995	1995–2000	2000–2004	2004–2005	2005–2006
Copper (000 ton)		103.62	58.28	206.9	401.70	402.80
Aluminum (000 ton)		165.8	223.6	973.675	1117.20	1552.40
Lead (000 ton)		62.28	98.4	208.65	456.90	323.50
Zinc (000 ton)		104.98	176.06	190.625	56.60	386.60
Nickel (000 ton)		2.28	2.4	6.225	19.30	6.80
Tin (000 ton)		6.38	8.94	0.725	6.50	10.30
Antimony (000 ton)		13.9	−3.24	3	13.00	2.10
Mercury (ton)		−30.2	−115.2	234.25	−46.00	−335.00
Magnesium (000 ton)		17.64	9.7	75.075	8.40	68.90
Titanium (ton)		−38	36.4	726	4352.00	8876.00
Ten non-ferrous metals (000 ton)		514.6	574.38	1617.025	2084.00	2761.90

Source: The yearbook of nonferrous metals industry of China 2007.

value of the production decreases regardless of the any changes in actual energy use. Indeed, the energy intensity reduction goal was reached in 2007 if the value-added is calculated by current price. It is difficult for industries or enterprises to calculate their value-added using constant prices. That raises two key questions: how can we measure energy efficiency more usefully and how can we set up an energy-efficiency improvement target to encourage enterprises to adopt more measures for efficiency improvements? The sector has nevertheless experienced important improvements in technical energy efficiency over the last two decades by building new large-scale facilities and phasing out small-scale ones. The norms of energy consumption per unite products of nonferrous metals enterprises effected on June 1st 2008 will force the enterprises to improve energy efficiency further through this approach. The enforcement of these norms is a key factor.

2. Nonferrous metals industry trends in China

2.1. Rapid expansion of production output

China's nonferrous metals output has increased rapidly, as shown in Table 1. Output for ten nonferrous metals in 2006 reached 19.2 million tons, up from 2.4 million tons in 1990. Fastest growth occurred in magnesium, aluminum, titanium, and lead production. Growth remains rapid in most metals production.

2.2. Broad and uneven distribution of production

Geographic distribution of nonferrous metals production across China corresponds with the distribution of metal ores and energy supply availability. There are only two provinces,[7] Beijing and Hainan, without nonferrous metals output, [8]as shown

[7] Provinces include autonomous regions and municipalities.
[8] Accounts for ten metals.

Table 2
Output of non-ferrous metals in 2006 (ton).

Province[a]	Ten metals[b]	Copper	Primary aluminum	Nickel
Total	19,152,225[c]	3,003,229	9,358,365	101,853
Beijing	0	0	0	0
Tianjin	33,164	29,669	0	0
Hebei	7995	7375	0	0
Shanxi	1,198,174	55,779	773,597	0
Inner Mongolia	640,308	63,014	682,072	0
Liaoning	495,917	71,717	119,077	0
Jilin	1083	438	0	0
Heilongjiang	814	1126	6130	0
Shanghai	150,632	144,148	0	0
Jiangsu	307,008	160,507	68,660	0
Zhejiang	351,205	249,663	72,668	0
Anhui	759,990	420,107	0	0
Fujian	82,242	10,993	62,824	0
Jiangxi	545,020	506,991	0	0
Shandong	1,297,503	309,500	988,003	0
Henan	3,270,880	29,026	2,106,754	0
Hubei	555,827	211,710	295,325	0
Hunan	1,431,661	5011	118,653	0
Guangdong	277,274	50,370	0	0
Guangxi	735,788	75	244,407	0
Hainan	0	0	0	0
Chongqing	129,443	0	104,284	1689
Sichuan	615,295	0	417,180	0
Guizhou	743,442	168	589,402	0
Yunnan	1,861,143	384,407	476,401	1266
Tibet	1207	1207	0	0
Shaanxi	509,374	5374	179,998	0
Gansu	1,294,735	276,482	637,361	95,273
Qinghai	862,737	0	810,675	0
Ningxia	684,112	210	556,554	0
Xinjiang	65,805	4667	48,340	3625

Source: The yearbook of nonferrous metals industry of China 2007.
[a] Province grouped here is based on divisions of administrative areas in China that used for present statistical system.
[b] Excluding recycled aluminum.
[c] There are 270,000 tonnes double account in lead and zinc output. The total ten metals output is 270,000 tonnes less than the sum of provincial data.

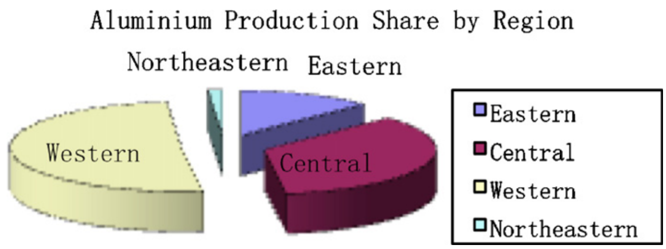

Fig. 1. Aluminum production share by region (2006).

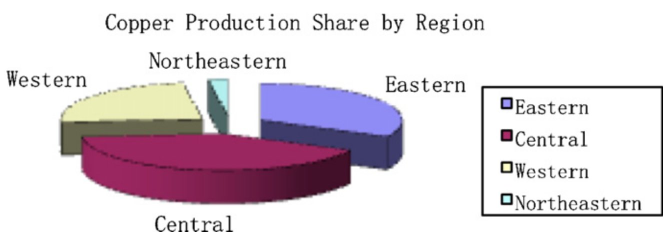

Fig. 2. Copper production share by region (2006).

in Table 2. Some 26 of 31 provinces produce copper, while 21 provinces produce aluminum and 4 provinces produce nickel.

