

Metallurgy Industry: Case 1
Replacement of Open Hearth Furnaces With BOF Process Technology
at Anshan Iron and Steel Works

Introduction

The iron and steel industry is one of the primary energy consuming sectors in the Chinese economy accounting for one tenth of total energy consumption. Because of outdated production technology, the Chinese steel industry remains energy intensive by international standards. One of the more energy intensive processes is open hearth furnace technology used to convert pig iron to steel. The Japanese eliminated the open hearth process in the 1970s, and the last open hearth furnaces were phased out in the 1980s in the U.K., France, the former West Germany, and Italy. Most open hearth furnaces have been eliminated in the U.S. and former Soviet Union; yet in China, open hearth furnaces still account for 13 million tons of steel per year, 18 percent of total production.

The Anshan Iron and Steel Company is the largest iron and steel works in China, accounting for 10 percent of total production. The company was established in 1919 and currently has a productive capacity of 8 million tons of pig iron and crude steel with annual energy consumption of 9 million tons of coal equivalent. Over the past decade, energy consumption per ton of output has decreased by 12.4 percent from 1.23 to 1.07 tce. Still, energy consumption at Anshan remains high by international standards as indicated in Table 1. Energy use per ton of steel is 70.6 percent higher than Japanese averages and 36.7 percent higher than U.S. averages. At Anshan as well as a number of older steel works in China, replacement of open hearth process technology is the area for which the greatest energy savings are likely to accrue.

Table 1. Energy Consumption per Ton Steel Production at Anshan and Selected National Averages (kgce/ton)

Producer	Energy use
1. Anshan	1073
2. Japan	629
3. USA	785
4. West Germany	732
5. France	739
6. Britain	726
7. Italy	639

Technology Assessment

Current Technology: Because Anshan is an older plant its production process remains outdated. Currently, 65 percent of steel is produced using open hearth technology, while 35 percent of production is based on BOF or converter process technology. Using oxygen injection to oxidize impurities in the metal, the BOF process uses considerably less heat for processing than open hearth furnaces. The older technology that predominates at Anshan involves the heating of pig iron and/or scrap steel in open hearth furnaces followed by ingot casting and then slabbing or rolling. Newer steel workshops typically heat pig iron or scrap

steel in converters followed by continuous casting and billeting. Various combinations of these production steps may be employed within individual steel workshops.

Proposed Technology: Modification of existing process technology is planned in two phases. The first phase will double the converter steel ratio at Anshan to 70 percent reducing the open hearth share of production to the remaining 30 percent of production. In the second phase, open hearth furnaces will be phased out completely with all output being converter steel. After renovation, the plant will use BOF process technology and replace ingot casting with continuous casting and steel billeting. For simplicity, only the first phase of open hearth furnace replacement is considered in this case. The second case for the metallurgy industry examines conversion from ingot to continuous casting at Benxi.

Financial Analysis

Production indicators with and without the project are depicted in Table 2. The project will increase production capacity with the new converter furnaces. Annual yield is expected to increase from 2.6 to 3.0 million tons. Sales price is assumed to stay constant at 855 RMB yuan per ton of steel output.

Table 2. Production Indicators With and Without Project

	With project	Without project
1. Yield (million tons)	3.00	2.60
2. Sales price (yuan/ton)	855.00	855.00
3. Sales income (million yuan)	2565.00	2223.00

Investment costs for the project are expected to be 1.2 billion RMB yuan as indicated in Table 3. Major costs include 300 million yuan for a new workshop building, 200 million each for a deduster and gas recovery system and for a water treatment system, and 150 million each for the new converter furnace and emissions control system. Without the project, investment costs of 150 million are projected for a water processor and emissions control system.

Operating costs with and without the project are shown in Table 4; with project costs are shown at full operation. Raw material costs per ton decrease by 2.7 percent with the project. Iron and scrap steel usage is projected to rise by 6.4 percent per ton; the principal raw material cost savings are in terms of solvents with modest savings in alloys and refractory costs. Energy costs are projected to decrease by 44.5 percent from 39.03 to 21.66 yuan per ton. Heavy oil use, currently 41.3 percent of energy costs, is completely eliminated. Other costs savings include coke gas, steam, and recycling water.

Table 3. Total Investment Costs With and Without Project (million yuan)

	With project	Without project
1. Building	300.00	0.00
2. Lifter	100.00	0.00
3. Furnace	150.00	0.00
4. Deduster and gas recovery	200.00	0.00
5. Water processor	100.00	100.00
6. Control system	150.00	50.00
7. Iron water purification	200.00	0.00
8. Total	1200.00	150.00

Table 4. Operating Costs With and Without Project (million yuan)

Item	With project		Without project	
	Unit costs (yuan/t)	Total costs	Unit costs (yuan/t)	Total costs
1. Material	616.84	1850.52	634.14	1648.77
2. Energy	21.66	64.98	39.03	101.47
3. Maintenance	4.33	13.00	15.69	40.80
4. Salary and welfare	4.61	13.82	3.20	8.33
5. Others	25.27	75.81	29.87	77.66
Total	672.71	2018.14	721.93	1877.03
Sales income	855.00	2565.00	855.00	2223.00
Net income	182.92	546.86	133.07	345.97

Cash flow tables with and without the project appear as Tables 5 and 6. Total costs increase by 8.0 percent at full production from 1.88 million yuan without the project to 2.03 million yuan with the project. Operating costs reflect a 15.4 percent increase in output and because price remains constant, a corresponding increase in benefits. As indicated earlier, investment costs with the project amount to 1.2 billion yuan; 150 million yuan in investment is required without the project. Combined repair and maintenance expenses decrease by 44 percent as periodic shutdown and maintenance of openhearth furnaces is eliminated. Overall energy costs decrease by 36 percent despite the increase in output.

Table 7 depicts incremental cash flow. The project has a nine year payback period (six years after the construction phase) which is substantial by Chinese standards. Net present value of the project is 242.1 million yuan, and the internal rate of return is 16.1 percent. The project is expensive with a projected investment cost of 1.05 billion yuan. Although it exceeds the minimum 12 percent rate of return, the returns are modest compared to other projects considered, and the payback period is long. Still, the project is viable with the environmental benefits enhancing this viability as indicated below.

Table 5. Financial Cash Flow With Project (million yuan)

Year	Investment			Operating Costs					Total Costs	Total Benefits	Net Benefits	
	Equip.	Repairs	Subtotal	Feed-stock	Energy	MTC*	Salary	Other				Subtotal
1	400.00		400.00	1648.77	101.47	24.80	8.33	77.66	1861.03	2261.03	2223.00	(38.03)
2	400.00		400.00	1648.77	101.47	24.80	8.33	77.66	1861.03	2261.03	2223.00	(38.03)
3	400.00		400.00	1648.77	101.47	24.80	8.33	77.66	1861.03	2261.03	2223.00	(38.03)
4			0.00	1850.52	64.98	13.00	13.82	75.81	2018.14	2018.14	2565.00	546.86
5		10.00	10.00	1850.52	64.98	13.00	13.82	75.81	2018.14	2028.14	2565.00	536.86
6		10.00	10.00	1850.52	64.98	13.00	13.82	75.81	2018.14	2028.14	2565.00	536.86
7		10.00	10.00	1850.52	64.98	13.00	13.82	75.81	2018.14	2028.14	2565.00	536.86
8			0.00	1850.52	64.98	13.00	13.82	75.81	2018.14	2018.14	2565.00	546.86
9		10.00	10.00	1850.52	64.98	13.00	13.82	75.81	2018.14	2028.14	2565.00	536.86
10		10.00	10.00	1850.52	64.98	13.00	13.82	75.81	2018.14	2028.14	2565.00	536.86
11		10.00	10.00	1850.52	64.98	13.00	13.82	75.81	2018.14	2028.14	2565.00	536.86
12			0.00	1850.52	64.98	13.00	13.82	75.81	2018.14	2018.14	2565.00	546.86
13		10.00	10.00	1850.52	64.98	13.00	13.82	75.81	2018.14	2028.14	2565.00	536.86
14		10.00	10.00	1850.52	64.98	13.00	13.82	75.81	2018.14	2028.14	2565.00	536.86
15		10.00	10.00	1850.52	64.98	13.00	13.82	75.81	2018.14	2028.14	2565.00	536.86
16			0.00	1850.52	64.98	13.00	13.82	75.81	2018.14	2018.14	2565.00	546.86
17		10.00	10.00	1850.52	64.98	13.00	13.82	75.81	2018.14	2028.14	2565.00	536.86
18		10.00	10.00	1850.52	64.98	13.00	13.82	75.81	2018.14	2028.14	2565.00	536.86
19		10.00	10.00	1850.52	64.98	13.00	13.82	75.81	2018.14	2028.14	2565.00	536.86
20			0.00	1850.52	64.98	13.00	13.82	75.81	2018.14	2018.14	2565.00	546.86
21		10.00	10.00	1850.52	64.98	13.00	13.82	75.81	2018.14	2028.14	2565.00	536.86
22		10.00	10.00	1850.52	64.98	13.00	13.82	75.81	2018.14	2028.14	2565.00	536.86
23`		10.00	10.00	1850.52	64.98	13.00	13.82	75.81	2018.14	2028.14	2565.00	536.86
Total	1200.00	150.00	1350.00	41956.80	1604.02	334.40	301.48	1749.19	45945.88	47295.88	57969.00	10673.12
PV	960.73	37.54	998.27	13798.57	589.18	128.68	93.51	589.58	15199.52	16197.79	18976.36	2778.56

* MTC, Maintenance Costs

Table 6. Financial Cash Flow Without Project (million yuan)

Year	Investment			Operating Costs						Total Costs	Total benefits	Net benefits
	Equip.	Repairs	Subtotal	Feed-stock	Energy	MTC*	Salary	Other	Subtotal			
1	150.00	16.00	16.00	1648.77	101.47	24.80	8.33	77.66	1861.03	2027.03	2223.00	195.97
2		16.00	16.00	1648.77	101.47	24.80	8.33	77.66	1861.03	1877.03	2223.00	345.97
3		16.00	16.00	1648.77	101.47	24.80	8.33	77.66	1861.03	1877.03	2223.00	345.97
4		16.00	16.00	1648.77	101.47	24.80	8.33	77.66	1861.03	1877.03	2223.00	345.97
5		16.00	16.00	1648.77	101.47	24.80	8.33	77.66	1861.03	1877.03	2223.00	345.97
6		16.00	16.00	1648.77	101.47	24.80	8.33	77.66	1861.03	1877.03	2223.00	345.97
7		16.00	16.00	1648.77	101.47	24.80	8.33	77.66	1861.03	1877.03	2223.00	345.97
8		16.00	16.00	1648.77	101.47	24.80	8.33	77.66	1861.03	1877.03	2223.00	345.97
9		16.00	16.00	1648.77	101.47	24.80	8.33	77.66	1861.03	1877.03	2223.00	345.97
10		16.00	16.00	1648.77	101.47	24.80	8.33	77.66	1861.03	1877.03	2223.00	345.97
11		16.00	16.00	1648.77	101.47	24.80	8.33	77.66	1861.03	1877.03	2223.00	345.97
12		16.00	16.00	1648.77	101.47	24.80	8.33	77.66	1861.03	1877.03	2223.00	345.97
13		16.00	16.00	1648.77	101.47	24.80	8.33	77.66	1861.03	1877.03	2223.00	345.97
14		16.00	16.00	1648.77	101.47	24.80	8.33	77.66	1861.03	1877.03	2223.00	345.97
15		16.00	16.00	1648.77	101.47	24.80	8.33	77.66	1861.03	1877.03	2223.00	345.97
16		16.00	16.00	1648.77	101.47	24.80	8.33	77.66	1861.03	1877.03	2223.00	345.97
17		16.00	16.00	1648.77	101.47	24.80	8.33	77.66	1861.03	1877.03	2223.00	345.97
18		16.00	16.00	1648.77	101.47	24.80	8.33	77.66	1861.03	1877.03	2223.00	345.97
19		16.00	16.00	1648.77	101.47	24.80	8.33	77.66	1861.03	1877.03	2223.00	345.97
20		16.00	16.00	1648.77	101.47	24.80	8.33	77.66	1861.03	1877.03	2223.00	345.97
21		16.00	16.00	1648.77	101.47	24.80	8.33	77.66	1861.03	1877.03	2223.00	345.97
22		16.00	16.00	1648.77	101.47	24.80	8.33	77.66	1861.03	1877.03	2223.00	345.97
23		16.00	16.00	1648.77	101.47	24.80	8.33	77.66	1861.03	1877.03	2223.00	345.97
Total	150.00	368.00	518.00	37921.75	2333.70	570.40	191.57	1786.23	42803.65	43321.65	51129.00	7807.35
PV	133.93	123.49	257.42	12725.94	783.15	191.42	64.29	599.43	14364.22	14621.65	17158.08	2536.43

* MTC, Maintenance Costs

Table 7. Incremental Cash Flow With and Without Project (million yuan)

Year	Investment			Operating Costs						Total Costs	Total benefits	Net benefits
	Equip.	Repairs	Subtotal	Feed-stock	Energy	MTC*	Salary	Other	Subtotal			
1	250.00	(16.00)	234.00	0.00	0.00	0.00	0.00	0.00	0.00	234.00	0.00	(234.00)
2	400.00	(16.00)	384.00	0.00	0.00	0.00	0.00	0.00	0.00	384.00	0.00	(384.00)
3	400.00	(16.00)	384.00	0.00	0.00	0.00	0.00	0.00	0.00	384.00	0.00	(384.00)
4	0.00	(16.00)	(16.00)	201.75	(36.48)	(11.80)	5.50	(1.85)	157.11	141.11	342.00	200.89
5	0.00	(6.00)	(6.00)	201.75	(36.48)	(11.80)	5.50	(1.85)	157.11	151.11	342.00	190.89
6	0.00	(6.00)	(6.00)	201.75	(36.48)	(11.80)	5.50	(1.85)	157.11	151.11	342.00	190.89
7	0.00	(6.00)	(6.00)	201.75	(36.48)	(11.80)	5.50	(1.85)	157.11	151.11	342.00	190.89
8	0.00	(16.00)	(16.00)	201.75	(36.48)	(11.80)	5.50	(1.85)	157.11	141.11	342.00	200.89
9	0.00	(6.00)	(6.00)	201.75	(36.48)	(11.80)	5.50	(1.85)	157.11	151.11	342.00	190.89
10	0.00	(6.00)	(6.00)	201.75	(36.48)	(11.80)	5.50	(1.85)	157.11	151.11	342.00	190.89
11	0.00	(6.00)	(6.00)	201.75	(36.48)	(11.80)	5.50	(1.85)	157.11	151.11	342.00	190.89
12	0.00	(16.00)	(16.00)	201.75	(36.48)	(11.80)	5.50	(1.85)	157.11	141.11	342.00	200.89
13	0.00	(6.00)	(6.00)	201.75	(36.48)	(11.80)	5.50	(1.85)	157.11	151.11	342.00	190.89
14	0.00	(6.00)	(6.00)	201.75	(36.48)	(11.80)	5.50	(1.85)	157.11	151.11	342.00	190.89
15	0.00	(6.00)	(6.00)	201.75	(36.48)	(11.80)	5.50	(1.85)	157.11	151.11	342.00	190.89
16	0.00	(16.00)	(16.00)	201.75	(36.48)	(11.80)	5.50	(1.85)	157.11	141.11	342.00	200.89
17	0.00	(6.00)	(6.00)	201.75	(36.48)	(11.80)	5.50	(1.85)	157.11	151.11	342.00	190.89
18	0.00	(6.00)	(6.00)	201.75	(36.48)	(11.80)	5.50	(1.85)	157.11	151.11	342.00	190.89
19	0.00	(6.00)	(6.00)	201.75	(36.48)	(11.80)	5.50	(1.85)	157.11	151.11	342.00	190.89
20	0.00	(16.00)	(16.00)	201.75	(36.48)	(11.80)	5.50	(1.85)	157.11	141.11	342.00	200.89
21	0.00	(6.00)	(6.00)	201.75	(36.48)	(11.80)	5.50	(1.85)	157.11	151.11	342.00	190.89
22	0.00	(6.00)	(6.00)	201.75	(36.48)	(11.80)	5.50	(1.85)	157.11	151.11	342.00	190.89
23	0.00	(6.00)	(6.00)	201.75	(36.48)	(11.80)	5.50	(1.85)	157.11	151.11	342.00	190.89
Total	1050.00	(218.00)	832.00	4035.05	(729.69)	(236.00)	109.91	(37.04)	3142.23	3974.23	6840.00	2865.77
PV	826.80	(85.96)	740.85	1072.64	(193.97)	(62.74)	29.22	(9.85)	835.30	1576.15	1818.28	242.13
IRR												16.08%

Payback time is 9 years including construction period

* MTC, Maintenance Costs

Energy Conservation

With the project, per unit energy use for steel conversion decreases by 64.6 percent from 75.1 to 26.6 kgce/ton of steel produced. Total annual energy savings are projected to be 145,556 tce of which 126,149 tce is direct savings at the same output level and 19,407 tce is indirect energy savings due to increased output.

