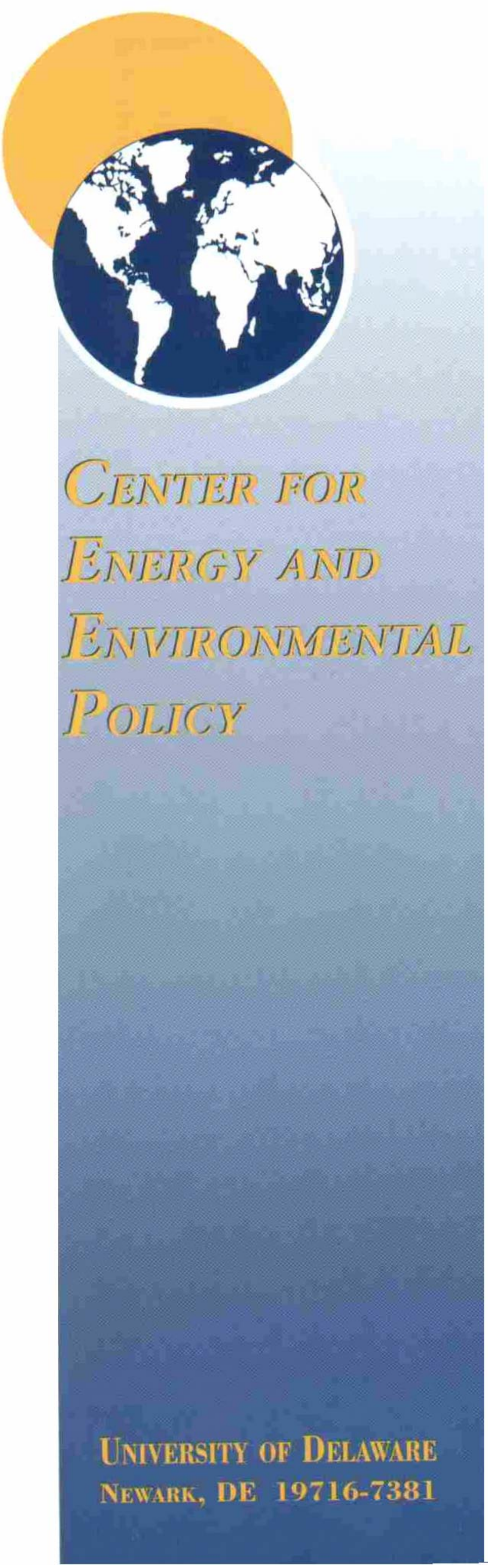
CARBON DIOXIDE EMISSION REDUCTION TECHNOLOGIES AND MEASURES IN US INDUSTRIAL SECTOR



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FINAL REPORT

TO

**KOREA ENVIRONMENT
INSTITUTE**

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CARBON DIOXIDE EMISSION REDUCTION TECHNOLOGIES AND MEASURES IN US INDUSTRIAL SECTOR

Final Report

to

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Carbon Dioxide (CO_2) Emission Reduction Technologies for Energy Intensive Industries in the United States

1. Introduction

Korea was the ninth largest CO_2 emitting country in the world in 2003 (CDIAC, 2006). Although Korea is currently not obligated to reduce CO_2 emission under the Kyoto protocol, it is expected to face binding international obligation on CO_2 emission reductions in the foreseeable future. In fact, in 1998, the national government announced a plan to voluntarily reduce greenhouse gas (GHG) emissions from the year 2018 (Byrne et al., 2004). Furthermore, due to the heavy dependence of domestic energy consumption on foreign imports, Korea will inevitably be exposed to geopolitical instability, occurring in oil-endowed regions, as well as global energy price volatility. Conventional supply-oriented energy strategy, particularly based on imported fossil fuels, may not be adequate to address the economic and environmental challenges posed by these situations.

In contrast, an approach that focuses on energy services in end-uses has great potential to deal with the problems presented by fuel scarcity and environmental impacts of conventional energy systems; this energy service focused approach incorporates improvement of energy efficiency, energy conservation and more sensible choices of energy technologies that appropriately match the quality and scale of the end-use energy needs. Efficiency opportunities provide substantial energy saving potential in energy intensive industries, particularly in South Korea, which currently uses more than one third of the country's total final energy consumption. These industries include: primary steel, oil refinery, petrochemical, cement and the paper/pulp industry (KEEI, 2006).

The purpose of this study is to identify five to ten of the most energy efficient technologies, currently used by energy intensive industries in the United States, and evaluate their potential savings in terms of energy, environment and the economy (E^3). In addition, the successful implementation practices of such technologies will be identified in order to assist the understanding of how and why these technologies were so successful.