By integrating provincial production data into four regions,[9] it can be shown that all nickel is produced in the Western Region, while the Northeastern Region plays a modest role both in copper and aluminum production. Half the output of aluminum is produced in the Western Region (as shown in Fig. 1) where cheap electricity is supplied by hydropower facilities. More than 40% of copper is produced in the Central Region (as shown in Fig. 2), which is rich in copper ore.

2.3. *Large enterprises dominate productions*

2.3.1. *Two-third of value-added of the industry comes from large-scale enterprises*

Only 14 enterprises produced three-quarters of total copper (including primary and fine copper, excluding copper products) in 2005 and, of those, twelve enterprises had annual output over 50,000 tons. Concentration of copper production increased in 2006 with 8 enterprises producing 2.11 million tons of copper, or over 70% of the national total.

Alumina output in 2005 was 8.1 million tons, with production coming from only seven companies. As newly built facilities have been commissioned, 21 enterprises in 2006 produced alumina and annual output reached 13.7 million tons, 39.3% higher than the previous year. Twenty-one enterprises with an annual output over 100,000 tons produced 7.14 million tons of aluminum, 76.4% of national total. The year 2005 share of these large plants was 10% lower.

A single enterprise in Gansu in Northwest China, the Yinchuan Nonferrous Metals (Group) Co., Ltd., produces almost 95% of China's total in nickel output. The rest of the nickel is produced by a few other enterprises located in Xinjiang, Chongqing, Yunnan and Liaoning.[10]

2.4. *Large enterprises retrofitted their facilities in the past two decades*

Only about one dozen major enterprises produced copper in China in 2005, and they have evolved dramatically in recent years (see Table 3, which provides data on the firms' age, production process, and smelting technology). Half of those enterprises, built in the 1960s, have retrofitted their smelting process to adopt more efficient technologies. Newer companies established since 1990 have also adopted efficient technologies. More than 10 Ausmelt/ISA smelters with high efficiency are used in China, with a total capacity of 1.5 million tons per year (Dong et al., 2007). Only one large enterprise, Huludao, still uses a blast furnace, and it was built in 2002.

All alumina is produced by 7 enterprises, as shown in Table 4. Except for the Guangxi Company which has adopted the Bayer process, all these firms have adopted a combination of sintering and Bayer processing. Zhongzhou and Shandong companies used to adopt a sintering method and changed to a combination of these two processes in 1992. The Bayer process, which combines an extraction (digestion with caustic soda) and calcination process, consumes less energy than the sintering process.

Table 5 shows the main producers of nickel and their processing technology adopted in China.

2.5. *Rapid growth in electricity and coal consumption*

Energy consumption in the industrial sector has, since 1990, increased tremendously, as shown in Table 6. Most industrial energy demand growth was met with electricity from the grid and direct consumption of coal. The year 2006 showed particularly rapid growth with an increase in industrial energy demand of more than 10%.

Energy use for metallurgy exceeds 0.1 exajoules in five provinces, as shown in Table 7. These provinces are Shanxi, Inner Mongolia, Shandong, Henan and Qinghai.

2.6. *High rates of coal use lead to high levels of carbon dioxide (CO_2) emissions*

Chinese industry, as noted, consumes mostly coal and electricity, which is also produced mainly by coal-fired power plants in China. Oil and natural gas make up only 5% of the total energy consumption (see Fig. 3).

Carbon dioxide emissions can be calculated easily from these energy consumption data (see Table 8). The calculation is based on the energy consumption data listed in Table 7[11] and the emission factor of various fuels issued by the Intergovernmental Panel on climate change (IPCC, 2006). Some 66 million tons of CO_2 were emitted directly from the nonferrous metals industry in 2006, 24.5% more than in 2005.[12]

A rough estimate of the national average emissions factor for electricity in 2006 is 788 kg-CO_2/MWh. Thus, the indirect CO_2 emissions of the industrial sector were 140 million tons.

[9] Provinces are grouped into four regions based on their geographical locations. Eastern region includes Beijing, Tianjin, Hebei, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong and Hainan. Central region includes Shanxi, Anhui, Jiangxi, Henan, Hubei and Hunan. The western region includes inner Mongolia, Guangxi, Chongqing, Sichuan, Guizhou, Yunnan and Tibet, Shanxi, Gansu, Qinghai, Ningxia and Xinjiang. Northeastern region includes Liaoning, Jilin and Heilongjiang. This regional group clarification is used only for national economic, social development and people's livelihood indicators in 2006 (data of 2005) for the first time.

[10] Jilin Haorong Nonferrous Metals (Group) Co., Ltd. produced 4210 tons of nickel (net nickel content) in the form of other products which is not accounted into the total nickel output by the statistical yearbook.

[11] Excluding "other."

[12] According to energy consumption data in 2005, 53 million tons of CO_2 were emitted directly from nonferrous metals industry in that year.

Table 3
Main copper producer.

Name of enterprises	2005 copper output (copper; tons)	Start of operation	Process	Smelting technology (time of adoption)
Zhongtiaoshan	120,926	April 1956	Ore—Primary–Fine	Ausmelt (1990s)
Huludao	57,803	December 2002	Ore—Primary–Fine	BF[a] (2002)
Shanghai Xinye	55,568	February 2001	Primary–Fine	–
Zhangjiagang	122,116	September 1993	Primary–Fine	–
Ningbo Jintian	100,010	January 1996	–	–
Tongling	447,615	November 1952	Ore—Primary–Fine	FS[b] & Ausmelt (1990s)
Jiangxi	421,738	January 1961	Ore—Primary–Fine	FS
Daye	178,191	March 1953	Ore—Primary–Fine	RS[c]-Noranda
Yunnan	322,551	April 1996	Ore—Primary–Fine	ISA(2002)
Jinchuan	156,300	January 1959	Ore—Primary–Fine	EF[d], FS, O_2-blow(1994)
Baiyin	77,527	June 1960	Ore—Primary–Fine	RS-Baiyin (1977)

Source: Dong et al. (2007).
[a] BF: Closed blast furnace.
[b] FS: Flash smelter.
[c] RS: Reverberatory smelter.
[d] EF: Electrode furnace.

