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CO_2 Emissions from a Steel Mill and a Petro-Chemical Industry

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ABSTRACT

The CO_2 emissions and energy flows of a steel mill A (mill A) and petro-chemical industry B (PCI B) in southern Taiwan were investigated in this study. And the feasibility of integrating the energy flows of mill A and nearby waste management plant E (WMP E) was also evaluated in order to improve the energy efficiency and reduce the CO_2 emission. The results show that the annual energy consumption of mill A and PCI B were 6,045,518 and 11,957,543 KLOE (kiloliter of crude oil equivalent), respectively. Mill A utilized less than 5% of Taiwan's total annual energy consumption, but it used high CO_2 emission coefficient fuels and accounted for 8–9% of Taiwan's total CO_2 emission inventory. However, the energy efficiency was improved, and at least 15% of total steam produced in mill A came from waste heat recycling. By recovering waste heat in mill A, 63,420 tonnes of heavy fuel oil (HFO) consumption was prevented, and thus 177,513 tonnes of CO_2 were not emitted. Furthermore, WMP E is able to produce about 578,993 tonnes of process steam (17.6 $kg/cm^2G \times 275°C$) annually. These results show that creating a steam-network between mill A and WMP E can not only reduce the amount of energy consumed by the industrial park, but also brought an extra benefit of 95 million NTD/yr for WMP E. This is the first study of an innovative steam-network at an industrial park in Taiwan, and the results of this work can further be applied in other locations to improve energy efficiency and reduce CO_2 emissions.

Keywords: Energy flow; Energy efficiency; CO_2 emission; Steam-network; Eco-society.

INTRODUCTION

The averaged temperature of troposphere and oceans are continuous rise since the large amounts of fossil fuel were consumed after the Industrial Revolution. A continuing and great deal use of these fuel couple with CO_2 emissions from their combustion processes of industries throughout the world, have brought out the greatest environmental challenge today: global warming. According to serious energy consumptions and pollutants emissions worldwide, the energy research institutes and governmental energy departments are committed themselves to developing methods for assessing energy efficiency, which can be used as reference for policy-making. Additionally, energy utilization status can be compared among different countries to achieve the common aim of reducing greenhouse gas emissions. Numerous analytical studies have been undertaken on energy audit or energy conservation for different industries, such as the iron and steel industry (Ross, 1987; Mohsen *et al.*, 1998; Thollander *et al.*, 2005), cement industry (Anand *et al.*, 2006), petroleum industry (Pollio *et al.*, 1999), small and medium scale industries (Priambodo *et al.*, 2001), manufacturing industry (Fromme *et al.*, 1996; Mukherjee, 2008), and industrial/commercial/residential sectors (Lang *et al.*, 1993; Kramer *et al.*, 1999; Ibrik *et al.*, 2005; Sardianou, 2007; Steg, 2008).

Steel is the foundation of industries at all levels and it is also the basic of national construction. Generally, it is an important indicator of whether a country is prosperous or not. In the point of the industrial integrity, steel industries have highly relevant to materials for upstream and downstream during the process of industrial development. Steel drives the integrated industries such as mining, mechanical engineering,

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electrical engineering, civil engineering, refractory, transportation, and information industries as well as the downstream of iron and steel materials required industries to develop their functions. However, the iron and steel industry is one of the top energy consuming and highly CO_2 emission sources in the world. For the next decades, the demand of iron and steel will definitely continue growth. The World Energy Council foresees a world production level of 1300 million tonnes by 2020. Hidalgo *et al.* (2005) also predicted that the steel sector would consume at least 600 million tonnes of oil equivalent in the world and CO_2 emissions would increase up to 1700 Mt CO_2-e by 2020.

On the other hand, petro-chemical materials (e.g., plastics, synthetics, resins, elastomers, and detergents) are produced by the feedstock of fossil fuels (e.g., natural gas) or petroleum refinery products (e.g., naphtha). The petro-chemical industry is in special challenge owing to the complexity and large amount of GHG emissions. Furthermore, it was accounted for 34 EJ of final energy use around the world, representing more than 30% of the global industrial energy use (including feedstocks), and it was equivalent 2000 Mt of CO_2-e emissions in 2004 (IEA, 2007; Ren, 2009).

In Taiwan, the major energy consumption sources are metallurgical industries, petro-chemical industry (e.g., fossil fuel refinery), cement industry, textile industry, and non-metallic mineral products industry. Intergovernmental Panel on Climate Change (IPCC) has defined five sectors (energy, industrial processes and product use, agricultural and forestry, waste, and others) to establish inventory of Greenhouse Gas emissions. The energy consumed and pollution emitted of the energy and industrial sectors are higher than the other sectors in Taiwan. It is estimated that about 296.6 Mt CO_2-e was emitted in Taiwan during the whole year of 2004; energy and industrial sectors contributed 87.0% and 7.8% to the total amounts of emitted CO_2, respectively (Taiwan EPA, 2005). For CO_2 emission, the largest emitting manufacturing in Taiwan include iron and steel, petro-chemical materials, transportation, commerce and other services. In the year of 2004, the energy used in industrial production accounted up to 59% of the Taiwan CO_2 inventory. Over the years, energy utilize by the industrial sector is higher than 50% of the total energy consumed in Taiwan, and the petro-chemical and steel industry contribute 53% and 10%, respectively, to the total industrial sector.

For petro-chemical and steel industries, large amount use of energy not only causes fossil fuel depletion but brings out serious pollution to the environment. Therefore, increasing its energy efficiency is a critical strategy for energy conservation and greenhouse gas reduction. Presently, energy efficiency in the petro-chemical industry could be increased by cogeneration, heat recovery and developing alternative energy, and in the iron and steel industry, cogeneration combined with coke dry quench, top pressure recovery turbine system, and waste heat recovery system during sintering process frequently been applied.

Cogeneration, or named combined heat and power (CHP), is achieved by simultaneously generate both electricity and usable thermal energy in a heat engine or a power station. For example, not all of the thermal energy from the combusted fuels is being converted into electricity in power plants and heat engines. Instead, most of the thermal enthalpy is lost as excess heat in the stack flue gases, steam, or condensed water. However, 80% of the thermal efficiency can be reached if the excess heat is captured by CHP in a conventional power plant (Shipley *et al.*, 2008).