Table 8. Total Energy Use With and Without Project

Items	With project	Without project	Incremental
Energy use			
1. Unit use (kgce/t)	26.60	75.11	(48.52)
2. Total (tce)	79787.57	195295.15	(115510.58)
Energy savings			
1. Direct (tce)	126148.93		
2. Indirect (tce)	19407.53		
3. Total (tce)	145556.45		

Environmental Benefits

Per unit emissions of CO₂ decrease by 55.9 percent with the project from 25.1 to 11.1 kg/ton as indicated in Table 9. SO₂, NO_x, and TSP emissions reduction are substantial at 95.8, 95.1, and 79.6 percent, respectively. Overall, annual CO₂ emissions are expected to decrease by 42,090 tons, 36,480 tons direct and 5,610 tons indirect through higher output levels. On an annual basis, NO_x emissions also decline by 18,500 tons with the project, while SO₂ emissions are projected to decrease by 35.4 tons and TSP emissions by 459.8 tons.

Table 9. Environmental Impacts With and Without Project

Items	With project	Without project	Incremental
Emissions per ton output			
1. CO ₂ (kg/t)	11.07	25.10	(14.03)
2. SO ₂ (g/t)	0.60	14.23	(13.63)
3. NO _x (g/t)	2.80	56.58	(53.78)
4. TSP (g/t)	45.20	222.05	(176.85)
5. Sludge (kg/t)	104.00	124.00	(20.00)
6. Soil Residual (kg/t)	0.16	0.00	0.16
Total emissions.			
1. CO ₂ (1000 t)	121.74	239.26	(117.52)
2. SO ₂ (t)	1.80	36.99	(35.19)
3. NO _x (t)	8.41	147.12	(138.71)
4. TSP (t)	135.59	577.32	(441.73)
5. Sludge (1000 t)	312.00	322.40	(10.40)
6. Soil Residual (t)	480.00	0.00	480.00
	<u>Direct</u>	<u>Indirect</u>	<u>Total</u>
Emission reduction			
1. CO ₂ (1000 t)	36.48	5.61	42.09
2. SO ₂ (t)	35.43	5.45	40.88
3. NO _x (t)	139.83	21.51	161.34
4. TSP (t)	459.80	70.74	530.54
5. Sludge (1000 t)	52.00	8.00	60.00
6. Soil Residual (t)	(416.00)	(0.06)	(416.06)

* Emissions based on carbon weight rather than CO₂ content.

Economic/Environmental Assessment

Table 10 depicts the economic/environmental cash flow for the project. Using economic prices, the internal rate of return decreases from 16.1 to 15.7 percent. Substantial savings are realized in oil and to a lesser extent coke, gas and steam. Electricity consumption increases are accentuated by a high economic conversion factor for electricity. Including local air pollution benefits with the project, the rate of return increases to 15.8 percent.

Table 10. Incremental Economic/Environmental Cash Flow Analysis (million yuan)

Year	Total	Total	Net	Global	Emissions	Local	Econ Value	Net
	Costs	Benefits	Benefits	CO2	Local	TSP	of Local	Economic/
				(t)	SO2	(t)	Pollution	Environmenta
							Reduction	l
								Benefits
1	234.00	0.00	(234.00)	0.00	0.00	0.00	0.00	(234.00)
2	384.00	0.00	(384.00)	0.00	0.00	0.00	0.00	(384.00)
3	384.00	0.00	(384.00)	0.00	0.00	0.00	0.00	(384.00)
4	145.44	342.00	196.56	(32.05)	(35.19)	(441.73)	0.78	197.34
5	155.44	342.00	186.56	(32.05)	(35.19)	(441.73)	0.78	187.34
6	155.44	342.00	186.56	(32.05)	(35.19)	(441.73)	0.78	187.34
7	155.44	342.00	186.56	(32.05)	(35.19)	(441.73)	0.78	187.34
8	145.44	342.00	196.56	(32.05)	(35.19)	(441.73)	0.78	197.34
9	155.44	342.00	186.56	(32.05)	(35.19)	(441.73)	0.78	187.34
10	155.44	342.00	186.56	(32.05)	(35.19)	(441.73)	0.78	187.34
11	155.44	342.00	186.56	(32.05)	(35.19)	(441.73)	0.78	187.34
12	145.44	342.00	196.56	(32.05)	(35.19)	(441.73)	0.78	197.34
13	155.44	342.00	186.56	(32.05)	(35.19)	(441.73)	0.78	187.34
14	155.44	342.00	186.56	(32.05)	(35.19)	(441.73)	0.78	187.34
15	155.44	342.00	186.56	(32.05)	(35.19)	(441.73)	0.78	187.34
16	145.44	342.00	196.56	(32.05)	(35.19)	(441.73)	0.78	197.34
17	155.44	342.00	186.56	(32.05)	(35.19)	(441.73)	0.78	187.34
18	155.44	342.00	186.56	(32.05)	(35.19)	(441.73)	0.78	187.34
19	155.44	342.00	186.56	(32.05)	(35.19)	(441.73)	0.78	187.34
20	145.44	342.00	196.56	(32.05)	(35.19)	(441.73)	0.78	197.34
21	155.44	342.00	186.56	(32.05)	(35.19)	(441.73)	0.78	187.34
22	155.44	342.00	186.56	(32.05)	(35.19)	(441.73)	0.78	187.34
23	155.44	342.00	186.56	(32.05)	(35.19)	(441.73)	0.78	187.34
Total	4,060.74	6,840.00	2,779.26	(641.02)	(703.80)	(8,834.51)	15.55	2,794.80
NPV	1,599.14	1,818.28	219.13	(170.40)	(187.09)	(2,348.48)	4.13	223.27
IRR			15.71%					15.78%

Table 11 adjusts the information in Table 10 to the without-project production level. That is to say, the output effect of the project is removed. The resulting incremental cost of CO₂ reduction is 226.71 RMB yuan per ton. Net benefits per ton CO₂ reduction are -226.71 RMB yuan without local environmental benefits and -204.66 RMB yuan with environmental benefits included.

**Table 11. Incremental Economic/Environmental Cash Flow Analysis
Adjusted for Output (million yuan)**

Year	Total	Total	Net	Global	Emissions	Local	Econ Value	Net
	Costs	Benefits	Benefits	CO2	Local	TSP	of Local	Economic/ Environmenta l
				(t)	(t)	(t)	Reduction	Benefits
1	202.80	0.00	(202.80)	0.00	0.00	0.00	0.00	(202.80)
2	332.80	0.00	(332.80)	0.00	0.00	0.00	0.00	(332.80)
3	332.80	0.00	(332.80)	0.00	0.00	0.00	0.00	(332.80)
4	(126.36)	0.00	126.36	(36.48)	(35.43)	(459.80)	0.80	127.17
5	(117.70)	0.00	117.70	(36.48)	(35.43)	(459.80)	0.80	118.50
6	(117.70)	0.00	117.70	(36.48)	(35.43)	(459.80)	0.80	118.50
7	(117.70)	0.00	117.70	(36.48)	(35.43)	(459.80)	0.80	118.50
8	(126.36)	0.00	126.36	(36.48)	(35.43)	(459.80)	0.80	127.17
9	(117.70)	0.00	117.70	(36.48)	(35.43)	(459.80)	0.80	118.50
10	(117.70)	0.00	117.70	(36.48)	(35.43)	(459.80)	0.80	118.50
11	(117.70)	0.00	117.70	(36.48)	(35.43)	(459.80)	0.80	118.50
12	(126.36)	0.00	126.36	(36.48)	(35.43)	(459.80)	0.80	127.17
13	(117.70)	0.00	117.70	(36.48)	(35.43)	(459.80)	0.80	118.50
14	(117.70)	0.00	117.70	(36.48)	(35.43)	(459.80)	0.80	118.50
15	(117.70)	0.00	117.70	(36.48)	(35.43)	(459.80)	0.80	118.50
16	(126.36)	0.00	126.36	(36.48)	(35.43)	(459.80)	0.80	127.17
17	(117.70)	0.00	117.70	(36.48)	(35.43)	(459.80)	0.80	118.50
18	(117.70)	0.00	117.70	(36.48)	(35.43)	(459.80)	0.80	118.50
19	(117.70)	0.00	117.70	(36.48)	(35.43)	(459.80)	0.80	118.50
20	(126.36)	0.00	126.36	(36.48)	(35.43)	(459.80)	0.80	127.17
21	(117.70)	0.00	117.70	(36.48)	(35.43)	(459.80)	0.80	118.50
22	(117.70)	0.00	117.70	(36.48)	(35.43)	(459.80)	0.80	118.50
23	(117.70)	0.00	117.70	(36.48)	(35.43)	(459.80)	0.80	118.50
Total	(1,528.86)	0.00	1,528.86	(729.56)	(708.59)	(9,196.10)	16.09	1,544.95
PV	43.97	0.00	(43.97)	(193.94)	(188.36)	(2,444.60)	4.28	(39.69)
					<u>CO2</u>	<u>COAL</u>		
Total Incremental Cost/Ton of CO2 Reduction (yuan at 12%)					226.71	65.56		
At RMB/US\$ = 5.50					\$41.22	\$11.92		
Total Net Benefits/Ton of CO2 Reduction (yuan at					(226.71)	(65.56)		
At RMB/US\$ = 5.50					(\$41.22)	(\$11.92)		
Net Benefits Incl'g Local Env. Benefits/Ton of CO2					(204.66)	(59.18)		
At RMB/US\$ = 5.50					(\$37.21)	(\$10.76)		

Metallurgy Industry: Case 2

Continuous Casting Technology at Benxi Steelmaking Plant

Introduction

The Chinese iron and steel industry accounts for one tenth of total industrial energy consumption. For that reason, improvement of production technology offers the potential for significant energy savings. One aspect of the production process for which substantial energy savings are possible is steel casting. In modern steel plants, continuous casting has become the casting technology of choice. With continuous casting, hot molten steel is poured slowly into large casts. The slabs are then routed directly through the roller mill. As such, this process saves energy presently required to reheat steel ingot and raises yield by 8-10 percent as less trimming is required.

By 1990, 59 percent of worldwide steel production employed continuous casting technology. In Japan, 93.9 percent of steel is produced with a continuous casting process, while 67.1 percent of U.S. steel is produced with continuous casting. Still, no continuous casting and roller processes are employed currently in China. The project at Benxi would be the first application of continuous casting technology in China.

The Benxi Steel Plant was established in 1910. Prior to 1979, the plant specialized in producing pig iron but is now an integrated iron and steel works including mining and ore processing plants through finished steel products. The plant has an annual production capacity of 2.6 million tons of steel and 3.2 million tons of pig iron. The plant is equipped with three sets of basic oxygen furnaces (BOF) put into operation twenty years ago. Since that time, no major technological improvement in the production process has occurred. The installation of continuous casting technology is planned as the next process technology to be adopted.

Technology Assessment

Current Technology: Benxi Steel Works employs conventional process technology for steel casting and rolling. Molten steel is poured into mold casts to produce ingot. The hot ingot is then transferred to another workshop where it is reheated in a soaking pit and then rolled into billet on the rough roller mill. The rough rolled billet is then cooled before reheating and processing into finished sheet steel on the fine roller mill.

The conventional process used in China is energy intensive given the number of times that ingot and billet is reheated in the production process. The process is also time consuming requiring 10 days on average to move from steel making to finished rolled steel.

Proposed Technology: With the proposed continuous casting and rolling technology, molten steel is poured directly into continuous casts where it hardens, but temperature is maintained. The steel is transferred directly to the roller mill bypassing standard reheating and rough rolling. In the process, energy consumption is reduced, and yields are increased by 8-10 percent because the billet does not require scrap to be trimmed from the edges as is currently required with ingot cast steel.

In the first stage, up to a third of energy is saved relative to the current process. In the second stage, where heating in the soaking pit and reheating furnace are replaced by heat

compensation around the edges, up to 63 percent of energy used in casting and rolling can be saved.

The first stage of renovation involves the installation of a two cast slab continuous caster with an annual productive capacity of 1.75 million tons. The continuous caster is placed near a 1700 mm hot strip mill to provide continuous heating of the slab before rolling begins. At this point the relative efficiency of the hot link will be 70-85 percent. Another two line slab continuous caster will be added in the second stage increasing production capacity to 3.5 million tons per year. After the second caster is put into operation, the slab will be processed using continuous roller technology, i.e. direct rolling.

Financial Analysis

Production indicators with and without the project are indicated in Table 1. Construction is scheduled in two phases. At full operation, production capacity is expected to be 3.5 million tons per year of slab. Half of that total is expected to be carbon steel with the other half being higher quality low alloy steel. The without project case calls for output to increase to 3.2 million tons of normal carbon steel.

Table 1. Production Indicators With and Without Project

	With project	Without project
1. Type of Steel		
a. Normal steel (million tons)	1.75	3.20
b. High quality steel (million tons)	1.75	0.00
2. Selling price (yuan/ton)	1080.00	1080.00
a. Normal steel	1340.00	1340.00
b. High quality steel	4235.00	3456.00
3. Sales income (million yuan)		

Investment costs for the project are expected to be 1.999 billion RMB yuan as indicated in Table 2. The first construction phase that was to begin in October 1993 is scheduled to last three years. The second phase scheduled for 1999 is projected to last for two years. The without project case is projected to require 300 million yuan for facility upgrades.

Operating costs with and without the project are summarized in Table 3; detailed operating costs for both ingot and continuous casting technology are shown in Appendices A and B at the end of this case study. The with project case includes costs for both normal carbon steel and for higher quality alloy steel. Feedstock costs per ton drop slightly (5.4 percent) in the with project case for normal steel but rise by 4.9 percent for higher quality steel. The greatest savings are in terms of energy costs which fall by 53.4 due principally to reheating cost savings. Overall, per ton costs fall by 4.1 percent for normal steel and rise by 5.6 percent for the higher quality steel. That cost increase is offset by a 20 percent price differential due to increased quality.