Table 4
Alumina production company.

Name of company/province	Output in 2005 (tons)	Processing technology	Adoption time
Shanxi/Shanxi	1,506,600	Combination	1992
Shandong/Shandong	930,000	Combination	After 1992
Chiping/Shandong	321,263	Combination	–
Henan/Henan	1,680,728	Combination	–
Zhongzhou/Henan	1,546,000	Combination	After 1992
Guangxi/Guangxi	924,630	Bayer	1998
Guizhou/Guizhou	942,338	Combination	1989

Source: Dong et al. (2007).
The yearbook of nonferrous metals industry of China 2006.

Table 5
Nickel producers.

Name of company/province	Output in 2005 (tons)	Smelting technology	Time of staring operation
Jilin Haorong/Jilin	4210 (nickel content)	Electricity	2000.12
Jinchuan/Gansu	90,112	Flash Electricity	1993.05 1969
Huili/Sichuan	–	Blast	–
Fukang/Xinjiang	3256	Wet process	2,002.03
Xinxin/Xinjiang	3873	Blast	1988.10

Source: The yearbook of nonferrous metals industry of China 2006; Tu (2003); Ma et al. (2007).

Table 6
Energy consumption and energy demand growth in the non-ferrous metals industry.

Consumption	1990	1995	2000	2004	2005	2006
Total energy (million GJ)	554	833	1124	1876	2110	2530
Electricity (TWh)	25.64	42.66	59.56	123.04	141.90	178.35
Coal (000 ton)	7360	10,329	13,101	19,086	21,907	27,949
Coke (000 ton)	1008	1475	1552	1586	1711	2273
Fuel oil (000 ton)	534	583	489	570	513	586
Average annual growth rate		1990–1995	1995–2000	2000–2004	2004–2005	2005–2006
Total energy (%)		8.5	6.2	13.7	12.4	19.9
Electricity (%)		10.7	6.9	19.9	15.3	25.7
Coal (%)		7.0	4.9	9.9	14.8	27.6
Coke (%)		7.9	1.0	0.5	7.9	32.8
Fuel oil (%)		1.8	−3.5	3.9	−10.0	14.2

Source: China energy statistical yearbook 1991 and 2007.
The yearbook of nonferrous metals industry of China 2007.

Table 7
Nonferrous metals industry energy consumption[a] in 2006.

	Electricity (10^4 kWh)	Coal (*t*)	Coke (*t*)	Fuel oil (*t*)	Diesel (*t*)	Gasoline (*t*)	NG (10^4 m^3)	Other (tce)	Total[b] (tce)	Total (million GJ)
Sum	17,834,716	27,949,346	2,272,596	586,158	448,921	118,670	64,095	585,021	52,384,481	1,534.87
Beijing	4028	10,603	0	3411	329	133	0	0	20,041	0.14
Tianjin	38,232	56,708	0	5217	20,138	308	759	0	145,368	0.59
Hebei	1,210,960	5,157,737	536,502	859	10,765	66,679	2358	200,000	6,997,777	4.26
Shanxi	1,052,015	3,422,702	15,439	1138	70,655	6096	2578	0	4,536,190	205.03
Inner Mongolia	2384	1118	129	0	79	137	41	1	4924	132.91
Liaoning	328,302	1,145,477	70,527	19,207	8126	1811	0		1,544,867	45.26
Jilin	66,541	96,665	209	0	1170	453	77		172,376	5.05
Heilongjiang	40,556	85,799	23,427	2307	549	298	0	2611	156,965	4.60
Shanghai	45,263	24,907	1491	9460	2041	586	0		96,844	2.84
Jiangsu	246,002	37,218	630	0	16,728	209	167	8608	371,956	10.90
Zhejiang	285,049	187,773	83,128	25,823	9992	383	1273	27	669,043	19.60
Anhui	135,668	112,528	28,871	45,595	7182	968	937		385,545	11.30
Fujian	174,715	44,149	5790	8492	18,359	3157	338	486	308,592	9.04
Jiangxi	315,258	249,179	30,787	41,721	48,317	12,479	46	3302	793,900	23.26
Shandong	1,636,447	1,552,169	171,467	164,031	21,134	725	6554	1148	3,929,221	115.13
Henan	3,324,844	5,907,030	171,966	10,980	33,359	2102	27203	1806	10,000,600	293.02
Hubei	515,015	124,360	89,768	6996	9174	703	468	682	863,381	25.30
Hunan	488,319	497,895	296,916	12,983	16,952	2237	0	3409	1,386,623	40.63
Guangdong	387,054	207,251	146,460	22,051	27,235	1272	0		877,544	25.71
Guangxi	518,604	1,257,607	134,281	2851	12,369	1125	0		1,923,402	56.36
Hainan	0	0	0	0	0	0	0		0	0.00
Chongqing	221,021	111,912	1226	962	1568	621	6759	6299	474,313	13.90
Sichuan	796,081	178,169	17,905	8145	16,976	5131	3717	31,005	1,280,491	37.52
Guizhou	909,082	1,162,676	26,069	109,784	8871	914	0	2029	2,362,131	69.21
Yunan	982,459	687,439	250,463	7946	30,781	2879	0	5520	2,135,396	62.57
Tibet	0	0	0	0	0	0	0		0	0.00
Shaanxi	396,972	374,884	6002	386	6871	1314	1493		863,458	25.30
Gansu	1449,099	1,182,910	96,161	73,813	15,670	4249	3997	63,313	3,189,980	93.47
Qinghai	1,327,458	2,940,663	10,691	2000	4280	839	1089	213,745	4,526,985	132.64
Ningxia	866,284	581,494	36,004	0	26,856	383	4241	16,172	1,735,255	50.84
Xinjiang	101,004	552,324	20,287	0	2395	479	0		645,127	18.90

Source: The yearbook of nonferrous metals industry of China 2007.