In southern Taiwan, steel mill A (mill A) has done a great effort, built a foregoing stated energy saving system, constructed a steam-transferring network to connect their union factories, and provide thermal steam to the nearby industries (World Steel Association website; CSC, 2008). The system in mill A recovered not only 30.2% waste heat (i.e., 449,333 KLOE/yr), but also reduced CO_2 emission by 1,300,000 tonnes per year in 2007. Nowadays, a successful eco-system in an Industrial Park has been organized and well operated in southern Taiwan. To reach the best benefit for the Industrial Park, a potential source is expected in mill A due to the higher energy efficiency and less CO_2 emission than traditional processes.

Respecting petro-chemical industry B (PCI B), both of “Water Resource Utilization And Development” and “Energy Saving and Carbon Reduction” task groups have conducted several projects to reduce water consumption, including process water reduction and wastewater and rainwater recycling, and also put in a lot of efforts to slow global warming effect and to improve energy efficiency, by the ways of improving heat recovery and developing alternative energy such as wind turbines. Up to the end of 2011, it has conducted 1,459 energy saving projects at this industrial park. Therefore, a 6.47 million tonnes of CO_2 emission has been reduced, which is equivalent to 860 million trees’ carbon up taking for one year (Formosa Plastics Group website).

Waste incineration is a process that converts organic waste materials into thermal energy (e.g., steam). The generated steam is further used to yield electricity from a gas turbine. Typically, the net energy that is produced per tonne municipal waste is about 2/3 MWh of electricity and 2 MWh of district heating (Ramboll, 2006). The generated electricity can further supply the demand of the plant or even sold to the Power Company as well. The waste management plant E (WMP E), a potential new steam source, is just 5 km away from the mill A. Thus, the steam connection among mill A and WMP E is highly expected to increase the energy utilization efficiency and decrease CO_2 emission in the Industrial Park.

Based on the aforementioned information, there are two main objects to be conducted. Firstly, the energy flow, CO_2 emission and energy cost of mill A and PCI B are analyzed in order to provide as a reference for further action in self-improving or government’s policy-making. Secondly, the subjects of integrating the energy flow of the mill A with the WMP E nearby, i.e., the energy saving, CO_2 reduction and the benefit created, through the steam connection networks, are analyzed and evaluated.

METHODS

Background of the Industrial Park

The mill A is one of the largest integrated steel makers of the Industrial Park in southern Taiwan. As described, the mill A is the 21th largest steel producer around the world in 2010. Moreover, there are 532 plants in the Industrial Park; they can be classified into 12 categories including: basic metal industries, fabricated metal products, chemical products, chemical materials, non-metallic mineral products, petrochemical products, rubber products, plastic products, pulp, paper and paper products, electronic parts, electrical and electronic machinery, and transport equipment. Beside, the PCI B belongs to the category of petro-chemical industry and it also locates in southern Taiwan. Respecting the scale, it includes an oil refinery plant with annual capacity of 25 million tons of crude oil, naphtha cracking plants for producing 2.94 million tons ethylene per annum, and other petrochemical plants, heavy machinery plants, a co-generation plant, an Industrial Harbor and a thermal power plant with a capacity of 3 million kilowatts. In addition, five kilometers away from the mill A was the WMP E. In this study, the mill A and PCI B are selected as the studying cases for the energy flow and CO_2 emission analysis and the feasibility of integrating the energy flow of the mill A and WMP E to form energy-based eco-society networks also studied.

Data Acquisition

The data of cost, price, specification of steam, production, the amount sold to other factories and other detail were acquired from the mill A and PCI B in 2008, 2009, and 2010. The steam produced by cogeneration system and waste-heat recover data was also supplied by the mill A. Additionally, the feasibility of energy flow between the mill A and WMP E were further discussed. The data were analyzed by: energy consumption (million kiloliter of oil equivalent), CO_2 emissions (million tons per year), and cash flows (million NTD per year).

Data Calculation

Data of the fuels used for energy utilization were converted into kiloliter oil equivalent (KLOE), a uniform unit in Taiwan, in the mill A and PCI B. Costs of energy consumed in 2008, 2009, and 2010 were further analyzed to realize the status of energy consumption. The analyzed data of energy were further converted into CO_2 emission amounts by using the activity amount (KLOE) times their corresponding CO_2 emission coefficients. The CO_2 emission coefficients were acquired from Taiwan EPA energy balance tables and the guidelines of IPCC 2006 (Taiwan EPA, http://ghgr egistry.epa.gov.tw/Tool/tools.aspx). The converted amount of CO_2 emitted was further discussed in the mill A and PCI B. Finally, the profits from steam connecting network among the mill A and WMP E were realized in this study.

RESULTS AND DISCUSSION

Analysis of Energy Consumption

Energy Consumption of Steel Mill A

Table 1 shows the energy consumption of mill A in 2008, 2009, and 2010. The data were in different unit originally. In order to understand different types of energy used in a coherent quantity for the blast furnace oxygen process, we convert all units into KLOE (kiloliter of crude oil equivalent). This conversion is based on the heat value given from mill A (see Table 2), and we assumed that the heat value of one KLOE is 9,000 kcal according to Bureau of Energy, Ministry of Economic Affairs.

Table 3 shows the energy consumption in the mill A of this study from 2008 to 2010. The total energy consumed of the mill A is 6,298,734, 5,392,028 and 6,445,791 KLOE each in 2008, 2009 and 2010. As shown in Fig. 1, coking coal accounts for 75.8% and PCI coal for 14.7% in total energy consumption. It is indicated that the amount of total coking coal is much larger than that of other energy categories. Besides, the CO_2 emission coefficient of coking coal, 3.059 ton CO_2/ton, is also a higher one. It means that the mill A is a considerable CO_2 emission source. Therefore, how to continuously promote the energy efficiency on the base of previous achievement of the mill A, is still an important job to do in the future.