Table 2. Total Investment With and Without Project (million yuan)

		With project	Without project
1.	Continuous casting	1501.33	
2.	Water processing	68.70	
3.	Gas purification	5.00	
4.	Air compressor station	20.00	
5.	Repairs workshop	4.62	
6.	Transportation	96.44	
7.	Other facilities	42.94	300.00
8.	Overhead and other	260.89	
9.	Total	1998.60	300.00
Investment schedule:			
1		359.60	
2		503.40	
3		335.60	
4		0.00	
5		0.00	
6		500.00	100.00
7		300.00	200.00
8		0.00	
9		0.00	
10		0.00	
	Total	1998.60	

Table 3. Comparison of Operating Costs With and Without Project (per ton)

Items	With project		Without project
	Normal steel	High quality	Normal steel
1. Feedstock	919.34	1019.27	971.51
2. Other materials	20.90	20.90	2.52
3. Energy	14.93	14.93	32.04
4. Maintenance	26.83	26.83	17.72
5. Salary and welfare	1.11	1.11	1.73
Total Costs	983.11	1083.05	1025.52

Cash flow tables with and without the project appear as Tables 4 and 5. Total costs increase to 3.62 million yuan at full production with the project compared with 3.28 million yuan without the project. Costs reflect both a higher level of output and slightly higher per unit costs given input costs for high quality steel. Substantial energy savings of 49 percent are realized with the project. Still, energy amounts to only 1.4 percent of total costs with the project. Total benefits doubled reflecting increased output and a higher price for higher quality steel.

Table 4. Financial Cash Flow With Project (million yuan)

Year	Investment		Operating Costs						Total Costs	Total Benefits	Net Benefits
	Facility	Subtotal	Feedstock	Energy	MTC*	Salary	Others	Subtotal			
1	359.60	359.60	1554.42	51.27	28.35	2.77	4.03	1640.83	2000.43	1728.00	(272.43)
2	503.40	503.40	1554.42	51.27	28.35	2.77	4.03	1640.83	2144.23	1728.00	(416.23)
3	335.60	335.60	1554.42	51.27	28.35	2.77	4.03	1640.83	1976.43	1728.00	(248.43)
4	0.00	0.00	1696.29	26.13	46.95	1.94	36.58	1807.89	1807.89	2117.50	309.61
5	0.00	0.00	1696.29	26.13	46.95	1.94	36.58	1807.89	1807.89	2117.50	309.61
6	500.00	500.00	1696.29	26.13	46.95	1.94	36.58	1807.89	2307.89	2117.50	(190.39)
7	300.00	300.00	1696.29	26.13	46.95	1.94	36.58	1807.89	2107.89	4235.00	9.61
8	(20.00)	(20.00)	3392.57	52.26	93.91	3.89	73.16	3615.78	3595.78	4235.00	639.22
9	0.00	0.00	3392.57	52.26	93.91	3.89	73.16	3615.78	3615.78	4235.00	619.22
10	0.00	0.00	3392.57	52.26	93.91	3.89	73.16	3615.78	3615.78	4235.00	619.22
11	0.00	0.00	3392.57	52.26	93.91	3.89	73.16	3615.78	3615.78	4235.00	619.22
12	0.00	0.00	3392.57	52.26	93.91	3.89	73.16	3615.78	3615.78	4235.00	619.22
13	0.00	0.00	3392.57	52.26	93.91	3.89	73.16	3615.78	3615.78	4235.00	619.22
14	0.00	0.00	3392.57	52.26	93.91	3.89	73.16	3615.78	3615.78	4235.00	619.22
15	0.00	0.00	3392.57	52.26	93.91	3.89	73.16	3615.78	3615.78	4235.00	619.22
16	0.00	0.00	3392.57	52.26	93.91	3.89	73.16	3615.78	3615.78	4235.00	619.22
17	0.00	0.00	3392.57	52.26	93.91	3.89	73.16	3615.78	3615.78	4235.00	619.22
18	0.00	0.00	3392.57	52.26	93.91	3.89	73.16	3615.78	3615.78	4235.00	619.22
19	0.00	0.00	3392.57	52.26	93.91	3.89	73.16	3615.78	3615.78	4235.00	619.22
20	0.00	0.00	3392.57	52.26	93.91	3.89	73.16	3615.78	3615.78	4235.00	619.22
21	0.00	0.00	3392.57	52.26	93.91	3.89	73.16	3615.78	3615.78	4235.00	619.22
22	(100.00)	0.00	3392.57	52.26	93.91	3.89	73.16	3615.78	3615.78	4235.00	619.22
23		(100.00)	3392.57	52.26	93.91	3.89	73.16	3615.78	3515.78	4235.00	719.22
Total	1878.60	1878.60	65729.54	1094.43	1775.35	78.23	1328.91	71885.06	71885.06	81414.00	9528.94
PV	1334.82	1334.82	18103.16	344.48	465.84	23.10	319.54	20590.94	20590.94	22088.30	1497.36

* MTC, Maintenance Costs

Table 5. Financial Cash Flow Without Project (million yuan)

Year	Investment		Operating Costs						Total Costs	Total Benefits	Net Benefits
	Facility	Subtotal	Feedstock	Energy	MTC*	Salary	Others	Subtotal			

Year	Facility	Subtotal	Feedstock	Energy	MTC	Salary	Others	Subtotal	Total Costs	Total Benefits	Net Benefits
1	0.00	0.00	1554.42	51.27	28.35	2.77	4.03	1640.83	1640.83	1728.00	87.17
2	0.00	0.00	1554.42	51.27	28.35	2.77	4.03	1640.83	1640.83	1728.00	87.17
3	0.00	0.00	1554.42	51.27	28.35	2.77	4.03	1640.83	1640.83	1728.00	87.17
4	0.00	0.00	1554.42	51.27	28.35	2.77	4.03	1640.83	1640.83	1728.00	87.17
5	0.00	0.00	1554.42	51.27	28.35	2.77	4.03	1640.83	1640.83	1728.00	87.17
6	100.00	100.00	1554.42	51.27	28.35	2.77	4.03	1640.83	1740.83	1728.00	(12.83)
7	200.00	200.00	1554.42	51.27	28.35	2.77	4.03	1640.83	1840.83	1728.00	(112.83)
8	0.00	0.00	3108.84	102.53	56.70	5.54	8.06	3281.67	3281.67	3456.00	174.33
9	0.00	0.00	3108.84	102.53	56.70	5.54	8.06	3281.67	3281.67	3456.00	174.33
10	0.00	0.00	3108.84	102.53	56.70	5.54	8.06	3281.67	3281.67	3456.00	174.33
11	0.00	0.00	3108.84	102.53	56.70	5.54	8.06	3281.67	3281.67	3456.00	174.33
12	0.00	0.00	3108.84	102.53	56.70	5.54	8.06	3281.67	3281.67	3456.00	174.33
13	0.00	0.00	3108.84	102.53	56.70	5.54	8.06	3281.67	3281.67	3456.00	174.33
14	0.00	0.00	3108.84	102.53	56.70	5.54	8.06	3281.67	3281.67	3456.00	174.33
15	0.00	0.00	3108.84	102.53	56.70	5.54	8.06	3281.67	3281.67	3456.00	174.33
16	0.00	0.00	3108.84	102.53	56.70	5.54	8.06	3281.67	3281.67	3456.00	174.33
17	0.00	0.00	3108.84	102.53	56.70	5.54	8.06	3281.67	3281.67	3456.00	174.33
18	0.00	0.00	3108.84	102.53	56.70	5.54	8.06	3281.67	3281.67	3456.00	174.33
19	0.00	0.00	3108.84	102.53	56.70	5.54	8.06	3281.67	3281.67	3456.00	174.33
20	0.00	0.00	3108.84	102.53	56.70	5.54	8.06	3281.67	3281.67	3456.00	174.33
21	0.00	0.00	3108.84	102.53	56.70	5.54	8.06	3281.67	3281.67	3456.00	174.33
22	0.00	0.00	3108.84	102.53	56.70	5.54	8.06	3281.67	3281.67	3456.00	174.33
23	0.00	0.00	3108.84	102.53	56.70	5.54	8.06	3281.67	3281.67	3456.00	174.33
Total	300.00	300.00	60622.36	1999.36	1105.73	107.95	157.10	63992.49	64292.49	67392.00	3099.51
PV	141.13	141.13	16901.37	557.42	308.27	30.10	43.80	17840.96	17982.09	18788.74	806.64

* MTC, Maintenance Costs

Table 6 depicts incremental cash flow with and without the project. The payback period for the project is nine years (six years after phase in construction). Net present value of the project is 690.7 million yuan, and the internal rate of return is 18.6 percent. The project has a high investment cost of 1.6 billion yuan but appears to be viable if investment capital can be found.

Table 6. Incremental Cash Flow With and Without Project (million yuan)

Year	Investment			Operating Costs						Total Costs	Total Benefits	Net Benefits
	Facility	Repairs	Subtotal	Feedstock	Energy	MTC*	Salary	Other	Subtotal			
1	359.60	0.00	359.60	0.00	0.00	0.00	0.00	0.00	0.00	359.60	0.00	(359.60)
2	503.40	0.00	503.40	0.00	0.00	0.00	0.00	0.00	0.00	503.40	0.00	(503.40)
3	335.60	0.00	335.60	0.00	0.00	0.00	0.00	0.00	0.00	335.60	0.00	(335.60)
4	0.00	0.00	0.00	141.87	(25.14)	18.60	(0.83)	32.55	167.05	167.05	389.50	222.45
5	0.00	0.00	0.00	141.87	(25.14)	18.60	(0.83)	32.55	167.05	167.05	389.50	222.45
6	400.00	0.00	400.00	141.87	(25.14)	18.60	(0.83)	32.55	167.05	567.05	389.50	(177.55)
7	100.00	0.00	100.00	141.87	(25.14)	18.60	(0.83)	32.55	167.05	267.05	389.50	122.45
8	(20.00)	0.00	(20.00)	283.73	(50.27)	37.20	(1.65)	65.10	334.11	334.11	779.00	464.89
9	0.00	0.00	0.00	283.73	(50.27)	37.20	(1.65)	65.10	334.11	334.11	779.00	444.89
10	0.00	0.00	0.00	283.73	(50.27)	37.20	(1.65)	65.10	334.11	334.11	779.00	444.89
11	0.00	0.00	0.00	283.73	(50.27)	37.20	(1.65)	65.10	334.11	334.11	779.00	444.89
12	0.00	0.00	0.00	283.73	(50.27)	37.20	(1.65)	65.10	334.11	334.11	779.00	444.89
13	0.00	0.00	0.00	283.73	(50.27)	37.20	(1.65)	65.10	334.11	334.11	779.00	444.89
14	0.00	0.00	0.00	283.73	(50.27)	37.20	(1.65)	65.10	334.11	334.11	779.00	444.89
15	0.00	0.00	0.00	283.73	(50.27)	37.20	(1.65)	65.10	334.11	334.11	779.00	444.89
16	0.00	0.00	0.00	283.73	(50.27)	37.20	(1.65)	65.10	334.11	334.11	779.00	444.89
17	0.00	0.00	0.00	283.73	(50.27)	37.20	(1.65)	65.10	334.11	334.11	779.00	444.89
18	0.00	0.00	0.00	283.73	(50.27)	37.20	(1.65)	65.10	334.11	334.11	779.00	444.89
19	0.00	0.00	0.00	283.73	(50.27)	37.20	(1.65)	65.10	334.11	334.11	779.00	444.89
20	0.00	0.00	0.00	283.73	(50.27)	37.20	(1.65)	65.10	334.11	334.11	779.00	444.89
21	0.00	0.00	0.00	283.73	(50.27)	37.20	(1.65)	65.10	334.11	334.11	779.00	444.89
22	0.00	0.00	0.00	283.73	(50.27)	37.20	(1.65)	65.10	334.11	334.11	779.00	444.89
23	(100.00)	0.00	(100.00)	283.73	(50.27)	37.20	(1.65)	65.10	334.11	234.11	779.00	544.89
Total	1578.60	0.00	1578.60	5,107.18	(904.92)	669.62	(29.72)	1171.81	6013.97	7592.57	14022.00	6429.43
PV	1193.68	0.00	1193.68	1,201.79	(212.94)	157.57	(6.99)	275.74	1415.17	3608.85	3299.56	690.71
IRR												18.64%

* Maintenance Costs

Energy Conservation

Total energy use is projected to decrease by 59.2 percent from 207.3 thousand tce without the project to 84.7 thousand tce with the project as indicated in Table 7. The majority of energy savings are due to reduced coking oven gas consumption down from 61.6 percent of energy use to 13.5 percent of energy use with the project. BF and BOF gas requirements are eliminated, while power consumption increases by 52 percent. Overall, 71,050 tce in energy savings are achieved in the first phase, while 142,110 tce in energy savings are

achieved in the second phase of the project. The majority of these energy savings (91.4 percent) are direct effects occurring at the same level of output.

Table 7. Total Energy Use With and Without Project

Type of energy (million m ³)	Energy Conver'n Factor	With project		Without project		Incremental	
		Actual Use	tce	Actual Use	tce	Actual Use	tce
1. Cooking oven gas	0.600	19.11	11.47	212.99	127.80	(193.88)	(116.33)
2. BF gas	0.110	0.00	0.00	240.00	26.40	(240.00)	(26.40)
3. BOF gas	0.230	0.00	0.00	61.18	14.07	(61.18)	(14.07)
4. Oxygen	0.334	22.74	7.50	3.97	1.33	18.50	6.18
5. Argon	0.540	2.31	1.25	0.00	0.00	2.31	1.25
6. Nitrogen	0.074	12.32	0.91	0.00	0.00	12.32	0.91
7. Compressed air	0.045	231.00	10.40	47.74	2.15	183.26	8.25
8. Steam	0.016	210.00	3.36	101.34	1.62	108.66	1.74
9. Water	0.100	2.80	0.28	15.01	1.50	(12.21)	(1.22)
10. Power (gwh)	0.404	122.50	49.49	80.35	32.46	42.15	17.03
Total use ('000 tce)			84.66		207.33		(122.67)
Total energy savings ('000 tce)			<u>Direct</u>		<u>Indirect</u>		<u>Total</u>
1. First phase							
2. Second phase			64.96		6.09		71.05
			129.93		12.18		142.11

Environmental Benefits

Emissions reductions are significant as indicated in Table 8. Per unit CO₂ emissions are reduced from 48.9 kg/ton without the project to 18.3 kg/ton with the project, a 62.7 percent reduction. Emissions of SO₂ are reduced from 1.5 to 0.6 kg/ton, while TSP are reduced from 1.4 to 0.5 kg/ton. Overall, annual CO₂ emissions are reduced by 107,280 tons. Of that figure, 49,040 tons are direct effects at the initial output of 1.6 million tons, while 58,240 are classified as indirect effects due to higher levels of output.