[a] From a sectoral management point of view, the nonferrous metals industry in China includes metal mining and metals metallurgy categorized as the mining and quarrying and manufacturing sectors of industry, respectively. The nonferrous metals industry also includes research institutes, trade companies, industrial associations and other entities which are categorized as other sectors in the national statistical system. Provincial energy consumption data published by China Nonferrous Metals Industry Association cannot easily be converted or compared with the data in China Energy Statistical Yearbook.

[b] Calculated by the authors. The conversion factors are as follows: electricity 0.1229 kgce/kWh; coal 0.9 kgce/kg; coke 0.9714 kgce/kg; fuel oil 1.4286 kgce/kg; diesel 1.4571 kgce/kg; gasoline 1.4714 kgce/kg; natural gas 1.33 kgce/cu m.

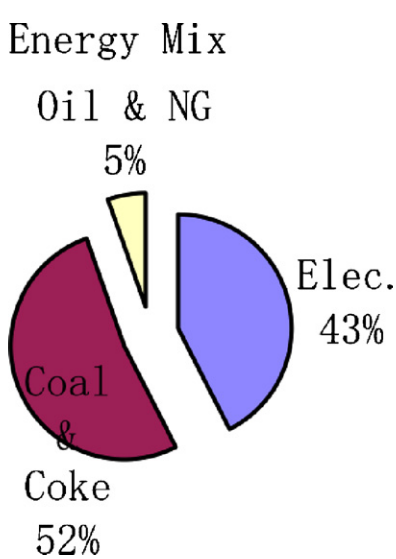

Fig. 3. Energy consumption mix of nonferrous metals industry (2005).

3. Processing and energy intensity

The energy intensity of metals is affected by many factors, including the production process, equipment capacity (scale), and quality of ore. Table 9 shows some indicators for the production of various metals in 2006.

Most large-scale nonferrous plants were built or had their production equipment and processes upgraded within the last two decades. For example, the aluminum sector in 2004 phased out 720,000 tons of in-situ baked smelters, reducing in-situ baked smelter production to only about 3% of primary aluminum output. Large-scale capacity (defined as requiring electrical service of 160 kA or more) pre-baked smelters in 2004 reached 7.33 million tons, accounting for 77.3% of total capacity (Pan, 2006). The electricity intensity of primary aluminum has already approached the 2010 target set by the International Aluminum Association, as shown in Table 10 and Figs. 4 and 5. The energy intensity of copper production has also decreased (Fig. 6).

Chinese government has issued norms of energy consumption per unit product which covered most of energy-intensive products. These norms provided two digital energy intensity values for each product that existing plants and new-built plants should meet respectively. The international advanced levels of energy intensity are included in these norms as targets for future efforts. The norms have been met by 70–80% of the existing plants. In other words, 20–30% of backwards production capacity must be phased out through technical retrofit or construction of new capacity to replace the old one. The norm for newly built plants was set by considering the international advanced levels, the possibility of improvement based on the existing plants and energy-efficiency improvement in the past years. The electricity

Table 8
Direct CO_2 emissions of nonferrous metals industry in China (2006).

Fuel	Consumption	Average low-calorific value (MJ/ton, km^3)	Emission factor (tC/TJ)	CO_2 emissions[a] (tCO_2e)
Coal	27,949,346 ton	20,908	25.80	55,280,922
Coke	2,272,596 ton	28,435	29.50	6,989,867
Fuel oil	58,158 ton	41,816	21.10	1,896,318
Diesel	448,921 ton	42,652	20.20	1,418,183
Gasoline	118,670 ton	43,070	18.90	354,200
NG	64,095 $10^4\,m^3$	38,931	15.30	139,985
Total	–	–	–	66,079,475

Source: The yearbook of nonferrous metals industry of China 2007, China energy statistical.
[a] Adopting 100%, the IPCC default value for the oxidation factor for all fuels.

Table 9
Indicators for selected metal productions (2006).

Indicators	Data
Copper	
Grade ore output (underground mining)	0.91%
Energy intensity of mining(underground mining)	179 MJ/ton
Grade ore output (open-pit mining)	0.51%
Energy intensity of mining(open-pit mining)	16.7 MJ/ton
Grade of concentrate ore	23.06%
Energy intensity of milling	157 MJ/ton
Recovery of smelting	97.03%
Recovery of copper refining	99.33%
Overall energy consumption of copper smelting and refining	17.4 GJ/ton
Overall energy consumption of blister copper	12.8 GJ/ton
Overall energy consumption of copper refining	4.7 GJ/ton
Coke consumption of blister copper	683.79 kg/ton
Coal consumption of blister copper	514.45 kg/ton
Electricity consumption of blister copper	775.23 kWh/ton
DC consumption of cathode copper	287.40 kWh/ton
Electricity consumption of copper material processing	1175.17 kWh/ton
Aluminum	
Grade ore output	51.8%
Energy intensity of mining	362.4 MJ/ton
DC consumption of aluminum pad (prebaked)	13524.41 kWh/ton
Energy intensity of aluminum ingot	55.24 GJ/ton
AC consumption of aluminum pad	14141.10 kWh/ton
AC consumption of electrolytic aluminum	14697.23 kWh/ton
Electricity consumption of aluminum material processing	1100.40 kWh/ton
Nickel	
Grade ore output	1.26%
Energy intensity of mining	270.7 MJ/ton
Energy intensity of milling	277.0 MJ/ton
Electricity consumption of smelting and electro-refining	8717.63 kWh/ton
Energy consumption of nickel matte	23.2 GJ/ton

Source: The yearbook of nonferrous metals industry of China 2007.

use of per tonne smelted aluminum is 14,400, 13,800 and 13,500 kWh for existing plant, newly built plant and target plant, respectively (GB, 2008). The current best practice of Hall–Heroult electrolysis cell is estimated at 12,900–13,000 kWh/t of aluminum according to IEA's study (IEA, 2007).