The production of crude steel of the mill A is 11.0, 8.9 and 12.7 million metric tons each in 2008, 2009 and 2010, as shown in Fig. 2 (World Steel Association website). With the energy consumption obtained from this research, we can calculate the energy consumed per ton product. Fig. 3 shows the energy consumption of per ton crude steel during 2008 to 2010. While the production and energy consumption is increasing steadily, the promotion of energy efficiency is slightly. Thus, the energy efficiency is still an important issue for the mill A in the future.

Energy Consumption of Petro-Chemical Industry B

The energy consumption of PCI B during 2008 to 2010 is shown in Table 4. In order to understand different types

Table 1. Raw data of energy consumption from the mill A.

Item	Unit	2008	2009	2010
Coking Coal	Ton	5,688,569	5,131,838	5,846,823
Anthracite (sinter plant)	Ton	106,755	55,488	135,823
PCI coal (blast furnace)	Ton	1,305,765	836,728	1,216,872
Steam Coal	Ton	286,885	270,440	323,862
Low sulfur fuel oil	Kiloliter	26,847	27,888	13,938
Natural gas	Kilo Cubic Meter	46,068	30,272	45,569
Diesel oil	Kiloliter	3,651	3,158	3,618
Purchased electricity	Million Watt Hour	1,917,584	1,987,156	2,162,445

Table 2. Heat values of different types of energy.

Item	Unit	Heat Value
Coking Coal	kcal/kg	7,400
Anthracite	kcal/kg	7,400
PCI coal	kcal/kg	7,150
Steam Coal	kcal/kg	7,072
Low sulfur fuel oil	kcal/liter	9,396
Natural gas	kcal/cubic meter	9,465
Diesel oil	kcal/liter	8,330
Purchased electricity	kcal/kilo watt-hour	860
Liquefied Petroleum Gas	kcal/liter	6,365
Petroleum Coke	kcal/kg	8,200
Naphtha	kcal/liter	7,800
Kerosene	kcal/liter	8,500
Fuel Oil	kcal/liter	9,600
Coke Oven Coke	kcal/kg	7,000

Table 3. Energy consumed of the mill A from 2008 to 2010 in KLOE.

Item	Unit	2008	2009	2010	Average
Coking Coal	KLOE	4,684,853	4,215,520	4,839,870	4,580,081
Anthracite	KLOE	87,919	45,580	112,431	81,977
PCI coal	KLOE	1,037,358	664,734	966,737	889,610
Steam Coal	KLOE	225,428	212,205	254,124	230,586
Low sulfur fuel oil	KLOE	28,028	29,258	14,627	23,971
Natural gas	KLOE	48,448	31,836	47,923	42,736
Diesel oil	KLOE	3,379	2,923	3,349	3,217
Purchased electricity	KLOE	183,321	189,972	206,730	193,341
Total	KLOE	6,298,734	5,392,028	6,445,791	6,045,518

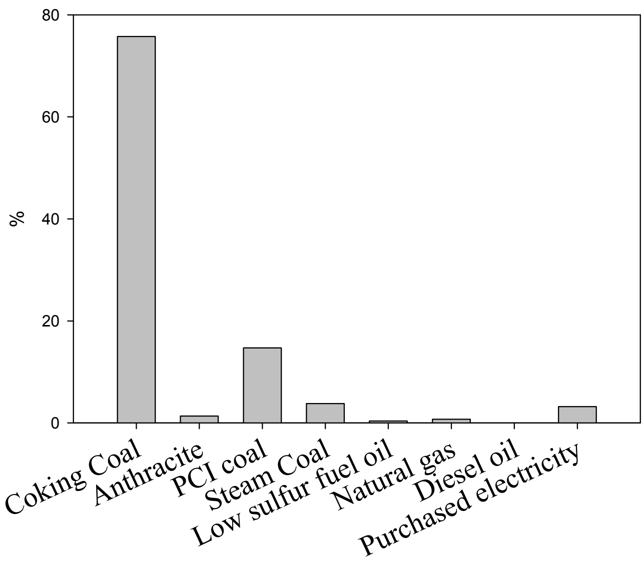

Fig. 1. Energy consumption profile of the mill A.

of energy used in a coherent quantity for the PCI B, all units are converted into KLOE as the previous case.

Table 5 shows the energy consumption in the PCI B of this study during 2008 to 2010. The total energy consumed of the PCI B is 11,844,379, 12,189,223 and 11,839,028 KLOE each in 2008, 2009 and 2010. And as shown in Fig. 4, steam coal accounts for 89.2% in total energy consumption. It is shown that the amount of total steam coal is much larger than that of other energy categories. Though the CO_2 emission coefficient of steam coal is 2.535 ton CO_2/ton, it can still emit large amounts of CO_2 due to the huge consumption. Therefore, for the PCI B, continuously increasing the energy efficiency is no doubt an important job to do in the future.

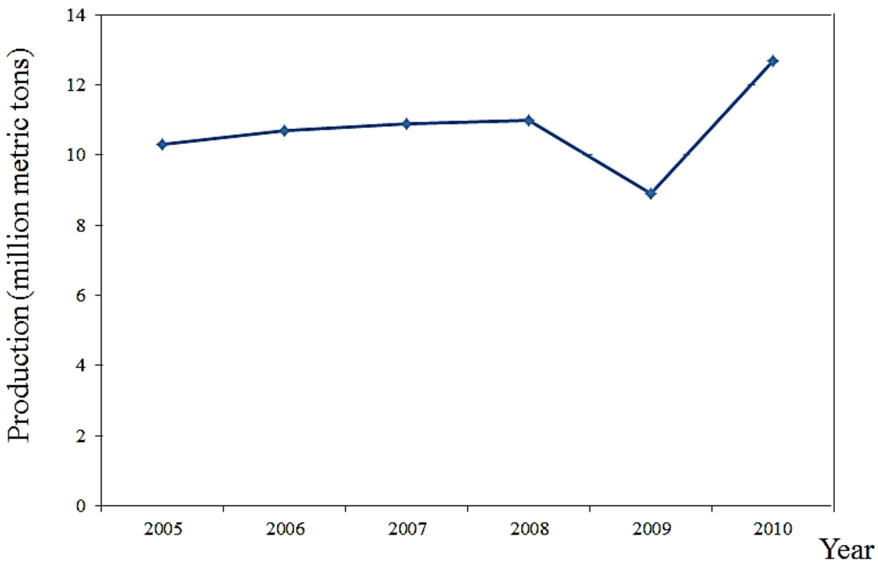

Fig. 2. Crude steel production of the mill A during 2005 to 2010.