Table 8. Environmental Impacts With and Without Project

Items	With project	Without project	Incremental
I. Per unit emissions (kg)			
1. CO ₂	18.26	48.91	(30.65)
2. SO ₂	0.57	1.52	(0.95)
3. TSP	0.51	1.38	(0.86)
II. Total emissions ('000 t)			
1. CO ₂	63.91	156.51	(92.61)
2. SO ₂	1.99	4.87	(2.88)
3. TSP	1.80	4.40	(2.60)
III. Emissions reduction ('000 t)			
1. CO ₂	<u>Direct</u> 49.04	<u>Indirect</u> 58.24	Total 107.28
2. SO ₂	1.52	1.81	3.34
3. TSP	1.38	1.64	3.02
Emission factors (kg/tce)			
1. CO ₂	754.91		
2. SO ₂	23.47		
3. TSP	21.23		

Economic/Environmental Assessment

Tables 9 depicts the economic/environmental cash flow for the project. Using economic prices, the internal rate of return increases from 18.6 to 19.4 percent reflecting slightly higher energy prices. Including local air pollution benefits with the project, the rate of return increases to 19.44 percent. In Table 10 adjusting for output, the incremental cost of CO₂ reduction is substantial at 2,635 RMB yuan per ton, largely because of the high investment cost for the project. Net benefits per ton CO₂ reduction become very positive reflecting both quantity and quality improvements. At 1,607 to 1,614 yuan per ton, net benefits at Benxi rank as the second highest figures among the 24 cases examined.

Table 9. Incremental Economic/Environmental Cash Flow Analysis (million yuan)

Year	Total Costs	Total Benefits	Net Benefits	Emissions			Econ Value of Local Pollution Reduction	Net Economic/Environmental Benefits
				Global CO2 (t)	Local SO2 (t)	Local TSP (t)		
1	359.84	0.00	(359.84)	0.00	0.00	0.00	0.00	(359.84)
2	503.73	0.00	(503.73)	0.00	0.00	0.00	0.00	(503.73)
3	335.82	0.00	(335.82)	0.00	0.00	0.00	0.00	(335.82)
4	156.11	389.50	233.39	(46.30)	(1.44)	(1.30)	0.34	233.74
5	156.11	389.50	233.39	(46.30)	(1.44)	(1.30)	0.34	233.74
6	556.44	389.50	(166.94)	(46.30)	(1.44)	(1.30)	0.34	(166.59)
7	256.31	389.50	133.19	(46.30)	(1.44)	(1.30)	0.34	133.54
8	292.21	779.00	486.79	(92.61)	(2.88)	(2.60)	0.69	487.47
9	312.21	779.00	466.79	(92.61)	(2.88)	(2.60)	0.69	467.47
10	312.21	779.00	466.79	(92.61)	(2.88)	(2.60)	0.69	467.47
11	312.21	779.00	466.79	(92.61)	(2.88)	(2.60)	0.69	467.47
12	312.21	779.00	466.79	(92.61)	(2.88)	(2.60)	0.69	467.47
13	312.21	779.00	466.79	(92.61)	(2.88)	(2.60)	0.69	467.47
14	312.21	779.00	466.79	(92.61)	(2.88)	(2.60)	0.69	467.47
15	312.21	779.00	466.79	(92.61)	(2.88)	(2.60)	0.69	467.47
16	312.21	779.00	466.79	(92.61)	(2.88)	(2.60)	0.69	467.47
17	312.21	779.00	466.79	(92.61)	(2.88)	(2.60)	0.69	467.47
18	312.21	779.00	466.79	(92.61)	(2.88)	(2.60)	0.69	467.47
19	312.21	779.00	466.79	(92.61)	(2.88)	(2.60)	0.69	467.47
20	312.21	779.00	466.79	(92.61)	(2.88)	(2.60)	0.69	467.47
21	312.21	779.00	466.79	(92.61)	(2.88)	(2.60)	0.69	467.47
22	312.21	779.00	466.79	(92.61)	(2.88)	(2.60)	0.69	467.47
23	212.21	779.00	566.79	(92.61)	(2.88)	(2.60)	0.69	567.47
Total	7,199.78	14,022.00	6,822.22	(1,666.90)	(51.82)	(46.88)	12.41	6,834.63
NPV	2,517.00	3,299.56	782.56	(392.24)	(12.19)	(11.03)	2.92	785.48
IRR			19.42%					19.44%

Table 10. Incremental Economic/Environmental Cash Flow Analysis Adjusted for Output (million yuan)

Year	Total Costs	Total Benefits	Net Benefits	Emissions			Econ Value of Local Pollution Reduction	Net Economic/Environmental Benefits
				Global CO2 (t)	Local SO2 (t)	Local TSP (t)		
1	328.99	0.00	(328.99)	0.00	0.00	0.00	0.00	(328.99)
2	460.56	0.00	(460.56)	0.00	0.00	0.00	0.00	(460.56)
3	307.04	0.00	(307.04)	0.00	0.00	0.00	0.00	(307.04)
4	0.28	208.00	207.72	(49.04)	(1.52)	(1.38)	0.37	208.08
5	0.28	208.00	207.72	(49.04)	(1.52)	(1.38)	0.37	208.08
6	366.30	208.00	(158.30)	(49.04)	(1.52)	(1.38)	0.37	(157.93)
7	91.89	208.00	116.11	(49.04)	(1.52)	(2.76)	0.45	116.56
8	(17.72)	416.00	433.72	(98.08)	(3.05)	(2.76)	0.73	434.45
9	0.56	416.00	415.44	(98.08)	(3.05)	(2.76)	0.73	416.17
10	0.56	416.00	415.44	(98.08)	(3.05)	(2.76)	0.73	416.17
11	0.56	416.00	415.44	(98.08)	(3.05)	(2.76)	0.73	416.17
12	0.56	416.00	415.44	(98.08)	(3.05)	(2.76)	0.73	416.17
13	0.56	416.00	415.44	(98.08)	(3.05)	(2.76)	0.73	416.17
14	0.56	416.00	415.44	(98.08)	(3.05)	(2.76)	0.73	416.17
15	0.56	416.00	415.44	(98.08)	(3.05)	(2.76)	0.73	416.17
16	0.56	416.00	415.44	(98.08)	(3.05)	(2.76)	0.73	416.17
17	0.56	416.00	415.44	(98.08)	(3.05)	(2.76)	0.73	416.17
18	0.56	416.00	415.44	(98.08)	(3.05)	(2.76)	0.73	416.17
19	0.56	416.00	415.44	(98.08)	(3.05)	(2.76)	0.73	416.17
20	0.56	416.00	415.44	(98.08)	(3.05)	(2.76)	0.73	416.17
21	0.56	416.00	415.44	(98.08)	(3.05)	(2.76)	0.73	416.17
22	0.56	416.00	415.44	(98.08)	(3.05)	(2.76)	0.73	416.17
23	(90.86)	416.00	506.86	(98.08)	(3.05)	0.00	0.56	507.42
Total	1,454.65	7,488.00	6,033.35	(1,765.50)	(54.89)	(48.27)	13.05	6,046.41
NPV	1,094.57	1,762.03	667.46	(415.44)	(12.92)	(12.10)	3.12	670.57

	CO2	COAL
Total Incremental Cost/Ton of CO2 Reduction (yuan at 12%)	2,634.70	1,988.96
At RMB/US\$ = 5.50	\$439.12	\$331.49
Total Net Benefits/Ton of CO2 Reduction (yuan at 12%)	1,606.60	1,212.84
At RMB/US\$ = 5.50	\$267.77	\$202.14
Net Benefits Incl'g Local Env. Benefits/Ton of CO2 Reduction	1,614.11	1,218.51
At RMB/US\$ = 5.50	\$269.02	\$203.08

Appendix A. Operating Costs for Ingot Casting Operations (per ton)

Items	Unit	Price(Y)	Use	Cost (Y)
I. Ingot cost				941.47
1. Feedstock				928.27
a. Steel water	t	906.00	1.041	943.15
b. Scrap steel recycling	t	744.00	0.020	-14.88
2. Ingot cost				13.20
II. Rough rolling cost				1032.24
1. Feedstock				971.51
a. Steel water	t	941.47	1.094	1029.97
b. Scrap steel recycling	t	744.00	0.079	-58.46
2. Other materials				2.52
a. Refractory	kg	0.48	1.220	0.59
b. Oil	kg	4.00	0.132	0.53
c. Rolling shaft	kg	10.80	0.130	1.40
3. Energy cost				32.04
a. Electricity	kwh	0.18	25.110	4.52
b. Steam gas	m ₃	0.04	31.670	1.14
c. Fresh water	m ₃	0.48	4.690	2.26
d. Recycling water	m ₃	0.24	6.320	1.51
e. Compressed air	m ₃	0.03	14.920	0.37
f. Coking oven gas	m ₃	0.28	66.560	18.37
g. BF gas	m ₃	0.02	75.000	1.80
h. BOF gas	m ₃	0.10	19.120	1.84
i. Oxygen	m ³	0.19	1.240	0.24
4. Salary and welfare			1.73	54.01
5. Repairs and maintenance				17.72
6. Depreciation				6.72
III. Total cost				1032.24
1. With depreciation				1025.52
2. Without depreciation				

*Taxes are not paid on intermediate steel products

Appendix B. Operating Costs for Continuous Casting Operations (per ton)

Items	Unit	Price(Y)	Use	Cost (Y)
I. Feedstock				
1. Normal steel				919.34
a. Steel water	t	906.00	1.04	943.15
b. Scrap steel recycling	t	744.00	-0.03	-23.81
2. High quality steel				1019.27
a. Steel water	t	1002.00	1.04	1043.08
b. Scrap steel recycling	t	744.00	-0.03	-23.81
II. Continuous casting cost				79.85
1. Other materials				16.70
a. Refractory	kg	1.20	10.00	12.00
b. Crystal slag	kg	1.67	0.60	1.00
c. Others				3.70
2. Energy cost				11.39
a. Electricity	kwh	0.18	35.00	6.30
b. Steam gas	m ₃	0.04	1.50	0.05
c. Fresh water	m ₃	0.48	0.72	0.35
d. Recycling water	m ₃	0.24	0.00	0.00
e. Compressed air	m ₃	0.03	66.00	1.65
f. Coking oven gas	m ₃	0.28	4.00	1.10
g. Argon gas	m ₃	1.80	0.42	0.76
h. Nitrogen gas	m ₃	0.10	0.40	0.04
i. Oxygen	m ³	0.19	6.00	1.14
3. Salary and welfare				1.11
4. Repairs and maintenance				26.83
5. Depreciation				23.82
III. Purification cost				7.74
1. Steam gas	m ₃	0.04	56.00	2.24
2. Oxygen	m ₃	0.19	0.40	0.08
3. Argon Gas	m ₃	1.80	0.23	0.41
4. Nitrogen	m ₃	0.14	3.00	0.42
5. Coking oven gas	m ³	0.28	1.40	0.39
6. Refractory	kg	1.20	3.50	4.20
III. Total cost				
1. With depreciation				
a. Normal steel				1006.93
b. High quality steel				1106.87
2. Without depreciation				
a. Normal steel				983.11
b. High quality steel				1083.05

Metallurgy Industry: Case 3

Renovations of Reheating Furnace at Dalian Steel Works

Introduction

Rolled steel is a major product of the iron and steel industry in China accounting for 56.4 million tons of production in 1991. The steel rolling process accounts for six million tons of coal equivalent energy use each year, nine percent of the industry total. The bulk of energy use in the rolling process (70 percent of the total) is accounted for by reheating furnaces used to reheat cast steel and steel billet before processing on the rolling mill.

In recent years, substantial improvements have been made in terms of energy efficiency. From 1979 to 1990, energy use in steel rolling plants in China has been reduced from 187 to 131 kgce, a 30 percent decrease, as indicated in Table 1. Still, on average Chinese plants use 40 kgce/ton more energy than advanced international standards with most Chinese plants being 45-50 percent higher in terms of energy consumption. Of the 479 reheating furnaces in key iron and steel enterprises, nearly 80 percent of those furnaces are high consumption units, leaving considerable room for energy efficiency improvements. In the case below, the No. 2 Steel Rolling Mill at Dalian Steel Works is used to assess the feasibility of furnace renovation for billet reheating.

**Table 1. Energy Use in Steel Rolling Processing
for Large and Medium Enterprises in China**

Year	Energy use (kgce)
1979	187.00
1980	163.00
1985	151.00
1990	131.00

The Dalian Steel Works was established in 1937. The plant's main products are high quality and special steels with an annual output of 300 thousand tons. The No. 2 rolling mill is one of the major workshops within the plant producing quality medium process steel used for carbon and alloy structural steel, carbon tool steel, spring steel, ball bearing steel, and stainless steel. Annual output from the No. 2 roller mill is 120 thousand tons.

Technology Assessment

Current Technology: In the typical rolling process, heated cast steel is rough rolled into billet. The rough rolled billet is stacked and cooled. Billet is then reheated in the reheating furnace to 1250°C and transferred to the fine roller mill, straightened, trimmed and bound as finished product.

The No. 2 rolling mill at Dalian uses a 3-zone pusher type reheating furnace to reheat the billet. The process uses heavy oil as fuel with an annual consumption of 6,000 tons. The reheating furnace is 23.4m long and 2.3m wide with a heating capacity of 32 tons per hour. It is equipped with a one fin metallic recuperator, two combustion fans, and one exhaust fan.

The primary disadvantages of the current reheating furnace are: 1) a short body life of the furnace with repairs required monthly, 2) poor heat exchange with reheating temperature limitations, 3) impeded exhaust systems with substantial heat transfer loss from burners, 4) insufficient oil feeding capacity, and 5) heat loss from cooling water tubes.

Proposed Technology: With the proposed project, a single mold furnace body is used for tightness and to reduce heat loss and service requirements. A tubular recuperator is substituted for the original fin type recuperator, increasing the preheating temperature of combustion air up to 450°C with decreased energy consumption. By enlarging the flue at the bottom of the exhaust chimney, fume exhaust resistance is decreased eliminating the need for the high temperature exhaust fan. Finally, new burners are used to improve the atomizing effect of the heavy oil thereby increasing combustion efficiency, reducing energy consumption, and decreasing pollution.

The net effect from modification of the reheating furnace is to:

- 1) increase the furnace temperature from 154 to 450°C,
- 2) eliminate the need for one 55 kw exhaust fan, and
- 3) increase monthly production capacity by 1000 tons.

Financial Analysis

Investment costs for the project are expected to be 912,000 RMB yuan as indicated in Table 2. The first construction phase that was to begin in October 1993 is scheduled to last three years. The second phase scheduled for 1999 is projected to last for two years. Principal costs include the new furnace body and air heat exchange unit. The without project case also is projected to require a new furnace body and air heat exchange unit. Total investment costs without the project are projected to be 630,000 RMB yuan.

Table 2. Investment With and Without Project (1,000 yuan)

Items	With project	Without project	Incremental
1. Furnace body	505.00	300.00	205.00
2. Air heating exchanger	200.00	220.00	(20.00)
3. Burner	90.00	50.00	40.00
4. Fuel oil reheater	25.00		25.00
5. Lifter	12.00		12.00
6. Instruments	80.00	60.00	20.00
7. Total	912.00	630.00	282.00

* Current furnace requires overhaul once every 4 years of 2 months duration.

Production indicators with and without the project are indicated in Table 3. Total sales are projected to increase by 10.3 percent from 110,100 to 121,400 tons. Sales are less than total processed steel to account for trimming. Energy use per ton is projected to decrease by 10.9 percent with decreases in fuel oil, power, and steam consumption. Total energy use is expected to decrease by 237.5 tce despite increased output.