3.1. Copper production

The nature of China's copper resource makes copper production in China relatively modest in scale and higher in energy intensity than in other countries. China has 18 million tonnes of copper ore reserves distributed across 910 sites. Most sites consist of low-grade ores with 87% of sulphidic ores ($CuFeS_2$, Cu_2S, Cu_5FeS_4, CUS, $4Cu_2SSb_2S_3$ and $4Cu_2S\cdot As_2S_3$), 10% of oxidic ores ($CuCO_3\cdot Cu(OH)_2$, $CuSiO_3\cdot 2H_2O$, $2CuCO_3\cdot Cu(OH)_2$, Cu_2O, CuO, $CuSO_4\cdot 5\ H_2O$, $CuSO_4\cdot 3Cu(OH)_2$, $Cu_2(OH)_3Cl$) and 3% of mixed ores. In 2006, the total copper output was 3.0 million tons, in which 33.26% came from recycled copper, 66.20% from general ores and only 0.5% from very low-grade ores.

Table 11 shows the energy intensity of different smelters. In general, large-scale equipment operates with higher energy efficiency than small-scale equipment. Table 12 shows the energy intensity for air-blow melting converter with various converter scales.

3.2. Aluminum production

China has 1.4 billion tones of bauxite reserves distributed across 300 sites in Shanxi, Guizhou Henan, Shandong and Guangxi provinces. Most bauxite found is an $Al_2O_3\cdot H_2O$ type with low Al/Si ratio (Table 13), hard to smelt, and requires more energy in smelting (dissolving temperature is above 240 °C). The type of bauxite resource in China limits use of Bayer technology, resulting in a high-energy intensity of alumina production. The energy intensity in 1999 of alumina production was 15.1 GJ/ton using Bayer technology and 36.32–40.19 GJ/ton using a combined method, as shown in Table 14. The average integrated energy intensity of alumina production in 2005 was 881.70 kgce/ton (25.83 GJ/ton) in 2005 and 836.57 kgce/ton (24.51 GJ/ton) in 2006 at key enterprises (NDRC, 2007). The Henan Company consumed 0.957 tce/t-alumina (28 GJ/t-alumina), 15073 kWh/ t-aluminum (AC), and integrated energy consumption (from mining to aluminum production) 8.99 tce/t-aluminum (263.4 GJ/t-aluminum) (Jiang 2006).

There were 115 aluminum producers operating in China at the end of 2004. The scale of their plants is shown in Table 15.

Some 17 enterprises using the electrolysis method produced 43.6% of total primary aluminum, as shown in Table 16. China has more than 60 medium and small-scale aluminum plants with around 3000 sets of Overberg cells (in-situ baked electrodes at 60 kA). These firms, using this technology, accounted for 40% of aluminum output in 2005.

All aluminum is produced by the electrolysis method, which has changed little over many years. But the structure of the electrobath has changed tremendously. The most-efficient electrobath is a pre-baked anodes type. The current efficiency of pre-baked anodes is 91–94% with an intensity of 13,320–13,750 kWh DC/ton-Al. The current efficiency of the in-situ baked method is 88%, using 14,530 kWh DC/ton-Al. The electrolysis temperature (about 950–970 °C) has a great impact on the energy intensity of aluminum production. For every 10 °C temperature increase, current efficiency will decrease by 1–2%.

For example, Yunnan Aluminum Co. retrofitted all 60 sets of 60 kA Soderberg cells with in-situ baked electrodes by upgrading them to 186 kA pre-baked set in 1998 and 300 kA pre-baked sets in 2004 with total capacity of 300,000 ton per year. As a result,

Table 10
Energy intensity of copper and aluminum production.

Year	2000	2001	2002	2003	2004	2005
Cu (kgce/ton)	1277.2	1079.5	1016.1	957.0	1056.2	779.8
Cu (GJ/ton)	37,421.96	31,629.35	29,771.73	28,040.1	30,946.66	22,848.14
Alumina (kgce/t)	1212	1180	1155	1109	1023.4	986
Alumina (GJ/t)	35,511.6	34,574	33,841.5	32,493.7	29,985.62	28,889.8
Primary Al (AC kWh/t)	15,480	15,470	15,362	15,026	14,795	14,622.0

Source: Kang, (2006).

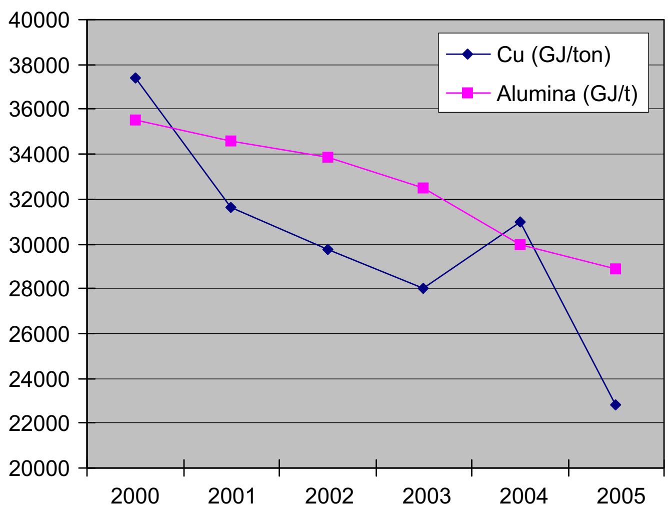

Fig. 4. Energy intensity of Cu and alumina.