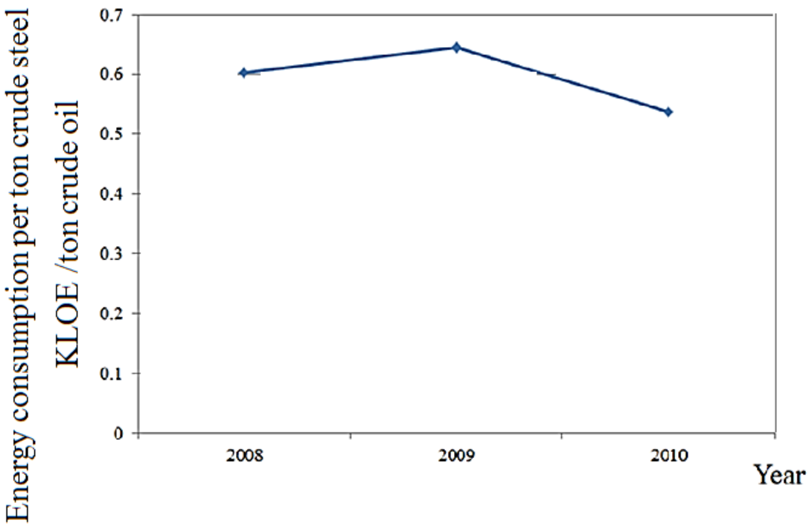

Fig. 3. Energy consumed per ton crude steel of the mill A.

Table 4. Raw data of energy consumption from the PCI B.

Item	Unit	2008	2009	2010
Liquefied Petroleum Gas	Kiloliter	57,205	36,242	34,765
Petroleum Coke	Ton	591,450	583,019	583,832
Naphtha	Kiloliter	53,658	62,588	49,605
Diesel Oil	Kiloliter	1,846	1,759	1,326
Kerosene	Kiloliter	468	457	592
Fuel Oil	Kiloliter	249,804	232,685	250,530
Coke Oven Coke	Ton	554,232	570,846	488,042
Steam Coal	Ton	13,386,899	13,851,537	13,476,222
Purchased electricity	Million Watt Hour	4,780	14	19,930

Cost from Energy Consumption

Unit price of energy is presented in Table 6 provided from the mill A. The total cost of energy consumption can be calculated from Table 1 and Table 6. Energy consumption times the unit price equals to total cost. The cost from all energy input of the mill A during 2008 to 2010 estimated in this research is 54.8, 51.5 and 49.2 billion NTD and details of each energy cost are shown in Table 7. Table 8 shows the income of three most extensive steel mills in Taiwan from 2006 to 2010. The cost of mill A (shown in

Table 5. Energy consumed of the PCI B in KLOE.

Item	Unit	2008	2009	2010	Average
Liquefied Petroleum Gas	KLOE	39,409	24,967	23,950	29,442
Petroleum Coke	KLOE	538,870	531,189	531,929	533,996
Naphtha	KLOE	46,505	54,245	42,993	47,914
Diesel Oil	KLOE	1,723	1,642	1,238	1,534
Kerosene	KLOE	442	432	559	478
Fuel Oil	KLOE	266,466	248,205	267,240	260,637
Coke Oven Coke	KLOE	431,082	444,004	379,599	418,228
Steam Coal	KLOE	10,519,425	10,884,538	10,589,615	10,664,526
Purchased electricity	KLOE	457	1	1,905	788
Total	KLOE	11,844,379	12,189,223	11,839,028	11,957,543

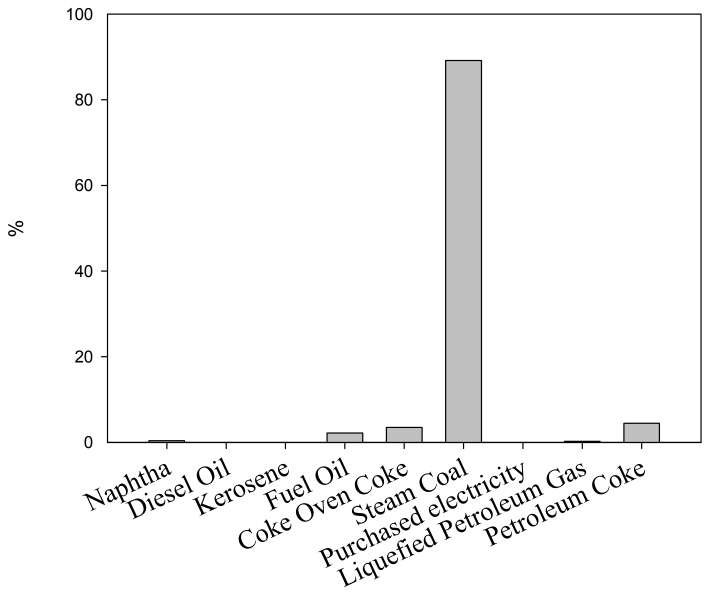

Fig. 4. Energy consumption profile of the PCI B.

Table 6. Unit price of energy provided by the mill A.