Table 3. Major Production Indicators With and Without Project

Items	Conversion factor	With project	Without project	Incremental
Sales income (yuan/t)		1600.00	1600.00	0.00
Total sales (1000 t)		121.40	110.10	11.30
I. Energy use per ton steel (kgce)		89.89	100.86	(10.97)
1. Fuel oil (kg)	1.3558	40.12	45.00	(4.88)
2. Oxygen (m ³)	0.3222	2.70	2.70	0.00
3. Power (kwh)	0.4040	43.40	49.00	(5.60)
4. Steam (kg)	0.0942	172.00	193.00	(21.00)
5. Water (t)	0.3704	2.40	2.70	(0.30)
II. Total steel processing (1000 t)		132.00	120.00	12.00
III. Steel use (1000 t)		132.00	120.00	12.00
IV. Total energy use (tce)		11865.24	12102.72	(237.48)
1. Fuel oil (t)	1.3558	5295.84	5400.00	(104.16)
2. Oxygen (1000 m ³)	0.3222	356.40	324.00	32.40
3. Power (mwh)	0.4040	5728.80	5880.00	(151.20)
4. Steam (t)	0.0942	22704.00	23160.00	(456.00)
5. Water (1000 t)	0.3704	316.80	324.00	(7.20)

Operating costs with and without the project are shown in Table 4. Total operating costs decrease by 5.3 percent with the project. Feedstock costs remain constant at 1045 yuan per ton. Energy costs decrease by 10.8 percent with the majority of those savings in fuel oil. Other operating costs in labour, repairs and miscellaneous expenses decrease by 9.1 percent with the project.

Table 4. Operating Costs With and Without Project (yuan/ton steel)

Items	Unit price	With project	Without project	Incremental
I. Energy use		26.72	29.96	(3.23)
1. Fuel oil (t)	350.00	14.04	15.75	(1.71)
2. Oxygen (1000 m ³)	260.00	0.70	0.70	0.00
3. Power (mwh)	200.00	8.68	9.80	(1.12)
4. Steam (t)	15.00	2.58	2.90	(0.32)
5. Water (1000 t)	300.00	0.72	0.81	(0.09)
II. Steel use (t)	1000.00	1045.45	1045.45	0.00
III. Salary and welfare		18.61	20.47	(1.86)
IV. Repairs		38.58	42.43	(3.86)
V. Others		37.16	40.88	(3.72)
Total		1116.52	1179.19	(12.67)

Cash flow tables with and without the project appear as Tables 5 and 6. Total costs increase to 148.0 million yuan at full production with the project compared with 136.1 million yuan without the project, an 8.8 percent increase. Increased costs reflect both a ten percent increase in raw material consumption offset by a 10.3 percent increase in output. Per unit energy savings are realized as indicated above.

Table 5. Cash Flow Analysis With Project (million yuan)

Year	Invest costs	Operating Costs					Total	Total Costs	Total Benefits	Net Benefits
		Energy	Material	Salary	Repairs	Others				
1	0.91			2.46		4.91	7.37	8.28		(8.28)
2		3.53	132.00	2.46	5.09	4.91	147.98	147.98	194.24	46.26
3		3.53	132.00	2.46	5.09	4.91	147.98	147.98	194.24	46.26
4		3.53	132.00	2.46	5.09	4.91	147.98	147.98	194.24	46.26
5		3.53	132.00	2.46	5.09	4.91	147.98	147.98	194.24	46.26
6		3.53	132.00	2.46	5.09	4.91	147.98	147.98	194.24	46.26
7		3.53	132.00	2.46	5.09	4.91	147.98	147.98	194.24	46.26
8		3.53	132.00	2.46	5.09	4.91	147.98	147.98	194.24	46.26
9		3.53	132.00	2.46	5.09	4.91	147.98	147.98	194.24	46.26
10		3.53	132.00	2.46	5.09	4.91	147.98	147.98	194.24	46.26
11		3.53	132.00	2.46	5.09	4.91	147.98	147.98	194.24	46.26
12		3.53	132.00	2.46	5.09	4.91	147.98	147.98	194.24	46.26
13		3.53	132.00	2.46	5.09	4.91	147.98	147.98	194.24	46.26
14		3.53	132.00	2.46	5.09	4.91	147.98	147.98	194.24	46.26
15		3.53	132.00	2.46	5.09	4.91	147.98	147.98	194.24	46.26
16		3.53	132.00	2.46	5.09	4.91	147.98	147.98	194.24	46.26
Total	0.91	52.91	1,980.00	39.30	76.38	78.48	2,227.08	2,227.99	2,913.60	685.61
PV	0.89	42.51	1,590.73	31.16	59.65	62.23	1,740.72	1,741.61	2,275.47	533.97

Table 6. Cash Flow Analysis Without Project (million yuan)

Year	Invest costs	Operating Costs					Total	Total Costs	Total Benefits	Net Benefits
		Energy	Material	Salary	Repairs	Others				
1	0.63	1.20	40.00	2.46	1.70	4.91	50.27	50.90	58.72	7.82
2		3.59	120.00	2.46	5.09	4.91	136.05	136.05	176.16	40.11
3		3.59	120.00	2.46	5.09	4.91	136.05	136.05	176.16	40.11
4		3.59	120.00	2.46	5.09	4.91	136.05	136.05	176.16	40.11
5		3.59	120.00	2.46	5.09	4.91	136.05	136.05	176.16	40.11
6		3.59	120.00	2.46	5.09	4.91	136.05	136.05	176.16	40.11
7		3.59	120.00	2.46	5.09	4.91	136.05	136.05	176.16	40.11
8		3.59	120.00	2.46	5.09	4.91	136.05	136.05	176.16	40.11
9		3.59	120.00	2.46	5.09	4.91	136.05	136.05	176.16	40.11
10		3.59	120.00	2.46	5.09	4.91	136.05	136.05	176.16	40.11
11		3.59	120.00	2.46	5.09	4.91	136.05	136.05	176.16	40.11
12		3.59	120.00	2.46	5.09	4.91	136.05	136.05	176.16	40.11
13		3.59	120.00	2.46	5.09	4.91	136.05	136.05	176.16	40.11
14		3.59	120.00	2.46	5.09	4.91	136.05	136.05	176.16	40.11
15		3.59	120.00	2.46	5.09	4.91	136.05	136.05	176.16	40.11
16		3.59	120.00	2.46	5.09	4.91	136.05	136.05	176.16	40.11
Total	0.63	55.12	1,840.00	39.30	78.08	78.49	2,090.98	2,091.61	2,701.12	609.57
PV	0.61	43.28	1,444.65	31.16	61.30	62.23	1,642.63	1,643.24	2,120.75	477.57

Table 7 depicts incremental cash flow with and without the project. The payback period for the project is four years (three years after renovation). Net present value of the project is 76.1 million yuan, and the internal rate of return is 37.9 percent. These figures differ slightly from figures used in the summary report as this case has been updated since the initial figures were published.

Where furnace replacement is required, upgrading to a more efficient reheating furnace at time a very viable undertaking at 1990 energy prices. Further energy price increases will make this investment still more viable.

Table 7. Incremental Cash Flow Analysis With and Without Project (million yuan)

Year	Invest costs	Operating Costs					Total	Total Costs	Total Benefits	Net Benefits
		Energy	Material	Salary	Repairs	Others				
1	0.28	(1.20)	(40.00)	0.00	(1.70)	0.00	(42.90)	(42.61)	(58.72)	(16.11)
2	0.00	(0.07)	12.00	0.00	0.00	0.00	11.93	11.93	18.08	6.15
3	0.00	(0.07)	12.00	0.00	0.00	0.00	11.93	11.93	18.08	6.15
4	0.00	(0.07)	12.00	0.00	0.00	0.00	11.93	11.93	18.08	6.15
5	0.00	(0.07)	12.00	0.00	0.00	0.00	11.93	11.93	18.08	6.15
6	0.00	(0.07)	12.00	0.00	0.00	0.00	11.93	11.93	18.08	6.15
7	0.00	(0.07)	12.00	0.00	0.00	0.00	11.93	11.93	18.08	6.15
8	0.00	(0.07)	12.00	0.00	0.00	0.00	11.93	11.93	18.08	6.15
9	0.00	(0.07)	12.00	0.00	0.00	0.00	11.93	11.93	18.08	6.15
10	0.00	(0.07)	12.00	0.00	0.00	0.00	11.93	11.93	18.08	6.15
11	0.00	(0.07)	12.00	0.00	0.00	0.00	11.93	11.93	18.08	6.15
12	0.00	(0.07)	12.00	0.00	0.00	0.00	11.93	11.93	18.08	6.15
13	0.00	(0.07)	12.00	0.00	0.00	0.00	11.93	11.93	18.08	6.15
14	0.00	(0.07)	12.00	0.00	0.00	0.00	11.93	11.93	18.08	6.15
15	0.00	(0.07)	12.00	0.00	0.00	0.00	11.93	11.93	18.08	6.15
16	0.00	(0.07)	12.00	0.00	0.00	0.00	11.93	11.93	18.08	6.15
Total	0.28	(2.21)	140.00	0.00	(1.70)	0.00	136.10	136.38	212.48	76.10
PV	0.27	(1.95)	101.69	0.00	(1.65)	0.00	98.09	98.36	154.72	56.36
IRR										37.86%

Energy Conservation

As indicated in Table 8, the proposed project reduces annual energy use for steel processing from 12.1 to 11.8 tce, a 2.0 percent energy saving despite a 10 percent increase in output. Adjusting for output change, 1,448 tce of energy savings are realized. The bulk of those savings are direct savings, while 132 tce are indirect energy savings due to higher output levels. Energy savings are realized in terms of fuel oil, power, steam, and water use.

Table 8. Energy Use With and Without Project

Items	With project	Without project	Incremental
I. Total energy use (tce)	11865.24	12102.72	(237.48)
1. Fuel oil (t)	5295.84	5400.00	(104.16)
2. Oxygen (1000 m ³)	356.40	324.00	32.40
3. Power (mwh)	5728.80	5880.00	(151.20)
4. Steam (t)	22704.00	23160.00	(456.00)
5. Water (1000 t)	316.80	324.00	(7.20)
II. Energy savings	<u>Direct</u>	<u>Indirect</u>	<u>Total</u>
1. Fuel oil (t)	585.60	58.56	644.16
2. Oxygen (1000 m ³)	0.00	0.00	0.00
3. Power (mwh)	672.00	67.20	739.20
4. Steam (t)	2520.00	252.00	2772.00
5. Water (1000 t)	36.00	3.60	39.60
Total energy savings (tce)	1316.14	131.61	1447.76

Environmental Benefits

Per unit CO₂ emissions decrease from 56.65 to 50.48 kg/ton output, a 10.9 percent decrease as indicated in Table 9. Adjusting for output, total emissions decline 814 tons per year. Of that figure 740 tons are direct CO₂ reductions, while 74 are indirect CO₂ effects. SO₂ emissions are expected to decrease by 13.5 tons per year, and TSP is projected to decline by 12.2 tons per year.

Table 9. Environmental Impacts With and Without Project

Items	With project	Without project	Incremental
I. Per unit emissions			
1. CO2 (kg)	50.48	56.65	(6.17)
2. SO2 (kg)	0.83	0.94	(0.10)
3. TSP (kg)	0.91	0.85	(0.09)
4. NOx (kg)	--	--	--
II. Total emissions			
1. CO2 (t)	6663.98	6798.16	(748.62)
2. SO2 (t)	109.96	112.22	(12.40)
3. TSP (t)	99.47	101.51	(11.22)
4. NOx (t)	--	--	--
III. Emissions reduction	<u>Direct</u>	<u>Indirect</u>	<u>Total</u>
1. CO2 (t)	739.99	74.00	813.99
2. SO2 (t)	12.26	1.23	13.49
3. TSP (t)	11.09	1.11	12.19
4. NOx (t)	--	--	--
Emission factor	Oil (kg/t)	Power (kg/MWh)	Others (kg/tce)
1. CO2 (kg)	590.47	304.98	754.91
2. SO2 (kg)	*	9.48	23.47
3. TSP (kg)	*	8.58	21.23
4. NOx (kg)	-	-	-

Economic/Environmental Assessment

Table 10 depicts the economic/environmental cash flow for the project. Using economic prices, the internal rate of return increases from 37.86 to 39.78 percent reflecting slightly higher energy prices. The addition of local air pollution benefits does not increase the rate of return in this case. Adjusting for output in Table 11, the incremental cost of CO₂ reduction is -7,169 RMB yuan per ton reflecting both emissions reduction and cost savings. Net benefits per ton CO₂ reduction are positive ranging from 1154.21 to 1158.17 RMB yuan with local environmental benefits included. Again, the figures used here are slightly updated from the figures released earlier in the summary report although the differences are not substantial.

Table 10. Incremental Economic/Environmental Cash Flow Analysis (million yuan)

Year	Total Costs	Total Benefits	Net Benefits	Emissions			Econ Value of Local Pollution Reduction	Net Economic/ Environmenta l Benefits
				Global CO2 (t)	Local SO2 (t)	Local TSP (t)		
1	(43.26)	(58.72)	(15.46)	0.00	0.00	0.00	0.0000	(15.46)
2	11.89	18.08	6.19	(134.17)	(2.26)	(2.04)	0.0005	6.19
3	11.89	18.08	6.19	(134.17)	(2.26)	(2.04)	0.0005	6.19
4	11.89	18.08	6.19	(134.17)	(2.26)	(2.04)	0.0005	6.19
5	11.89	18.08	6.19	(134.17)	(2.26)	(2.04)	0.0005	6.19
6	11.89	18.08	6.19	(134.17)	(2.26)	(2.04)	0.0005	6.19
7	11.89	18.08	6.19	(134.17)	(2.26)	(2.04)	0.0005	6.19
8	11.89	18.08	6.19	(134.17)	(2.26)	(2.04)	0.0005	6.19
9	11.89	18.08	6.19	(134.17)	(2.26)	(2.04)	0.0005	6.19
10	11.89	18.08	6.19	(134.17)	(2.26)	(2.04)	0.0005	6.19
11	11.89	18.08	6.19	(134.17)	(2.26)	(2.04)	0.0005	6.19
12	11.89	18.08	6.19	(134.17)	(2.26)	(2.04)	0.0005	6.19
13	11.89	18.08	6.19	(134.17)	(2.26)	(2.04)	0.0005	6.19
14	11.89	18.08	6.19	(134.17)	(2.26)	(2.04)	0.0005	6.19
15	11.89	18.08	6.19	(134.17)	(2.26)	(2.04)	0.0005	6.19
16	11.89	18.08	6.19	(134.17)	(2.26)	(2.04)	0.0005	6.19
Total	135.11	212.48	77.37	(2,012.62)	(33.89)	(30.66)	0.00	77.38
PV	97.25	154.72	57.47	(1,571.83)	(26.47)	(23.94)	0.00	57.48
IRR			39.78%					39.78%