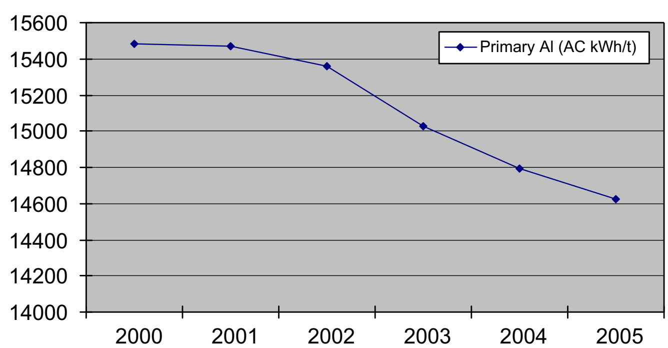

Fig. 5. Primary aluminum AC electricity intensity.

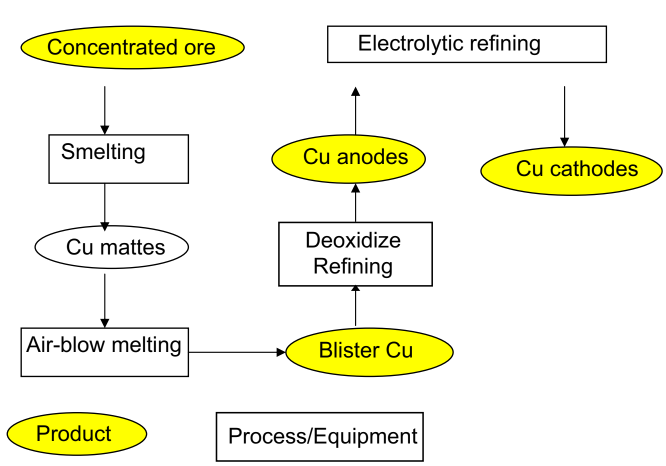

Fig. 6. Copper production diagram.

electric energy intensity declined to 13,200 kWh DC/ton, the lowest electricity intensity among all companies in China because the firm has a low electrolysis temperature compared to other companies, as shown in Table 17. Research is under way to explain how the low electrolysis temperature was achieved, but until now is not clearly understood. It is clear that large-scale facilities have lower energy intensity (higher energy efficiency) than small-scale facilities.

3.3. Nickel production

Sulfide nickel is the main resource in China for nickel production. There are three types of smelting furnaces used for nickel smelting: electric furnace, flash smelter and blast furnace. The technical parameters of the electric furnace are listed in Table 18. Because more than 90% of nickel produced in China is made by one company—the Jinchuan Group— the energy efficiency of that company essentially represents that of the country.

4. Recycling system

China has 5000–6000 firms involved in the recycling business with employees numbering between 15 and 18 million persons. Of this number, about 10 million people are individual businesspersons who collect various recyclable materials from residences and industries. These individual operators collect 80% of all recycled material. No data are available on the number of persons whose work involves only the collection of nonferrous materials. China recycles about 500 thousand tons of aluminum and 400 thousand tons of copper every year (see Fig. 7 for a diagram of the recycling system in China).

China imports a significant amount of recycled material to meet the domestic demand for raw materials. There are 1100 firms with 1.4 million employees that are in the business of disassembling used electronics and other devices and recycle about 800 thousand tons of copper and 1 million tons of aluminum imported waste each year. Fig. 8 shows a diagram of recycling imported waste material and Table 19 presents the imported waste copper data in the past decade.

4.1. Copper recycling

Secondary copper production is classified into three categories, depending on the source of the raw material. One category is home-scrap or run-around scrap that comes from the copper electrolytic refining process such as off-specification anodes and cathodes. Home-scrap is usually returned on site to the electrolytic refining furnace. No publicly available data are available on this practice. The second category is new scrap, including prompt industrial scrap and internally arising scrap that comes from the copper products production processes. New scrap is usually in

Table 11
Energy intensity of copper production by different process technologies.

Smelter	Average (tce/t-Cu)	Average (GJ/t-Cu)
Reverberatory furnace	1.123	32.90
Closed-top blast furnace	0.965	28.27
Electric furnace	0.760	22.27
Flash smelting furnace	0.606	17.76
Baiyin furnace	0.917	26.87

Source: ECCCMB (2004).

Table 12
Key indicators of converter.

Indicator	Scale of converter (ton)			
	15	50	80	100
Cu content of mattes (%)	37–42	20–21	50–55	55
Cu recover rate (%)	96	90	93.5	94
Flux rate (%)	16–18	20	8–10	6–8
Cold feedstock ratio (%)	10–15	25–30	26–63	30–37
Lifetime (ton-Cu/turn)	1500	2200	26,400	–
Electricity consumption (kWh/ton-Cu)	350–400	650–700	50–60	40–50

Source: Dong et al. (2007).

Table 13
Bauxite resources chemical components.

Province	Chemical components (%)			Al/Si ratio	Percentage of total resources
	Al_2O_3	SiO_2	Fe_2O_3		
Guangxi	58–60	5–6	15–17	9.9	12.2
Guizhou	67–68	8.8–11.1	2.2–3.0	6.1–7.8	18.1
Henan	64–71	7.5–13.7	3.0–5.1	4.7–9.4	16.4
Shandong	54–61	15–22	5.0–9.0	3.7–3.9	3.8
Shanxi	63–65	2–3	11–13	5.0–5.6	16.0

Source: Tu (2003).

Table 14
Energy intensity of alumina.