Item	Unit	2008	2009	2010
Coking Coal	NTD/ton	7,040	7,720	6,088
Anthracite	NTD/ton	7,040	7,720	6,088
PCI coal	NTD/ton	6,006	6,276	5,172
Steam Coal	NTD/ton	2,784	4,152	2,753
Low sulfur fuel oil	NTD/kiloliter	17,223	12,691	16,894
Natural gas	NTD/cubic meter	17.6	15.1	15.9
Diesel oil	NTD/liter	24.3	24.0	26.8
Purchased electricity	NTD/kilo-watt-hour	2.1	2.1	2.1

Table 7) is much greater than the incomes of mill C and D (shown in Table 8). It reveals that the mill A is a significant energy consumption plant in Taiwan. So, a small piece of energy efficiency improved in the mill A can cause a tremendous reduction of energy consumption and pollutant emission in this country. Additionally, the result also indicates the fact that since the huge energy budget of the mill A can be compared to the income of other domestic mills, so reducing the cost of energy consumption by energy efficiency promotion and seeking other possible steam connection resource are important for mill A.

CO_2 Emission

CO_2 Emission of Steel Mill A

The estimated annual CO_2 emission during 2008 to 2010 of the mill A is 23.7, 20.4 and 24.2 million tons. However, the annual CO_2 emission of Taiwan in 2008 and 2009 is 264 and 250 million tons each. Accordingly, the CO_2 emission of the mill A is about 8–9% for the total emission of entire Taiwan, and it is a tremendous amount for a single mill. Hence, the topics of improving energy efficiency and using green energy must be further concerned in the future. Table 9 and Table 10 show the CO_2 emission coefficients and

Table 7. Cost of each energy during 2008 to 2010 in the mill A.

Item	Unit	2008	2009	2010	Average
Coking Coal	billion NTD	40.0	39.6	35.6	38.4
Anthracite	billion NTD	0.75	0.43	0.83	0.67
PCI coal	billion NTD	7.84	5.25	6.29	6.46
Steam Coal	billion NTD	0.80	1.12	0.89	0.94
Low sulfur fuel oil	billion NTD	0.46	0.35	0.24	0.35
Natural gas	billion NTD	0.81	0.46	0.73	0.66
Diesel oil	billion NTD	0.09	0.08	0.1	0.06
Purchased electricity	billion NTD	4.03	4.17	4.54	4.25
Total	billion NTD	54.8	51.5	49.2	51.8

Table 8. Incomes and growth rates of top three steel mills in Taiwan.

Year	Steel mill A		Mill C		Mill D	
	Income (billion)	growth rate (%)	Income (billion)	growth rate (%)	Income (billion)	growth rate (%)
2005	186.3	--	27.1	--	8.1	--
2006	177.7	–4.65	33.6	23.8	9.2	13.1
2007	207.9	17.0	40.2	20.0	10.6	15.0
2008	256.4	23.3	49.7	23.5	9.5	–10.7
2009	165.4	–35.5	22.3	–55.1	6.5	–31.4
2010	239.2	44.6	32.6	46.1	10.7	64.6

CO_2 emissions of the mill A estimated in this research. As Coking coal and PCI coal are the most energy used in this mill, and they account for 75.8% and 14.7%, shown in Fig. 1. Moreover, the CO_2 emission coefficients of these two items are relative high compared with other energy category. This is why the consumption of the mill A just accounts for about 5% of the total energy consumption, but the CO_2 emission of only a mill A reaches about 8–9% of the total emission of entire Taiwan.

CO_2 Emission of Petro-Chemical Industry B

The estimated annual CO_2 emissions during 2008 to 2010 of the PCI B are 38.7, 39.8 and 38.6 million tons each. However, the annual CO_2 emissions of Taiwan in 2008 and 2009 are 264 and 250 million tons each as mentioned previously. The CO_2 emission of the PCI B is about 15% for the total emission of entire Taiwan. Table 11 and Table 12 show the CO_2 emission coefficients and CO_2 emissions of PCI B estimated in this research. Steam coal is the most energy used in PCI B, 89.2%, as shown in Fig. 4. In this study, the two cases (the mill A and PCI B) contribute about 23–24% of CO_2 emission in Taiwan, so on the environment-protection point of view, improving the energy efficiency and seeking other possible steam connection resource are still very important issues.

Steam Connection System of the Industrial Park and the Possible Connection with Waste Management Plant

Present Steam Connection

The mill A established equipments of waste heat recovery system to produce steams in the past few years. Fig. 5 shows the procedure of steam production and Fig. 6 is the comparison of before and after the construction of steam network in the industrial park.

The cogeneration system onsite uses main steam produced by boilers as input then produces process steam and electricity. Table 13 shows the annual data of the system. There are eight turbine generators for generating electricity. And the specifications of main steams are 60 $kg/cm^2G \times 480°C$ for TG-1,2,3, 94 $kg/cm^2G \times 513°C$ for TG-4,5,6,7 and 128 $kg/cm^2G \times 538°C$ for TG-8. And the specification of process steam output from cogeneration system is 17.6 $kg/cm^2G \times 275°C$. The thermal efficiency of this cogeneration system can be calculated with information

Table 9. CO_2 emission factors of individual energy.

Item	Emission factor	Unit
Coking Coal	3.059	ton CO_2/ton
Anthracite	2.784	ton CO_2/ton
PCI coal	2.955	ton CO_2/ton
Steam Coal	2.535	ton CO_2/ton
Low sulfur fuel oil	3.153	ton CO_2/kiloliter
Natural gas	2.014	ton CO_2/cubicmeter
Diesel oil	2.606	ton CO_2/kiloliter
Purchased electricity (2008/2009/2010)	0.636/0.623/0.612	ton CO_2/MWh

Table 10. CO_2 emissions estimated of the mill A during 2008 to 2010.

Item	Year		
	2008	2009	2010
Coking Coal	17,401,333	15,698,292	17,885,432
Anthracite	297,206	154,479	378,131
PCI coal	3,858,536	2,472,531	3,595,857
Steam Coal	727,253	685,565	820,990
Low sulfur fuel oil	84,649	87,931	43,947
Natural gas	92,781	60,968	91,776
Diesel oil	9,515	8,230	9,429
Purchased electricity	1,219,583	1,237,998	1,323,416
Total (tons)	23,690,856	20,405,994	24,148,978

Table 11. CO_2 emission factors of each energy.