**Table 11. Incremental Economic/Environmental Cash Flow Analysis
Adjusted for Output (million yuan)**

Year	Total	Total	Net	Global	Emissions	Local	Econ Value	Net
	Costs	Benefits	Benefits	CO2	Local	TSP	of Local	Economic/ Environmenta l
				(t)	(t)	(t)	Reduction	Benefits
1	(43.29)	(58.72)	(15.43)	0.00	0.00	0.00	0.0000	(15.43)
2	(1.71)	0.42	2.13	(0.74)	(12.26)	(11.09)	0.0029	2.14
3	(1.71)	0.42	2.13	(0.74)	(12.26)	(11.09)	0.0029	2.14
4	(1.71)	0.42	2.13	(0.74)	(12.26)	(11.09)	0.0029	2.14
5	(1.71)	0.42	2.13	(0.74)	(12.26)	(11.09)	0.0029	2.14
6	(1.71)	0.42	2.13	(0.74)	(12.26)	(11.09)	0.0029	2.14
7	(1.71)	0.42	2.13	(0.74)	(12.26)	(11.09)	0.0029	2.14
8	(1.71)	0.42	2.13	(0.74)	(12.26)	(11.09)	0.0029	2.14
9	(1.71)	0.42	2.13	(0.74)	(12.26)	(11.09)	0.0029	2.14
10	(1.71)	0.42	2.13	(0.74)	(12.26)	(11.09)	0.0029	2.14
11	(1.71)	0.42	2.13	(0.74)	(12.26)	(11.09)	0.0029	2.14
12	(1.71)	0.42	2.13	(0.74)	(12.26)	(11.09)	0.0029	2.14
13	(1.71)	0.42	2.13	(0.74)	(12.26)	(11.09)	0.0029	2.14
14	(1.71)	0.42	2.13	(0.74)	(12.26)	(11.09)	0.0029	2.14
15	(1.71)	0.42	2.13	(0.74)	(12.26)	(11.09)	0.0029	2.14
16	(1.71)	0.42	2.13	(0.74)	(12.26)	(11.09)	0.0029	2.14
Total	(68.98)	(52.39)	16.59	(11.10)	(183.84)	(166.29)	0.04	16.63
PV	(62.15)	(52.14)	10.01	(8.67)	(143.58)	(129.87)	0.03	10.04
					<u>CO2</u>	<u>COAL</u>		
Total Incremental Cost/Ton of CO2 Reduction (yuan at 12%))					(7168.90)	(4030.67)		
At RMB/US\$ = 5.50					(\$1303.44)	(\$732.85)		
Total Net Benefits/Ton of CO2 Reduction (yuan at					1154.21	648.95		
At RMB/US\$ = 5.50					\$209.86	\$117.99		
Net Benefits Incl'g Local Env. Benefits/Ton of CO2					1158.17	651.17		
At RMB/US\$ = 5.50					\$210.5826	\$118.40		

Metallurgy Industry: Case 4

Blast Furnace Gas Recovery for Co-generation at Xingtai Steel Works

Introduction

Pig iron is an essential component of the iron and steel industry. Typically, pig iron is produced in blast furnaces in which iron ore, coke, and flux are combined with hot air blown in from the bottom of the furnace. The coke and hot air combine to raise furnace temperature to 1700-1800°C reducing the iron ore and producing molten pig iron to deliver to the steelmaking shop. The process generates CO-enriched gas within the furnace. On average 2000-2200 m³ of by-product gas is generated per ton of pig iron smelted. The waste heat in the gas amounts to 40 percent of the heat value of the coke consumed (3600KJ/m³).

In integrated iron and steel works, steel ingot and billet have to be heated several times during the production process. The option exists then to convert the waste gas from pig iron production to usable energy for later steelmaking stages. Using co-generation technology, surplus blast furnace gas is recovered to drive steam generators. In plants producing only pig iron or primarily pig iron, this option is not feasible, and the waste gas is released as a net loss.

The case study site for blast furnace gas recovery is Xingtai Steel Works. The enterprise is a medium-sized iron and steel operation with 4 blast furnaces, 4 sintering machines, 3 coke oven batteries, and 1 bar rolling workshop. In 1991, Xingtai Steel Works produced 504.8 thousand tons of pig iron, 84.8 thousand tons of wire bar, and 8400 tons of cast steel pipe. Output was valued at 430 million RMB yuan; annual energy consumption was 525.4 thousand tce.

Technology Assessment

Current Technology: Xingtai Steel Works has four blast furnaces (215 m³ x 3, 300 m³ x 1) with annual production capacity of 600 thousand tons of pig iron. Because of raw material constraints, the plant is operating below capacity with 1991 production of 500 thousand tons.

The discharge of blast furnace gas at Xingtai Steel Works has been increasing in recent years from 18.0 percent of the total in 1989 to 22.0 percent in 1990 and to 26.9 percent in 1991 as production has increased. By-product gas is 2100 m³ per ton of pig iron produced.

Because pig iron is the primary product at Xingtai, there are few downstream consumers as would be the case with a higher concentration of steel production where blast furnace gas is more likely to be recycled. Still, power consumption in 1991 amounted to 166.97 million kwh. The majority of that power (69.3 percent) was purchased at the planned price. All additional power above the 115.76 gwh allocation is purchased at market prices. With convergence of market and planned prices and capacity constraints on electricity generation, co-generation becomes increasingly attractive for iron works like Xingtai that previously would have been content to release waste blast furnace gas.

Proposed Technology: To make full use of surplus blast furnace gas, Xingtai Steel is planning to install a new exhaust power generator with 6000 kw capacity. The turbine generator will be supplied by a new 35 ton/hour boiler fueled by blast furnace gas. Specifications appear below.

Boiler Type: DHS35/450-Q,
Fuel: 100% blast furnace gas,
Rated evaporative capacity: 35 t/h,
Steam pressure: 40 ata.

Turbine type: C6-35/5 exhaust heat supply set,
Power: 6000 kw, rotating speed 3000 rpm,
Steam inlet pressure: 35 ata,
Temperature: 435°C,
Steam: 57.6 t/h,
Industrial steam exhaust pressure: 5 ata,
Steam outlet pressure: 0.073 ata.

With co-generation of surplus blast furnace gas, the amount of power purchased is decreased. All of the power replaced is purchased currently at market prices. During the winter months, 4,200 kwh power will be generated with 20 tons/hour of exhaust steam. In the summer months, 6,000 kw power will be generated with 8 tons/hour discharged. The heat recovery also allows the plant to shut down 11 small coal-fired boilers with an annual savings of 15 thousand tons of steam coal.

Table 1. Major Production Indicators With and Without Project

Items	Unit	With project	Without project
1. Boilers	t/h	35.00	60.00
2. Generator	kw	6000.00	
3. Total heat use	1000 t	121.70	121.70
4. Total electricity use	gwh	176.51	176.51
5. Total coal use	t		15.75
6. Total gas use	tce	29.95	
7. Total generation	gwh	33.82	0.00
8. Total heat supply	1000 t	87.20	87.20
9. Steam price	yuan/t	26.15	26.15
10. Electricity price	yuan/mwh	180.00	180.00

Financial Analysis

The investment cost for the project is 17.4 million RMB yuan as indicated in Table 2. Half of that cost (8.2 million yuan) is for the steam system. The construction period is expected to be two years beginning in the second half of 1991 and ending in the first half of 1993. Production start up is scheduled for the second half of 1993 with design capacity reached in 1994.

Table 2. Investment With and Without Project (1,000 yuan)

Items	With project	Without project
1. Steam system	8,181.00	
2. Fuel supply system	645.00	
3. Water processing	1,679.00	
4. Water supply	202.10	
5. Electrical system	1,133.00	
6. Thermal control	875.00	
7. Other equipment	2,001.00	
8. Intangible fee	883.00	
9. Overhead	1,846.00	
10. Total	17,445.10	0.00
Investment schedule		
First year	5,233.53	
Second year	8,722.55	
Third year	3,489.02	
Total	17,445.10	

At full operation, operating costs for the project are projected to be 1.79 million RMB yuan well below the cost of comparable heat and power of 8.37 million RMB yuan. Principal operating costs include water, repairs, and salary.

Table 3. Operating Costs With Project (1,000 yuan)

Items	Unit	Price	Use	Costs
1. Fuel	Mm ³	0.00	238.00	0.00
2. Water	1,000 t	200.00	1,120.00	224.00
3. Materials				118.20
4. Repairs				393.60
5. Salary & welfare	person	2,850.00	75.00	213.75
6. Other				843.10
7. Total				1,792.65
8. Heat supply cost without project	(yuan/t)			1.17
9. Total cost without project				1690.66
10. Incremental costs with project				101.99
11. Generation costs (yuan/mwh)				49.99

The cash flow analysis is a partial analysis based on power substitution of generated power for purchased power. At full operation, the project will generate 33.8 million kwh electricity. This power will substitute for a portion of the 54.2 million kwh of electricity currently purchased at negotiated prices above allocations at planned and guiding prices. The market price for electricity in 1990 prices was 23 fen/kwh. The total value of heat and power substitution is 8.37 million RMB yuan.

Table 4. Cash Flow Analysis With Project (1,000 Yuan)

Year	Investment costs	Operating Costs					Sub-total	Heat purchase	Power purchase	Total Costs
		Water	Material	Repairs	Salary	Others				
1	5233.53						0.00	2280.28	6087.60	13601.41
2	8722.55						0.00	2280.28	6087.60	17090.43
3	3489.02	62.00	32.90	393.60	210.00	781.10	1479.60	1365.03	5396.40	11730.05
4		224.00	118.20	393.60	213.75	843.10	1792.65			1792.65
5		224.00	118.20	393.60	213.75	843.10	1792.65			1792.65
6		224.00	118.20	393.60	213.75	843.10	1792.65			1792.65
7		224.00	118.20	393.60	213.75	843.10	1792.65			1792.65
8		224.00	118.20	393.60	213.75	843.10	1792.65			1792.65
9		224.00	118.20	393.60	213.75	843.10	1792.65			1792.65
10		224.00	118.20	393.60	213.75	843.10	1792.65			1792.65
11		224.00	118.20	393.60	213.75	843.10	1792.65			1792.65
12		224.00	118.20	393.60	213.75	843.10	1792.65			1792.65
13		224.00	118.20	393.60	213.75	843.10	1792.65			1792.65
14		224.00	118.20	393.60	213.75	843.10	1792.65			1792.65
15		224.00	118.20	393.60	213.75	843.10	1792.65			1792.65
16		224.00	118.20	393.60	213.75	843.10	1792.65			1792.65
17		224.00	118.20	393.60	213.75	843.10	1792.65			1792.65
18		224.00	118.20	393.60	213.75	843.10	1792.65			1792.65
19		224.00	118.20	393.60	213.75	843.10	1792.65			1792.65
20		224.00	118.20	393.60	213.75	843.10	1792.65			1792.65
21		224.00	118.20	393.60	213.75	843.10	1792.65			1792.65
22		224.00	118.20	393.60	213.75	843.10	1792.65			1792.65
23		224.00	118.20	393.60	213.75	843.10	1792.65			1792.65
Total	17445.10	4542.00	2396.90	8265.60	4485.00	17643.00	37332.60	5925.59	17571.60	78274.89
PV	14109.77	1235.05	651.84	2372.77	1285.90	5038.40	10583.96	4825.39	14129.41	43648.53

Table 5. Cash Flow Analysis Without Project (1,000 yuan)

Year	Total investment	Operating Costs					Sub-total	Heat purchase	Power purchase	Total Costs
		Water	Material	Repairs	Salary	Others				
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2280.28	6087.60	8367.88
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2280.28	6087.60	8367.88
3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2280.28	6087.60	8367.88
4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2280.28	6087.60	8367.88
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2280.28	6087.60	8367.88
6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2280.28	6087.60	8367.88
7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2280.28	6087.60	8367.88
8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2280.28	6087.60	8367.88
9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2280.28	6087.60	8367.88
10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2280.28	6087.60	8367.88
11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2280.28	6087.60	8367.88
12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2280.28	6087.60	8367.88
13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2280.28	6087.60	8367.88
14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2280.28	6087.60	8367.88
15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2280.28	6087.60	8367.88
16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2280.28	6087.60	8367.88
17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2280.28	6087.60	8367.88
18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2280.28	6087.60	8367.88
19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2280.28	6087.60	8367.88
20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2280.28	6087.60	8367.88
21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2280.28	6087.60	8367.88
22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2280.28	6087.60	8367.88
23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2280.28	6087.60	8367.88
Total	0.00	0.00	0.00	0.00	0.00	0.00	0.00	50166.16	133927.20	184093.40
PV	0.00	0.00	0.00	0.00	0.00	0.00	0.00	13896.63	37099.40	50996.10

The incremental cash flow analysis with and without the project is shown in Table 6, the project has a six year payback period (three years beyond construction). The net present value of the project is 20.94 million yuan with an internal rate of return of 28.2 percent. The project appears to be viable as a power substitution project despite the limited amount of steel production within the plant to make direct use of the waste energy. The project is sensitive to electricity price becoming more viable still with higher electricity prices.

Table 6. Incremental Cash Flow Analysis With and Without Project (1,000 yuan)

Operating Costs	
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Year	Total investment	Water	Material	Repairs	Salary	Others	Sub-total	Heat purchase	Power purchase	Total Costs
1	5233.53	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5233.53
2	8722.55	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8722.55
3	3489.02	62.00	32.90	393.60	210.00	781.10	1479.60	(915.25)	(691.20)	3362.17
4	0.00	224.00	118.20	393.60	213.75	843.10	1792.65	(2280.28)	(6087.60)	(6575.23)
5	0.00	224.00	118.20	393.60	213.75	843.10	1792.65	(2280.28)	(6087.60)	(6575.23)
6	0.00	224.00	118.20	393.60	213.75	843.10	1792.65	(2280.28)	(6087.60)	(6575.23)
7	0.00	224.00	118.20	393.60	213.75	843.10	1792.65	(2280.28)	(6087.60)	(6575.23)
8	0.00	224.00	118.20	393.60	213.75	843.10	1792.65	(2280.28)	(6087.60)	(6575.23)
9	0.00	224.00	118.20	393.60	213.75	843.10	1792.65	(2280.28)	(6087.60)	(6575.23)
10	0.00	224.00	118.20	393.60	213.75	843.10	1792.65	(2280.28)	(6087.60)	(6575.23)
11	0.00	224.00	118.20	393.60	213.75	843.10	1792.65	(2280.28)	(6087.60)	(6575.23)
12	0.00	224.00	118.20	393.60	213.75	843.10	1792.65	(2280.28)	(6087.60)	(6575.23)
13	0.00	224.00	118.20	393.60	213.75	843.10	1792.65	(2280.28)	(6087.60)	(6575.23)
14	0.00	224.00	118.20	393.60	213.75	843.10	1792.65	(2280.28)	(6087.60)	(6575.23)
15	0.00	224.00	118.20	393.60	213.75	843.10	1792.65	(2280.28)	(6087.60)	(6575.23)
16	0.00	224.00	118.20	393.60	213.75	843.10	1792.65	(2280.28)	(6087.60)	(6575.23)
17	0.00	224.00	118.20	393.60	213.75	843.10	1792.65	(2280.28)	(6087.60)	(6575.23)
18	0.00	224.00	118.20	393.60	213.75	843.10	1792.65	(2280.28)	(6087.60)	(6575.23)
19	0.00	224.00	118.20	393.60	213.75	843.10	1792.65	(2280.28)	(6087.60)	(6575.23)
20	0.00	224.00	118.20	393.60	213.75	843.10	1792.65	(2280.28)	(6087.60)	(6575.23)
21	0.00	224.00	118.20	393.60	213.75	843.10	1792.65	(2280.28)	(6087.60)	(6575.23)
22	0.00	224.00	118.20	393.60	213.75	843.10	1792.65	(2280.28)	(6087.60)	(6575.23)
23	0.00	224.00	118.20	393.60	213.75	843.10	1792.65	(2280.28)	(6087.60)	(6575.23)
Total	17445.10	4542.00	2396.90	8265.60	4485.00	17643.10	37332.60	(46520.85)	(122443.20)	(114186.35)
PV	14109.77	1235.05	651.84	2372.77	1285.90	5038.40	10583.96	(12774.80)	(32857.33)	(20938.40)
IRR										28.21%

Energy Conservation

Total energy use decreases by 45.4 percent from 54,866 tce without the project to 29,954 tce with the project as indicated below in Table 7. Blast furnace gas recovery eliminates the need for 87,200 tons of steam and 33.8 gwh of electricity required under current operating conditions. Gas purchases are not affected by the project.