Name of company/province	Processing technology[a]	Energy intensity[b] GJ/ton
Shanxi/Shanxi	Combination	37.32
Shandong/Shandong	Combination	40.19
Henan/Henan	Combination	36.32
Guangxi/Guangxi	Bayer	15.1

Source: Dong et al. (2007).
[a] The output of Bayer and sintering process in combination process is almost same.
[b] Data of 1999.

form of alloy. The last category is old scrap including obsolete, post-consumer products or so-called externally arising scrap. It is the main type of secondary copper production. It is difficult to re-process old scrap because of its complicated components with low copper content.

Jintian Copper (Group) Co., Ltd. is one of large-scale enterprises mainly processing secondary copper. In 2005, it re-processed about 300 thousand tons of secondary copper. It uses reverberatory smelter with an energy intensity of 461.8 kWh/t.

Table 20 shows the energy intensity of selected copper recycling firms in China through case study.

Table 15
Aluminum plant scale.

Capacity (ton)	Number of plant	Total capacity (million ton)	Share of total capacity (%)
>200,000	11	3.18	33.6
200,000–100,000	26	3.51	37.1
<100,000	79	2.77	29.3
Total	115	9.46	100

Source: Pan (2006).

Table 16
Main aluminum production companies.

Name of company/province	Output in 2005 (ton)	Time of staring operation
Gansu/Shanxi	112,742	1998.06
Baotou/ Inner Mongolia	256,041	1958.12
Fushun/Liaoning	126,894	1938.10
Anshan/Shandong	155,182	1992.06
Chiping/Shandong	243,259	1972.10
Shandong/Shandong	100,370	1954.07
Henan/Henan	51,981	2002.04
Longquan/Henan	307,423	2002.06
Wanfang/Henan	204,011	1993.03
Tianyuan/Henan	102,474	1958.09
Guangxi/Guangxi	139,874	1994.07
Guizhou/Guizhou	232,311	1958.08
Yunnan/Yunnan	323,507	1972.09
Lanzhou/Gansu	166,167	1999.04
Liancheng/Gansu	177,113	1974.12
Qinghai/Qinghai	353,771	1985.04
Qingtongxia/Qinghai	353,073	1970.01
Total	3,406,193	

Source: The yearbook of nonferrous metals industry of China 2006.

4.2. Aluminum recycling

There are no publicly available, systematic statistical data on aluminum recycling in China. According to data from China Nonferrous Industrial Association (CNIA), recycled aluminum output was 1.66 million tons in 2004, accounting for 27% of aluminum consumption that year (Qiu et al., 2006). Fig. 9 diagrams the aluminum recycling process in China.

Single chamber reverberatory smelters are used for recycling in China with low-energy efficiency at 25–30% (Qiu et al., 2006). Shanghai Xinge Nonferrous Co, Ltd. is the largest aluminum recycling enterprises in China with annual production capacity of 300,000 ton.

5. Prospects for energy-efficiency improvement

5.1. Projections of production

Domestic demand for copper and aluminum is estimated to reach 6.5 million tons and 14.4 million tons, respectively, by 2020.[13] Though there is no long-term forecast available, some experts expect those levels to be the peak of historical demand. The central government has issued several decrees intended to limit the development of the energy-intensive sectors, including

[13] 2007 China Nonferrous Metals Industry Research Report.

Table 17
Energy intensity of aluminum (January 2004).

Scale of pre-baked anodes	Company/province	Current intensity (A)	Current efficiency (%)	Electricity intensity of primary Al (kWh DC/ton)	Electricity intensity of Al ingot (kWh/ton)
Large	Guangxi/Guangxi	158627	92.37	13,504	14,797
	Weiqiao/Shandong	239060	94.30	13,328	14,656
	Qinghai/Qinghai	153545	93.96	13,374	15,047
	Baotou/Inner Mongolia	192482	92.05	13,764	14,599
	Yunnan/Yunnan	189820	94.78	13,257	14,325
Small	Shanhe/Shanxi	72,332	95.02	13,750	15,411
	Yuzhou/Henan	75,240	91.72	14,370	15,118
	Longmen/Shanxi	74,221	93.04	14,002	15,353
	Yili/Xingjiang	74,410	89.01	14,708	15,751
	Jinxin/Shanxi	75,098	90.47	14,373	15,653

Source: Dong et al. (2007).

Table 18
Technical parameters of electric furnace.

Parameter	Jinchuan	Jilin
Bed area (m^2)	118, 132	75
Capacity ($t/m^2/d$)	3–4.5	3.6
Nickel recovery ratio (%)	94.7	95.8
Electricity intensity (kWh/t)	550–630	740
Fine ore grade	Cu 2.7%, Ni 5.9%	Cu 0.85%, Ni 6.8%
Low nickel mattes	Cu 6.6%, Ni 13.2–17%	Cu 0.7%, Ni 14%

Source: Tu (2003).

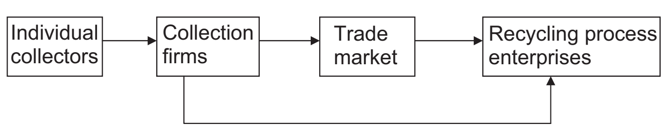

Fig. 7. Diagram of recycling system.

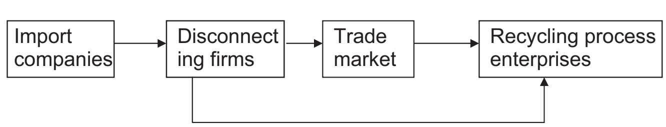

Fig. 8. Diagram of recycling imported waste system.

nonferrous metals industry. The effect of these decrees has not yet become evident.