Item	Emission factor	Unit
Liquefied Petroleum Gas	1.753	ton CO_2/kiloliter
Petroleum Coke	3.347	ton CO_2/ton
Naphtha	2.394	ton CO_2/kiloliter
Diesel Oil	2.606	ton CO_2/kiloliter
Kerosene	2.559	ton CO_2/kiloliter
Fuel Oil	3.111	ton CO_2/kiloliter
Coke Oven Coke	3.136	ton CO_2/ton
Steam Coal	2.535	ton CO_2/ton
Purchased electricity	0.636/0.623/0.612	ton CO_2/MWh

Table 12. CO_2 emissions estimated of the PCI B.

Item	Year		
	2008	2009	2010
Liquefied Petroleum Gas	100,280	63,532	60,943
Petroleum Coke	1,979,583	1,951,365	1,954,086
Naphtha	128,457	149,836	118,754
Diesel Oil	4,811	4,584	3,456
Kerosene	1,198	1,169	1,515
Fuel Oil	777,140	723,883	779,399
Coke Oven Coke	1,738,072	1,790,173	1,530,500
Steam Coal	33,935,789	35,113,646	34,162,223
Purchased electricity	3,040	9	12,197
Total (tons)	38,668,370	39,798,197	38,623,072

of input and output energy. Table 14 showed the average thermal efficiency of the system is 81.8%, and it indicates that the total thermal efficiency of cogeneration system is very well.

The productions of steam during 2008 to 2010 of the mill A are 3,998, 3,872 and 4,561 thousand tons, respectively. According to the data provided by the mill A, the waste heat recovered from the CDQ-4 (Coke Dry Quenching Plant) and RMTP (Residual Material Treatment Plant) produced 843,052 ton steam in 2010, contributed about 18.5% of total process steam (with an enthalpy of 710.89 kcal/kg) produced (4,561,202 ton steam) for the mill A. Again, it can reduce 63,420 tons of heavy fuel oil consumption annually, which is equal to about 177,513 tons of CO_2 emission. This illustrates waste heat recovery plants being proven effective and serves an essential part of process steam. In another word, these technologies not only improve energy efficiency, but also reduce energy consumption and CO_2 emission.

On the other hand, the amounts of steam sold by the mill A are 1,873, 1,939 and 2,468 thousand tons in each year as shown in Table 15. It is found that the percentage of steam sold to other plants has increased from 46.8% in 2008 to 54.1% in 2010. Due to the fact of persistently increasing percentage of steam sold, it might reveal that the profit of steam network might be much better than originally expected by the mill A.

Reduction of CO_2 and Profit of Present Steam Network

This research tells that the iron and steel industry consumes large amount of energy and emits huge amount of the CO_2 in Taiwan, so improving the energy efficiency of iron and steel industry is an important issue all along. The mill A has realized that and dedicated itself to improve

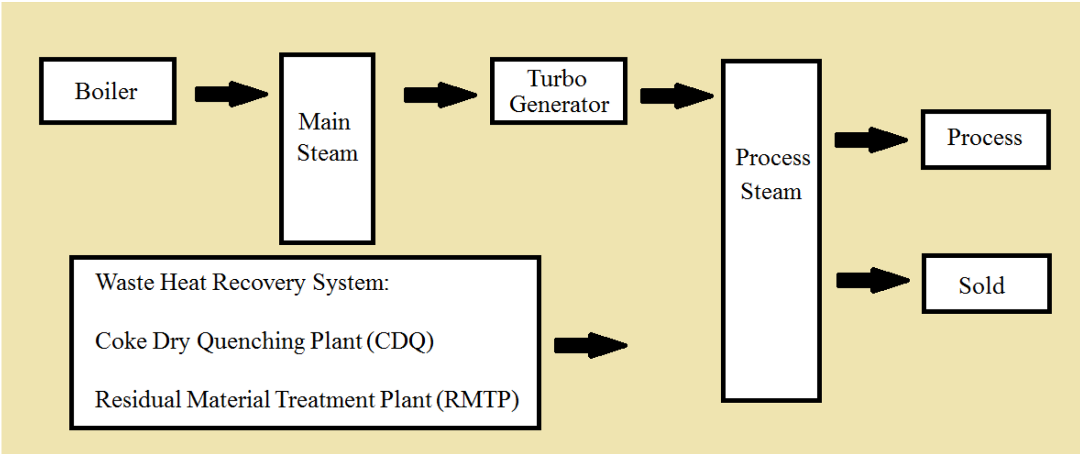

Fig. 5. Steam processing in the mill A.