Table 7. Energy Use With and Without Project

Items	With project	Without project	Incremental
Total energy use (tce)	29954.00	54866.08	(24912.08)
1. Steam (1000 t)		87.20	(87.20)
2. Electricity (gwh)		33.82	(33.82)
3. Gas (million cubic meter)	238.00	238.00	0.00

Environmental Benefits

With the project, annual CO₂ emissions are expected to decrease by 62.0 percent from 41,419 tons to 15,741 tons as indicated in Table 8. Other emission levels decrease substantially as well. SO₂ emissions decrease by 91.4 percent, while NO_x and TSP emissions decrease by 45.4 percent and 82.0 percent, respectively.

Table 8. Environmental Impact With and Without Project

Items	Technical Adjustment Factor		Total Emissions		
	Factor	kg/kgce	With project	Without project	Incremental
1. CO ₂ (t)	525.50	754.91	15740.83	41418.95	(25678.13)
2. SO ₂ (t)	3.70	23.47	110.83	1287.71	(1176.88)
3. NO _x (t)	23.70	23.70	709.91	1300.33	(590.42)
4. TSP (t)	7.00	21.23	209.68	1164.81	(955.13)

Economic/Environmental Assessment

Table 9 depicts the economic/environmental cash flow for the project. Using economic prices, the internal rate of return increases 28.21 to 41.44 percent. The change

primarily reflects the conversion factor for electricity. Including local air pollution benefits with the project, the rate of return increases to 42.27 percent. After the project results are adjusted for output the incremental per ton cost of CO₂ reduction is -307.91 RMB yuan reflecting cost savings and emissions reduction. Net benefits per ton CO₂ reduction are the converse—307.91 RMB yuan. This value climbs to 318.61 RMB yuan when local environmental benefits are considered.

Table 9. Incremental Economic/Environmental Cash Flow Analysis (1000 yuan)

Year	Total	Net	Global	Emissions	Local	Econ Value	Net
	Costs	Benefits	CO ₂	Local	TSP	of Local	Economic/ Environmental
			(t)	SO ₂	(t)	Reduction	Benefits
1	5,233.53	(5,233.53)	0.00	0.00	0.00	0.00	(5,233.53)
2	8,722.55	(8,722.55)	0.00	0.00	0.00	0.00	(8,722.55)
3	2,880.37	(2,880.37)	(4.27)	(0.20)	(0.16)	45.73	(2,834.64)
4	(10,655.01)	10,655.01	(25.68)	(1.18)	(0.96)	274.89	10,929.89
5	(10,655.01)	10,655.01	(25.68)	(1.18)	(0.96)	274.89	10,929.89
6	(10,655.01)	10,655.01	(25.68)	(1.18)	(0.96)	274.89	10,929.89
7	(10,655.01)	10,655.01	(25.68)	(1.18)	(0.96)	274.89	10,929.89
8	(10,655.01)	10,655.01	(25.68)	(1.18)	(0.96)	274.89	10,929.89
9	(10,655.01)	10,655.01	(25.68)	(1.18)	(0.96)	274.89	10,929.89
10	(10,655.01)	10,655.01	(25.68)	(1.18)	(0.96)	274.89	10,929.89
11	(10,655.01)	10,655.01	(25.68)	(1.18)	(0.96)	274.89	10,929.89
12	(10,655.01)	10,655.01	(25.68)	(1.18)	(0.96)	274.89	10,929.89
13	(10,655.01)	10,655.01	(25.68)	(1.18)	(0.96)	274.89	10,929.89
14	(10,655.01)	10,655.01	(25.68)	(1.18)	(0.96)	274.89	10,929.89
15	(10,655.01)	10,655.01	(25.68)	(1.18)	(0.96)	274.89	10,929.89
16	(10,655.01)	10,655.01	(25.68)	(1.18)	(0.96)	274.89	10,929.89
17	(10,655.01)	10,655.01	(25.68)	(1.18)	(0.96)	274.89	10,929.89
18	(10,655.01)	10,655.01	(25.68)	(1.18)	(0.96)	274.89	10,929.89
19	(10,655.01)	10,655.01	(25.68)	(1.18)	(0.96)	274.89	10,929.89
20	(10,655.01)	10,655.01	(25.68)	(1.18)	(0.96)	274.89	10,929.89
21	(10,655.01)	10,655.01	(25.68)	(1.18)	(0.96)	274.89	10,929.89
22	(10,655.01)	10,655.01	(25.68)	(1.18)	(0.96)	274.89	10,929.89
23	(10,655.01)	10,655.01	(25.68)	(1.18)	(0.96)	274.89	10,929.89
Total	(196,263.65)	196,263.65	(517.83)	(23.73)	(19.26)	5,543.51	201,807.16
PV	(42,971.88)	42,971.88	(139.56)	(6.40)	(5.19)	1,494.03	44,465.90
IRR		41.44%					42.27%
				<u>CO₂</u>		<u>COAL</u>	
Total Incremental Cost/Ton of CO ₂ Reduction (yuan at 12%)				(307.91)		(317.38)	
At RMB/US\$ = 5.50				(\$55.98)		(\$57.70)	
Total Net Benefits/Ton of CO ₂ Reduction (yuan at 12%)				307.91		317.38	
At RMB/US\$ = 5.50				\$55.98		\$57.70	
Net Benefits Incl'g Local Env. Benefits/Ton of CO ₂				318.61		328.41	
At RMB/US\$ = 5.50				\$57.93		\$59.71	

Metallurgy Industry: Case 5

Industrial Kiln Renovations at Shandong Aluminum Works

Introduction

Aluminum production accounts for over 50 percent of energy consumption by the non-ferrous metals industry in China. From bauxite mining through aluminum ingot production, energy consumption for one ton of aluminum amounts to 11.5 tce. Energy consumed in intermediate alumina production amounts to 35 percent of the total, while aluminum production accounts for 65 percent of energy use.

Many of China's aluminum plants were built in the 1950s and 1960s, often with processes and equipment from the former Soviet Union. Because of the high cost of both facilities and equipment, modifications to plants have been minimal, and the Chinese aluminum industry continues to operate at production efficiencies well below international standards. High production costs, recent increases in raw material costs, and environmental concern have focused attention on process improvements to increase process efficiencies. The current process technology using soda lime sintering uses three times the energy of the Bayer-sintering process and twice the energy of a combination process. The Bayer-sintering process is not being used in the Chinese aluminum industry at the present time. The proposed project calls for modifications at the Shandong Aluminum Works (SAW) to substitute a combined Bayer-sintering process for the current soda-lime sintering process.

Shandong Aluminum Works is located in the west-central part of the Shandong peninsula, 110 km from the provincial capital. The plant began operations in 1954 and now is one of the 500 largest enterprises in China. The annual capacity of the plant is 480,000 tons of alumina, 35,000 tons of electrolyzed aluminum, 1.1 million tons of cement, 6,000 tons of aluminum profile and 250 million beverage cans. Under current conditions, the cost of a ton of alumina is 1203 RMB yuan, and energy costs amount to 45.7 percent of alumina costs. Despite continuous process improvements over time, the plant remains outdated by international standards.

Technology Assessment

Current Technology: The "soda-lime sintering process" is used exclusively in China to produce alumina. In the typical production process, bauxite is extracted from ore, crushed and blended with lime, soda ash, and anthracite coal. Slurry is prepared from the ground raw materials and recycled water. The slurry is injected into a grog kiln and sintered at 1300°C. The grog then is conveyed to a digestion mill to produce sodium aluminite liquid. After carbonization and precipitation, aluminum hydroxide particles are produced. The aluminum hydroxide is calcined at a temperature of 1200°C to produce alumina.

The grog sintering process accounts for 54 percent of energy consumption in alumina production. The bulk of the remaining energy consumption is accounted for by calcination (over 11 percent), desilication (11 percent), and slurry preparation (9 percent).

Proposed Technology: The proposed project calls for a shift from the conventional sintering process to a Bayer and sintering combination process. The principal renovations include replacement of six of 16 rotary grog kilns. The modifications include flash heat drying and cyclone preheating technology, which are expected to reduce heat consumption by 30 percent. Only six of the kilns will be replaced at this time because of capital constraints. The kilns will be replaced one at a time to limit impacts on production.

The second part of the renovation involves the replacement of older rotary calciners with suspension calcines. One suspension calcine of 1300 tons per day capacity can substitute for three rotary kilns. Projected fuel savings amount to 45 kg of fuel oil per ton of alumina produced. After each advanced suspension calcine is built, three existing calciners will be dismantled. The remainder of the calciners will be replaced at a later date.

Financial Analysis

Production indicators with and without the project are indicated in Table 1. At full operation, production capacity is expected to increase from 470,000 to 500,000 tons per year. Accounting for actual production and self-use, annual sales are projected to be 419,000 tons with the project compared with 380,050 tons without the project. Sales income is projected to increase from 765.1 million to 831.3 million yuan with the project.

Table 1. Production Indicators With and Without Project

Items	With project	Without project
1. Production capacity (1000 t/year)	500.00	470.00
2. Real production (1000 t/year)	489.00	450.05
3. Total sales (1000 t/year)	419.00	380.05
Self-use	70.00	70.00
4. Sales price (yuan/t)	1700.00	1700.00
5. Sales costs (million yuan)	57.07	39.50
6. Sales income (million yuan)	831.30	765.08
7. Sales tax (million yuan)	90.44	17.86

Investment costs for the project are expected to be 248 million RMB yuan. Sixty percent of investment costs are for old equipment replacement. Principal equipment investment is for replacement of the grog kiln system at 31.5 million yuan and updating the calciner system at 46.3 million yuan. The first construction phase that was scheduled to begin in October 1993 and is slated to last three years. The second phase scheduled for 1999 is projected to last two years.

Per unit operating costs decrease by 6.0 percent from 1145 yuan per ton to 1076 yuan per ton as indicated in Table 2. The most substantial cost savings are for energy which decrease by 8.8 percent from 539 to 492 yuan per ton. The majority of those cost savings are for bituminous coal and fuel oil.

Table 2. Operating Costs With and Without Project Per Ton Al₂O₃ (yuan)

Items	With project	Without project	Incremental
I. Raw materials	368.34	382.33	-13.99
1. Alumina ore	169.75	169.75	-0.00
2. Limestone	22.40	22.95	-0.55
3. Alkali powder	155.00	168.69	-13.69
4. Others	21.19	20.94	0.25
II. Energy use	492.01	539.24	-47.22
1. Coke	36.50	37.23	-0.73
2. Bituminous coal	151.58	174.22	-22.64
3. Anthracite coal	28.00	28.30	-0.30
4. Fuel oil	42.23	64.37	-22.14
5. Power	121.90	120.74	1.16
6. Steam	111.80	114.39	-2.59
III. Other operating costs	215.39	223.31	-7.92
1. Salary and welfare	13.88	15.03	-1.16
2. Maintenance	65.32	72.08	-6.76
3. Sales costs	136.19	136.19	0.00
IV. Transfers*			
1. Depreciation	25.15	27.55	-2.39
2. Sales tax	90.44	17.86	72.58
3. Pollution levies	1.11	1.76	0.64
Total costs			
1. With transfers	1075.74	1144.87	-69.14
2. Without transfers	1075.74	1144.87	-66.74

- * Management costs are included in maintenance expenses.
 * Transfer payments include depreciation, taxes, and pollution fines.
 * Transfers are not included in the cash flow tables.

Cash flow tables with and without the project appear as Tables 3 and 4. Due to intermittent replacement and repair expenses, total costs vary from 532-548 million yuan with the project to 521-539 million yuan without the project. Because of increased output, total benefits increase from 765 to 831 million yuan at full production to more than offset increased production costs. Net benefits increase by approximately 25 percent although some variation occurs by year depending on annual replacement schedules.

Table 3. Financial Cash Flow Analysis With Project (million yuan)

Year	Investment			Operating Costs							Total Costs	Total benefits	Net benefits
	Old equip. replace	New invest.	Invest sub-total	Raw Material	Energy use	Repairs and Mainten.	Salary and Welfare	Other Oper'g costs	Total Oper'g costs				
1994	9.20	49.25	58.45	172.07	242.68	32.44	6.77	61.29	515.25	573.70	765.08	191.38	
1995	2.60	31.49	34.09	172.07	242.68	32.44	6.77	61.29	515.25	549.34	765.08	215.75	
1996	7.55		7.55	180.12	240.59	31.94	6.79	66.60	526.04	533.59	831.30	297.71	
1997	22.45		22.45	180.12	240.59	31.94	6.79	66.60	526.04	548.49	831.30	282.81	
1998	9.40		9.40	180.12	240.59	31.94	6.79	66.60	526.04	535.44	831.30	295.86	
1999	5.80		5.80	180.12	240.59	31.94	6.79	66.60	526.04	531.84	831.30	299.46	
2000	6.80	6.00	12.80	180.12	240.59	31.94	6.79	66.60	526.04	538.84	831.30	292.46	
2001	5.40		5.40	180.12	240.59	31.94	6.79	66.60	526.04	531.44	831.30	299.86	
2002	10.40		10.40	180.12	240.59	31.94	6.79	66.60	526.04	536.44	831.30	294.86	
2003	6.40		6.40	180.12	240.59	31.94	6.79	66.60	526.04	532.44	831.30	298.86	
2004	9.05	5.00	14.05	180.12	240.59	31.94	6.79	66.60	526.04	540.09	831.30	291.21	
2005	7.80		7.80	180.12	240.59	31.94	6.79	66.60	526.04	533.84	831.30	297.46	
2006	8.20		8.20	180.12	240.59	31.94	6.79	66.60	526.04	534.24	831.30	297.06	
2007	2.00	6.00	8.00	180.12	240.59	31.94	6.79	66.60	526.04	534.04	831.30	207.26	
2008	13.20		13.20	180.12	240.59	31.94	6.79	66.60	526.04	539.24	831.30	292.06	
2009	6.40		6.40	180.12	240.59	31.94	6.79	66.60	526.04	532.44	831.30	298.86	
2010	7.40		7.40	180.12	240.59	31.94	6.79	66.60	526.04	533.44	831.30	297.86	
2011	6.25		6.25	180.12	240.59	31.94	6.79	66.60	526.04	532.29	831.30	299.01	
2012	10.60		10.60	180.12	240.59	31.94	6.79	66.60	526.04	536.64	831.30	294.66	
2013	-6.50		-6.50	180.12	240.59	31.94	6.79	66.60	526.04	519.54	831.30	311.76	
Total	150.40	97.70	248.10	2881.90	3849.50	511.00	108.60	1321.40	10499.10	10747.30	16493.60	5746.30	
PV	62.10	74.50	136.50	1256.10	1677.90	222.70	47.30	488.50	3911.00	4047.50	6097.40	2050.00	

Table 4. Financial Cash Flow Analysis Without Project (million yuan)