5.2. *Equipment upgrade for efficiency improvement*

Existing large-scale industrial process equipment cannot easily be improved without scrapping existing facilities and completely replacing them. This is particularly a problem for relatively new facilities built within, say, the last decade and a half, and which have not yet been fully depreciated. Improving their low-energy efficiency would require large investment sums. But plants can improve their energy efficiency to a certain degree by better management, maintenance, and replacement of certain types of smaller scale equipment such as motors and fans.

Increasing the use of secondary resources can reduce energy consumption significantly. The literature suggests that compared to producing metal from ores, recycling nickel, copper, and aluminum saves over 62, 80, and 95% of the energy required for production, respectively (Peng, 1994).

5.3. *Barriers to energy-efficiency improvement and increased recycling*

Several new issued policies for controlling overheating of the economy have negative impacts on energy-efficiency improvement and increased recycling metals.

5.3.1. *'Loans control' policy*

In order to control investment and prevent economic overheating, the Bank Supervision Committee limits growth in the amount of loans provided by commercial banks. Each bank can increase year-on-year lending more than 15% over the previous year. This policy limits investment in all fields including investment for energy efficiency. For example, Industrial Bank set up a "10-billion [RMB] Green Loan" program for energy-efficiency improvement projects under the support from the IFC in 2006, but the limitation of 15% forced banks to provide less lending to energy-efficiency projects. From the banks' point of view, energy-efficiency projects are not a priority because of high transaction costs (21st, 2007).

5.3.2. *"Too intensive sectors" policy*

To slow expansion of production capacity, the government limits investment in energy-intensive, pollutant intensive, and resource consuming sectors such as steel, cement, and nonferrous metals. Commercial banks stop providing loans to these sectors in order to avoid conflict with the government, even for energy-efficiency projects.

5.3.3. *'Energy-intensive product export' policy*

To secure the domestic supply, the government phased out the rebate of the relatively large value-added tax and increased the export tax on exporting energy-intensive products. Because the aluminum recycling and primary production sectors share a common tax identification number, and because of a shortage of domestic secondary resources, the metal recycling industry heavily relies on international trade by importing recyclable inputs and exporting finished products. This policy limits the recycling of aluminum exports and, in turn, the development of the recycling business.

6. Summary and conclusions

The analysis in this paper suggests several areas in which policy revisions could improve energy efficiency in nonferrous metals production in China. The Chinese government could

Table 19
Imported waste copper (kton).

Year	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Total stuff	1193.8	717.9	801.0	959.8	1701.4	2504.4	2707.4	3830	3160	3960
Copper content	222.0	147.6	172.5	163.0	388.0	507.0	572.0	618.0	632.0	792.0

Source: Zhao et al. (2007).

Table 20
Energy intensity of copper recycling.

Indicator	Unit	Plant 1	Plant 2	Plant 3	Plant 4	Plant 5
Current intensity	(A/m^2)	230–322	23040	221	290–300	–
Current efficiency	(%)	97	97.39	96	97	93
DC electricity intensity	(kWh DC/t Cu)	260–280	293	260–310	275–285	400
AC electricity intensity	(kWh /t Cu)	–	–	<380	–	–
Steam consumption	T/t Cu	1	–	$\leqslant 1.2$	0.85	0.7
Cu recovery rate	%	99.90	–	>99.80	–	–

Source: Zhao et al. (2007).

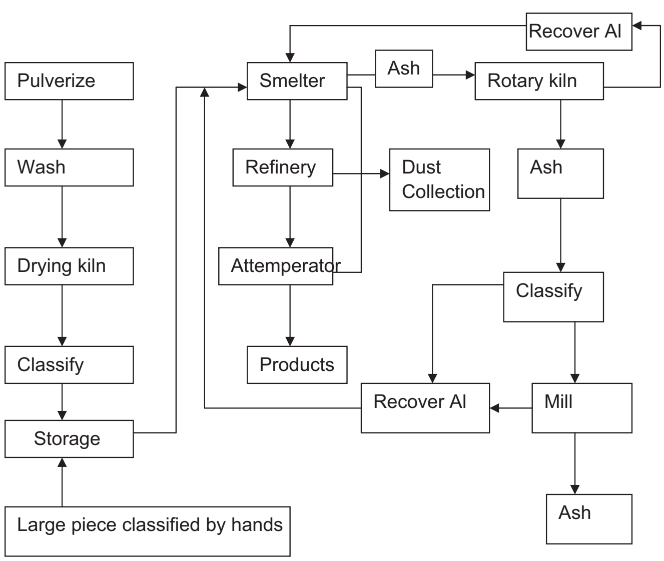

Fig. 9. Diagram of aluminum recycling.

probably improve efficiency in this energy-intensive sector by implementing the following measures:

- Encouraging recycling. Policy makers may need to rethink the long-running practice of encouraging increases in scale as a means of increasing energy efficiency because smaller scale nonferrous metals production plants using recycled inputs can be very efficient and competitive.
- Focus on deploying the most-efficient technologies even in the new, modern process industrial plants. Many options for improving efficiency have not yet been captured and are not implemented even in brand new factories. These options include improving pumps, motors, waste heat recovery and cogeneration.
- Reconsider the unintended consequences of macro-economic policies which are meant to constrain the expansion of heavy, energy-intensive industries, but have the unintended and unfortunate effect of reducing investments in energy efficiency. Policy makers should consider giving special exemptions to lenders and equity investors for deploying energy-efficiency measures in the energy-intensive materials sectors.
- Rethink the targets previously set for the metals industries. The rapid run-up in commodity prices has enabled sectors like the aluminum industry to meet their targets early if only because the prices of their products have increased, meaning that the energy required to produce aluminum in physical terms may not have improved very much, while appearing in monetized terms to have improved significantly.

Stated simply, China's national government may not want to allow provincial leaders and the energy-intensive industries they regulate to claim credit for meeting energy intensity reduction goals simply because the goals have been distorted and perhaps even made meaningless by increases in product prices.

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