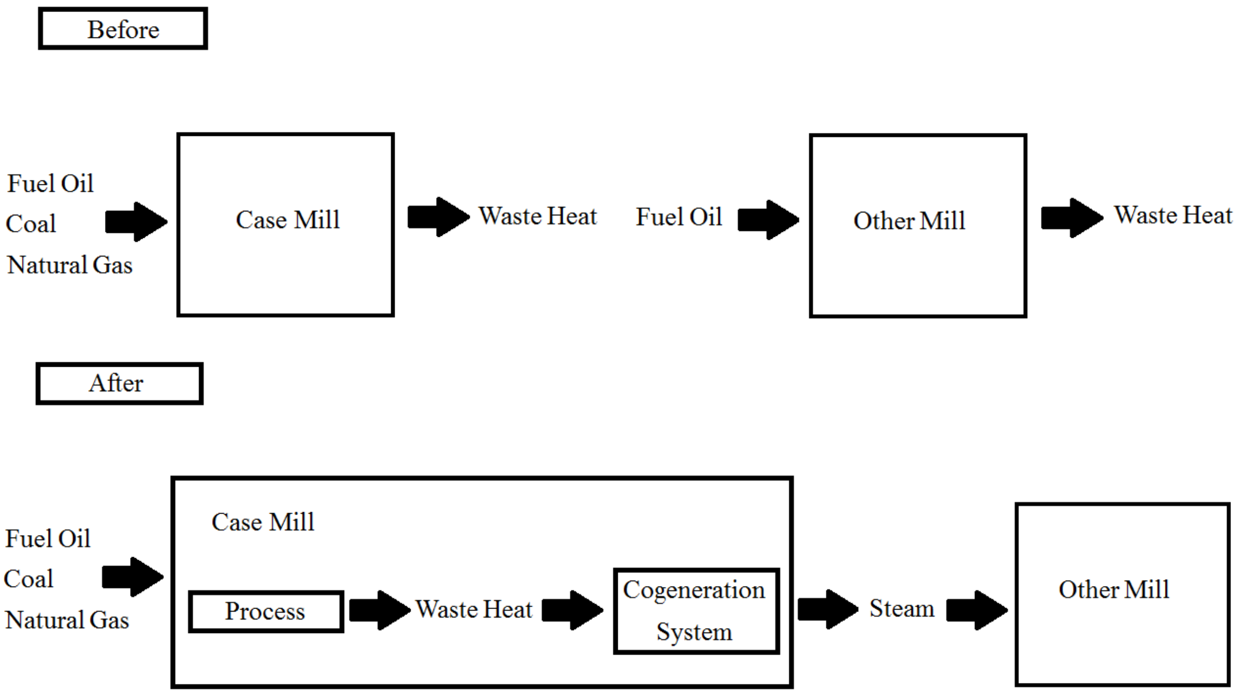

Fig. 6. Comparison before and after the construction of steam network in the mill A.

Table 13. Annual data of onsite cogenerators in the mill A.

Generator	Input	Output	
	Main Steam (t)	Process Steam (t)	Electricity (MWh)
TG-1,2,3	2,842,071	1,198,919	445,228
TG-8	2,358,362	719,542	447,615
TG-4,5,6,7	7,061,909	1,177,329	1,336,610

Table 14. Thermal efficiency of cogeneration system in the ***mill A***.

Generator	Input	Output	Thermal Efficiency (%)
	Main Steam (kcal)	Process Steam + Electricity (kcal)	
TG-1,2,3	2.30×10^{12}	1.94×10^{12}	84.3
TG-8	1.94×10^{12}	1.61×10^{12}	83
TG-4,5,6,7	1.48×10^{12}	1.13×10^{12}	76.4
Average	5.72×10^{12}	4.68×10^{12}	81.8

Table 15. The steam production and purposes of the mill A.

	2008	2009	2010
Production (tons)	3,997,757	3,872,105	4,561,202
Process Use (tons)	2,125,211	1,933,515	2,093,455
Sold (tons)	1,872,546	1,939,590	2,467,747

the energy efficiency of the whole corporation, even the whole industrial park.

During 2008 to 2010, the mill A sold millions tons of steam per year to other plants in the industrial park. It can reduce averaged 157,446 tons of heavy fuel oil consumption annually, which is equal to about 440,691 tons of CO_2 emission as described in Table 16. Although the cost of steam network is 1.5 billion NTD, the profit by selling steams brings 0.34, 0.36 and 0.46 billion NTD incomes in 2008, 2009 and 2010. Consequently, the steam connecting system not only brings advantages to the mill A, but also reduces the CO_2 emission and improving the energy efficiency.

Possible Steam Connection with Waste Management Plant E

The WMP E is located near the mill A within 5 kilometer, shown in Fig. 7, therefore the connection should be technically possible.

The amounts of waste incinerated in WMP E during 2008 to 2010 are 323,197 tons, 297,373 tons and 373,227 tons, respectively. The electricity produced and sold is also described in Table 17 (Taiwan EPA, http://edw.epa.gov.tw/reportStatistic.aspx?StatDataId=20). Averagely WMP E incinerates 331,266 tons of wastes and produces 139,618 MWh of electricity per year. The thermal efficiency of this plant is calculated by this research and presented in Table 18. The average thermal efficiency of WMP E from 2008 to 2010 is 17.5%. If the steam produced from waste incineration can be delivered to the mill A, and the energy can be recovered more efficiently than nowadays.

Table 17 showed that WMP E sold about 97,760 MWh of electricity to power company. And the prices of electricity sold to power-company during 2008 to 2010 are 1.87 NTD/kWh, 2.31 NTD/kWh and 2.24 NTD/kWh, respectively (Haixiao Information website). In other word, it brings an annually averaged benefit of 209 million NTD to WMP E.

In order to compare the benefit of selling electricity to power-company or steam to mill A, the amount of steam produced from WMP E must be quantified. And the data from Table 18 show the total energy (in kcal) released from waste incineration: 6.86×10^{11} kcal. As described above, the specification of process steam in mill A is 17.6 kg/cm^{2}G × 275°C, and the specific enthalpy of the steam is about 710.89 kcal/kg. (Steam Table Online wesite) After calculation, it was estimated that WMP E can produce 578,993 tons of process steam (17.6 kg/cm^{2}G × 275°C), annually (assuming the thermal efficiency is 60% and neglecting the enthalpy of the feeding water). In addition,

Table 16. Energy savings and reductions of CO_2 emission of the mill A by selling steams.

Item	Year			
	2008	2009	2010	Average
Steam Sold (tons)	1,872,546	1,938,590	2,467,747	2,092,961
Specific enthalpy (kcal/kg for 17.5 kg/cm^{2}G × 275°C steam)	710.89	710.89	710.89	710.89
Reduction of heavy fuel oil (tons) (assume a heat value of 10500 kcal/kg and 0.9 thermal efficiency of boiler)	140,865	145, 833	185,640	157,446
Reductions of CO_2 emission (tons)	394, 281	408,187	519,606	440,691

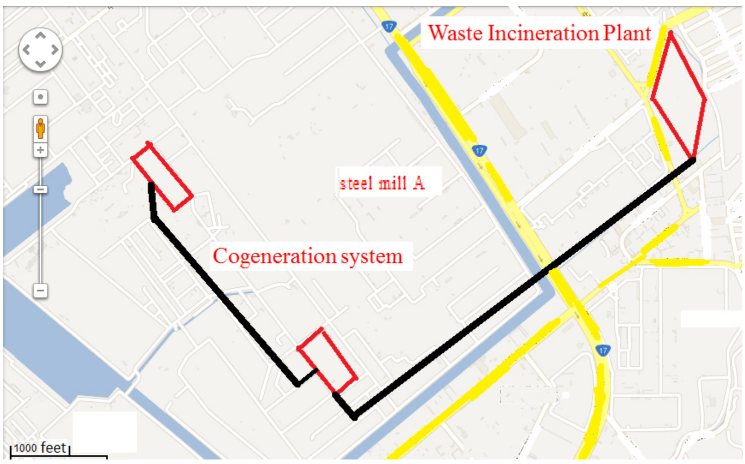

Fig. 7. Locations of the mill A and the WMP E.