Year	Investment			Operating Costs						Total Costs	Total benefits	Net benefits
	Old equip. replace	New invest.	Invest sub-total	Raw Material	Energy use	Repairs and Mainten.	Salary and welfare	Other Oper'g costs	Total Oper'g costs			
1994	24.20		24.20	172.07	242.68	32.44	6.77	61.29	515.25	539.45	765.08	225.63
1995	22.60		22.60	172.07	242.68	32.44	6.77	61.29	515.25	537.85	765.08	227.23
1996	23.80		23.80	172.07	242.68	32.44	6.77	61.29	515.25	539.05	765.08	226.03
1997	22.45		22.45	172.07	242.68	32.44	6.77	61.29	515.25	537.70	765.08	227.38
1998	9.40		9.40	172.07	242.68	32.44	6.77	61.29	515.25	524.65	765.08	240.43
1999	5.80		5.80	172.07	242.68	32.44	6.77	61.29	515.25	521.05	765.08	244.03
2000	10.80		10.80	172.07	242.68	32.44	6.77	61.29	515.25	526.05	765.08	239.03
2001	10.40		10.40	172.07	242.68	32.44	6.77	61.29	515.25	525.65	765.08	239.43
2002	10.40		10.40	172.07	242.68	32.44	6.77	61.29	515.25	525.65	765.08	239.43
2003	10.40		10.40	172.07	242.68	32.44	6.77	61.29	515.25	525.65	765.08	239.43
2004	9.05		9.05	172.07	242.68	32.44	6.77	61.29	515.25	524.30	765.08	240.78
2005	7.80		7.80	172.07	242.68	32.44	6.77	61.29	515.25	523.05	765.08	242.03
2006	12.20		12.20	172.07	242.68	32.44	6.77	61.29	515.25	527.45	765.08	237.63
2007	11.00		11.00	172.07	242.68	32.44	6.77	61.29	515.25	526.25	765.08	238.83
2008	13.20		13.20	172.07	242.68	32.44	6.77	61.29	515.25	528.45	765.08	236.63
2009	10.40		10.40	172.07	242.68	32.44	6.77	61.29	515.25	525.65	765.08	239.43
2010	7.40		7.40	172.07	242.68	32.44	6.77	61.29	515.25	522.65	765.08	242.43
2011	6.25		6.25	172.07	242.68	32.44	6.77	61.29	515.25	521.50	765.08	243.58
2012	10.60		10.60	172.07	242.68	32.44	6.77	61.29	515.25	525.85	765.08	239.23
2013	9.80		9.80	172.07	242.68	32.44	6.77	61.29	515.25	525.05	765.08	240.03
Total	248.00	0.00	248.00	2753.10	3882.90	519.00	108.30	1225.90	10305.00	10552.90	15301.70	4748.70
PV	113.20	0.00	113.20	1200.00	1692.50	226.20	47.20	457.80	3848.60	3961.80	5714.70	1752.90

Table 5 depicts incremental cash flow with and without the project. The payoff for the project occurs in the first year. Net present value of the project is 297 million yuan, and the internal rate of return is 84.3 percent. The project has a relatively low net investment, although 45.74 million yuan is required in the first two years of the project. From a financial perspective the project appears to be very viable.

Table 5. Incremental Cash Flow Analysis With and Without Project (million yuan)

Year	Investment			Operating Costs						Total Costs	Total benefits	Net benefits
	Old equip. replace	New invest.	Invest sub-total	Raw Material	Energy use	Repairs and Mainten.	Salary and Welfare	Other Oper'g costs	Total Oper'g costs			
1994	-15.00	49.25	34.25	0.00	0.00	0.00	0.00	0.00	0.00	34.25	0.00	34.25
1995	-20.00	31.49	11.49	0.00	0.00	0.00	0.00	0.00	0.00	11.49	0.00	-11.49
1996	-16.25	0.00	-16.25	8.05	-2.09	-0.50	0.02	5.30	10.79	-5.46	66.22	71.68
1997	0.00	0.00	0.00	8.05	-2.09	-0.50	0.02	5.30	10.79	10.79	66.22	55.43
1998	0.00	0.00	0.00	8.05	-2.09	-0.50	0.02	5.30	10.79	10.79	66.22	55.43
1999	0.00	0.00	0.00	8.05	-2.09	-0.50	0.02	5.30	10.79	10.79	66.22	55.43
2000	-4.00	6.00	2.00	8.05	-2.09	-0.50	0.02	5.30	10.79	12.79	66.22	53.43
2001	-5.00	0.00	-5.00	8.05	-2.09	-0.50	0.02	5.30	10.79	5.79	66.22	60.43
2002	0.00	0.00	0.00	8.05	-2.09	-0.50	0.02	5.30	10.79	10.79	66.22	55.43
2003	-4.00	0.00	-4.00	8.05	-2.09	-0.50	0.02	5.30	10.79	6.79	66.22	59.43
2004	0.00	5.00	5.00	8.05	-2.09	-0.50	0.02	5.30	10.79	15.79	66.22	50.43
2005	0.00	0.00	0.00	8.05	-2.09	-0.50	0.02	5.30	10.79	10.79	66.22	55.43
2006	-4.00	0.00	-4.00	8.05	-2.09	-0.50	0.02	5.30	10.79	6.79	66.22	59.43
2007	-9.00	6.00	-3.00	8.05	-2.09	-0.50	0.02	5.30	10.79	7.79	66.22	58.43
2008	0.00	0.00	0.00	8.05	-2.09	-0.50	0.02	5.30	10.79	10.79	66.22	55.43
2009	-4.00	0.00	-4.00	8.05	-2.09	-0.50	0.02	5.30	10.79	6.79	66.22	59.43
2010	0.00	0.00	0.00	8.05	-2.09	-0.50	0.02	5.30	10.79	10.79	66.22	55.43
2011	0.00	0.00	0.00	8.05	-2.09	-0.50	0.02	5.30	10.79	10.79	66.22	55.43
2012	0.00	0.00	0.00	8.05	-2.09	-0.50	0.02	5.30	10.79	10.79	66.22	55.43
2013	-16.30	0.00	-16.30	8.05	-2.09	-0.50	0.02	5.30	10.79	-5.51	66.22	71.73
Total	-97.60	97.70	0.20	128.80	-33.40	-8.00	0.30	95.50	194.20	194.30	1191.90	997.60
PV	-51.10	74.50	23.30	56.20	-14.60	-3.50	0.10	30.70	62.30	85.70	382.70	297.00
IRR												84.31%

Energy Conservation

Per ton energy use is projected to decrease by 8.1 percent with the project from 2024 to 1859 kgce as indicated in Table 6. The most significant changes in energy use are fuel oil consumption down 34.4 percent and bituminous coal consumption down 13.0 percent. Power consumption is expected to increase by one percent with the project. Overall, annual energy consumption is projected to decrease by 87,012 tce. Of that figure, 80,562 tce occurs as a

direct energy saving at the same level of output, while 6,420 tce is indirect energy saving due to increased output with the project. The most significant energy savings are bituminous coal (54,335 tons), fuel oil (22,693 tons), and steam (52,542 tons).

Table 6. Energy Use With and Without Project

Items	Unit	With Project	Without Project	Incremental
I. Energy use per ton output	kgce/t	1858.97	2023.78	-164.81
1. Coke	kg/t	100.00	101.99	-1.99
2. Bituminous coal	kg/t	689.00	791.91	-102.92
3. Anthracite coal	kg/t	280.00	282.97	-2.97
4. Fuel oil	kg/t	82.00	124.99	-42.98
5. Power	kwh/t	530.00	524.94	5.06
6. Steam	kg/t	4300.00	4399.52	-99.52
II. Total energy savings	tce	<u>Direct</u> 80592.29	<u>Indirect</u> 6419.53	<u>Total</u> 87011.81
1. Coke	t	972.57	77.47	1050.04
2. Bituminous coal	t	50325.83	4008.67	54334.51
3. Anthracite coal	t	1451.93	115.65	1567.59
4. Fuel oil	t	21018.34	1674.20	22692.55
5. Power	MW/h	-2472.95	-196.98	-2669.93
6. Steam	t	48665.74	3876.44	52542.18
Energy conversion factors				
1. Coke	0.9430	tce/t		
2. Bituminous coal	0.8571	tce/t		
3. Anthracite coal	0.8230	tce/t		
4. Fuel oil	1.3980	tce/t		
5. Power	0.4040	tce/mwh		
6. Steam	0.1430	tce/t		

Environmental Benefits

Per unit CO₂ emissions are reduced by 7.1 percent from 1,470 kg/ton without the project to 1,365 kg/ton with the project as indicated in Table 7. SO₂ and TSP emissions are projected to decrease by 5.7 percent. Overall, annual CO₂ emissions are reduced by 51,069 tons with the project. Of this figure, 47,001 tons are direct effects substituting for the same level of output; 4,048 tons are indirect effects reflecting increased output. Annual SO₂ emissions are reduced by 1,202 tons, while TSP is reduced by 1,087 tons.

Table 7. Environmental Impacts With and Without Project

Items	Unit	With Project	Without Project	Incremental
Total emissions per ton output				
1. CO ₂	kg/t	1365.23	1469.67	(104.43)
2. SO ₂	kg/t	40.94	43.40	(2.46)
3. TSP	kg/t	37.03	39.26	(2.22)
Total emissions reduction with project		<u>Direct</u>	<u>Indirect</u>	<u>Total</u>
1. CO ₂	t	47000.77	4067.84	51068.61
2. SO ₂	t	1106.13	95.73	1201.87
3. TSP	t	1000.56	86.60	1087.16
Emission factor	Fuel oil (kg/t)	Power (kg/mwh)	Coal and steam (kg/tce)	
1. CO ₂	590.47	304.98	754.91	
2. SO ₂	-	9.48	23.47	
3. TSP	-	8.58	21.23	

Economic/Environmental Assessment

Table 8 depicts the economic/environmental cash flow for the project. Using economic prices, the internal rate of return decreases from 84.3 to 82.8 percent. Substantial savings occur in the use of bituminous coal and fuel oil, but market prices are at or above economic price equivalents for these commodities. Electricity consumption

risers slightly where economic prices come into to play and labour cost savings are scaled slightly by average labour conversion factors below one. Including local air pollution benefits with the project, the rate of return increases to 82.9 percent. Adjusting for output in Table 9, the incremental cost of CO₂ reduction is -685.40 RMB yuan per ton reflecting both substantial cost savings and environmental benefits. Net benefits per ton CO₂ reduction are the opposite 685.40 RMB yuan or 691.03 RMB yuan with local environmental benefits included.

Table 8. Incremental Economic/Environmental Cash Flow Analysis (million yuan)

Year	Total Costs	Total Benefits	Net Benefits	Emissions			Econ Value of Local Pollution Reduction	Net Economic/ Environmental Benefits
				Global CO2 (t)	Local SO2 (t)	Local TSP (t)		
1	34.25	0.00	(34.25)	0.00	0.00	0.00	0.00	(34.25)
2	11.49	0.00	(11.49)	0.00	0.00	0.00	0.00	(11.49)
3	(3.98)	66.22	70.20	6,176.42	488.50	441.88	0.12	70.32
4	12.27	66.22	53.95	6,176.42	488.50	441.88	0.12	54.07
5	12.27	66.22	53.95	6,176.42	488.50	441.88	0.12	54.07
6	12.27	66.22	53.95	6,176.42	488.50	441.88	0.12	54.07
7	14.27	66.22	51.95	6,176.42	488.50	441.88	0.12	52.07
8	7.27	66.22	58.95	6,176.42	488.50	441.88	0.12	59.07
9	12.27	66.22	53.95	6,176.42	488.50	441.88	0.12	54.07
10	8.27	66.22	57.95	6,176.42	488.50	441.88	0.12	58.07
11	17.27	66.22	48.95	6,176.42	488.50	441.88	0.12	49.07
12	12.27	66.22	53.95	6,176.42	488.50	441.88	0.12	54.07
13	8.27	66.22	57.95	6,176.42	488.50	441.88	0.12	58.07
14	9.27	66.22	56.95	6,176.42	488.50	441.88	0.12	57.07
15	12.27	66.22	53.95	6,176.42	488.50	441.88	0.12	54.07
16	8.27	66.22	57.95	6,176.42	488.50	441.88	0.12	58.07
17	12.27	66.22	53.95	6,176.42	488.50	441.88	0.12	54.07
18	12.27	66.22	53.95	6,176.42	488.50	441.88	0.12	54.07
19	12.27	66.22	53.95	6,176.42	488.50	441.88	0.12	54.07
20	(4.03)	66.22	70.25	6,176.42	488.50	441.88	0.12	70.37
Total	220.97	1,191.90	970.93	111,175.48	8,792.98	7,953.77	2.10	973.03
PV	94.22	382.69	288.47	35,695.93	2,823.23	2,553.77	0.68	289.15
IRR			82.80%					82.92%

Table 9. Incremental Economic/Environmental Cash Flow Analysis Adjusted for Output (million yuan)

Year	Total Costs	Total Benefits	Net Benefits	Emissions			Econ Value of Local Pollution Reduction	Net Economic/ Environmental Benefits
				Global CO2 (t)	Local SO2 (t)	Local TSP (t)		
1	31.52	0.00	(31.52)	0.00	0.00	0.00	0.00	(31.52)
2	10.57	0.00	(10.57)	0.00	0.00	0.00	0.00	(10.57)
3	(64.11)	0.00	64.11	(47,000.77)	(1,106.13)	(1,000.56)	0.26	64.38
4	(34.09)	0.00	34.09	(47,000.77)	(1,106.13)	(1,000.56)	0.26	34.36
5	(33.05)	0.00	33.05	(47,000.77)	(1,106.13)	(1,000.56)	0.26	33.32
6	(32.77)	0.00	32.77	(47,000.77)	(1,106.13)	(1,000.56)	0.26	33.03
7	(29.48)	0.00	29.48	(47,000.77)	(1,106.13)	(1,000.56)	0.26	29.75
8	(42.34)	0.00	42.34	(47,000.77)	(1,106.13)	(1,000.56)	0.26	42.60
9	(33.13)	0.00	33.13	(47,000.77)	(1,106.13)	(1,000.56)	0.26	33.40
10	(40.50)	0.00	40.50	(47,000.77)	(1,106.13)	(1,000.56)	0.26	40.76
11	(23.82)	0.00	23.82	(47,000.77)	(1,106.13)	(1,000.56)	0.26	24.09
12	(32.93)	0.00	32.93	(47,000.77)	(1,106.13)	(1,000.56)	0.26	33.19
13	(40.64)	0.00	40.64	(47,000.77)	(1,106.13)	(1,000.56)	0.26	40.90
14	(38.70)	0.00	38.70	(47,000.77)	(1,106.13)	(1,000.56)	0.26	38.97
15	(33.36)	0.00	33.36	(47,000.77)	(1,106.13)	(1,000.56)	0.26	33.62
16	(40.50)	0.00	40.50	(47,000.77)	(1,106.13)	(1,000.56)	0.26	40.76
17	(32.89)	0.00	32.89	(47,000.77)	(1,106.13)	(1,000.56)	0.26	33.16
18	(32.80)	0.00	32.80	(47,000.77)	(1,106.13)	(1,000.56)	0.26	33.07
19	(33.15)	0.00	33.15	(47,000.77)	(1,106.13)	(1,000.56)	0.26	33.41
20	(63.09)	0.00	63.09	(47,000.77)	(1,106.13)	(1,000.56)	0.26	63.35
Total	(639.24)	0.00	639.24	(846,013.86)	(19,910.39)	(18,010.12)	4.77	644.01
PV	(186.18)	0.00	186.18	(271,635.90)	(6,392.77)	(5,782.64)	1.53	187.71
					<u>CO2</u>	<u>COAL</u>		
Total Incremental Cost/Ton of CO2 Reduction (yuan at 12%)					(685.40)	(434.31)		
At RMB/US\$ = 5.50					(\$124.62)	(\$78.97)		
Total Net Benefits/Ton of CO2 Reduction (yuan at 12%)					685.40	434.31		
At RMB/US\$ = 5.50					\$124.62	\$78.97		
Net Benefits Incl'g Local Env. Benefits/Ton of CO2					691.03	437.88		
At RMB/US\$ = 5.50					\$125.64	\$79.61		