Table 17. Annual operating data of the WMP E.

Plant A	2008	2009	2010	average
Waste incinerated (ton)	323,197	297,373	373,227	331,266
Electricity produced (MWh)	145,704	119,558	153,592	139,618
Electricity sold (MWh)	103,155	80,605	109,520	97,760

Table 18. Thermal efficiency of the WMP E.

Plant A	2008	2009	2010	average
Waste incinerated (kcal)	6.69×10^{11}	6.16×10^{11}	7.73×10^{11}	6.86×10^{11}
Electricity produced (kcal)	1.23×10^{11}	1.03×10^{11}	1.32×10^{11}	1.20×10^{11}
Efficiency (%)	18.7	16.7	17.1	17.5

the unit cost of process steam of the mill A is 630–900 NTD/ton, with an average of 810 NTD/ton. It was assumed that the mill A purchased the steam produced from WMP E in 810 NTD/ton, then the gross benefit of WMP E can be up to 469 million NTD. However, part of the steam need to be converted into electricity which is demanded inside WMP E. This demand of electricity is 41,858 MWh per year (calculated from Table 17), which is about 90 million NTD per year. Subtracting the cost of electricity, there are still 379 million NTD benefits to WMP E. This benefit is still much higher than selling electricity to power company. At the same time, selling this steam to industrial park can reduce 43,556 tons of heavy fuel oil consumption annually (assume a 0.9 thermal efficiency for boiler), which is equal to about 121,912 tons of CO_2 emission.

However, the cost of constructing the steam network system should be further considered. The distance between the WMP E and the mill A is 5 km estimated from the Google map in Fig. 7. The unit cost is about 100 million NTD per kilometer. Here it was assumed that the WMP E pay for all the connection system then the benefit of the WMP E can be calculated. Subtracting the costs of construction (under 10% rate of depreciation), demand of electricity and 5% of maintenance. It is expected that the benefit will at least reach about 304 million/year, and this result shows that the WMP E would have an extra 95 million/year benefit than just selling electricity to power company.

Finally, this study reveals that the connection of industries and the WMP E will bring appreciable benefit to WMP E, and mainly reduce the energy consumption and CO_2 emission of the industrial park studied. Besides, it also brings some additional incomes to the mill A. It is believed that the way conducted in this research can approach the goal of energy-saving and CO_2 reduction, and in the points of economic consideration and environmental protection, the similar connections should be extended to other potential industrial parks and communities worldwide.

CONCLUSIONS

1. The average energy consumed of the mill A is 6.03 million KLOE (kiloliter of crude oil equivalent) during 2008 to 2010. Coking coal accounts for 75.8% in total energy consumption, PCI coal for 14.7%. The amount of total coking coal is much larger than that of other energy categories. Besides, the CO_2 emission coefficient of coking coal, 3.059 ton CO_2/ton, is also a high one. This is also an important reason for the huge CO_2 emission.
2. The average energy consumed of the PCI B is 12.0 million KLOE (kiloliter of crude oil equivalent) during 2008 to 2010. Steam coal accounts for 89.2% in total energy consumption and the consumption of steam coal is much larger than that of other energy categories. Though the CO_2 emission coefficient of steam coal is 2.535 ton CO_2/ton, it can still emit large amounts of CO_2 due to the huge consumption.
3. The average production of crude steel of the mill A is 10.9 million metric tons during 2008 to 2010. With the energy consumption from this research, we can calculate the energy consumed per ton production. While the production and energy consumption is increasing steadily, the increasing of energy efficiency is slightly. Thus, the energy efficiency is still an important issue for the mill A in the future.
4. The average cost of mill A (51.8 billion) is much greater than the income of mill C and mill D (34.9 and 8.9 billion) in Taiwan, so a small piece of energy efficiency improvement in mill A can cause a big reduction of energy consumption and pollutant emission.
5. The estimated annual CO_2 emission during 2008 to 2010 of the mill A is about 8–9% for the total emission of entire Taiwan, and the estimated annual CO_2 emission of the PCI B is about 15% for the total emission of entire Taiwan. In this study, the summation of the mill A and PCI B contribute about 23–24% of CO_2 emission in Taiwan, so on the environment-protection point of view, improving the energy efficiency and seeking other possible steam connection resource are still very important issues.
6. In the mill A, the average thermal efficiency of the cogeneration system is 81.8%, and it indicates that the total thermal efficiency of cogeneration system is quite well.
7. The productions of process steam during 2008 to 2010 of the mill A are 3,998, 3,872 and 4,561 thousand tons. The amounts of steam sold are 1,873, 1,939 and 2,468 thousand tons in each year. It is found that the percentage of steam sold to other plants has increased from 46.8% in 2008 to 54.1% in 2010.

8. The steam linkage in the industrial park can reduce about 157,446 tons of heavy fuel oil consumption annually for industrial park, which is equal to about 440,691 tons of CO_2 emission. Although the cost of steam network system is 1.5 billion NTD, the profit by selling steams still brings 0.34, 0.36 and 0.46 billion NTD incomes in 2008, 2009 and 2010. Consequently, the steam connecting system not only brings advantages to the mill A, but also reduces the CO_2 emission and improving the energy efficiency of the industrial park.
9. This research evaluated the steam connection between the mill A and the WMP E nearby. It is found that for the WMP E, selling electricity can only bring 209 million NTD/year but the steam linkage can bring about 304 million NTD/year for WMP E. And this connection will also reduce the CO_2 emission and improve the energy efficiency of the whole system studied.

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