2. CO_2 Emission Reduction Technologies

2.1 Classification of Industries

The industrial sector consumes about 33 % of all energy used in the United States. The Industrial Technology Program at the US Department of Energy (DOE) focuses on the eight most energy intensive industries—aluminum, chemicals, forest products, glass, metal casting, mining, petroleum refining and steel—for development of energy efficiency technologies and processes.

In this report, five industries, which are the most energy intensive industries in Korea, are considered: steel, petroleum refining, petrochemical, cement and paper and pulp. In order to identify energy efficient technologies and measures in these industries, the Industrial Assessment Center (IAC) database was used: this database was developed as part of a program carried out by Industrial Technology Program at US DOE, using on-site inspection of existing facilities to evaluate options and provide recommendations. To date more than 90,000 recommendations have been made by this program. Each recommendation is classified in accordance with the Standard Industrial Classification (SIC) code (Muller & Glaeser, 2004) and Assessment Recommendation Code (ARC), which represents the principal product manufactured by the plant and recommendation type, respectively. Table 2.1 shows the corresponding SIC code in bold for each industry. For example, the steel industries considered in this paper include blast furnace and basic steel products (SIC 331) and iron and steel foundries (SIC 332) within the category of the primary metal industry.

Table 2.1 Classification of Five Energy Intensive Industries by SIC Code

KEI	SIC Code
Steel	33xx (Primary metal industries) **331x: Blast furnace and basic steel products** **332x: Iron and steel foundries**
Refinery	29xx (Petroleum and coal products) **291x: Petroleum refining**
Petrochemical	28xx (Chemicals and allied products) **2869 Petrochemical**
Cement	32xx (Stone, Clay and Glass products) **324x: Cement, hydraulic**
Paper/pulp	**26xx (Paper and allied products)**

In addition to the IAC database, a number of studies conducted by other organizations including Lawrence Berkeley National Laboratory (LBNL) and Center for Analysis and Dissemination of Demonstrated Energy Technologies (CADDET) are also used in this report. The Energy Savings Assessment (ESA) report, which is now being conducted as part of US DOE's Energy Saving Now program, is also used. Since the method of assessing technologies is different in each study, the unit of energy savings may vary depending on the sources. Also, while some literatures contain information about Carbon Dioxide (CO_2) emission reduction, environmental improvement is not always clearly assessed for each technology. For those cases, CO_2 emission reduction can be estimated using typical energy savings and a CO_2 emission coefficient.

2.2 Criteria for Selection

Three criteria were used in the selection of the energy efficient technologies for the five energy intensive industries:

Electricity and fossil fuels saving technologies

There are four resource saving streams tracked in the IAC database: 1) energy savings; 2) waste reduction; 3) resource costs and 4) production. In this report, only energy saving is considered, particular attention has been paid to electricity and fossil fuel savings. This report is focused only on process-related technologies and measures. Operational and managerial technologies, such as energy management systems or process control systems, are not considered and general measures such as efficient lightings and insulation of buildings are also not discussed in this report due to the commonality of their implementation.

Payback period of less than 3 years

The economic feasibility of energy efficient technology can be evaluated by how quickly investment cost can be recovered. Payback period is used for this purpose, which is obtained by dividing implementation cost ($) by annual economic saving ($). For the purposes of this report, only technologies with a payback period of less than 3 years were considered.

Substantial energy savings potential: energy savings of more than 10%.

Conserved energy savings are important criteria for the selection of energy efficient technologies. Since the methods of calculating conserved energy differ study to study, uniform criteria cannot always be applied. In most cases, technologies and measures that resulted in energy savings of greater than 10% were selected. Technologies with relatively greater energy saving potential have been selected from the other literatures. For example, in case of the steel industry, technologies with energy savings of more than 0.3GJ/ton of crude steel were chosen from LBNL report.

2.3 Energy Efficiency Technologies and Measures

The energy efficiency measures and technologies in the IAC database are classified in accordance with the Assessment Recommendation Code (ARC) (Muller et al., 2004) for each industrial sector. This report will follow that classification.

2.3.1 Steel industry

The energy intensity of the U.S. steel industry in 1970-1990 was higher than that of South Korea, Germany, Japan or France. While the energy intensity of U.S. steel industry hovered around 25-30 MBtu[1] in the 1980s, the energy intensity of South Korea's steel industry, one of the most efficient steel industry in the world, was around 19-22 MBtu (Worrell et al., 1999). However, as shown in figure 2.1, the energy intensity of U.S. iron and steel industry has improved by 28% since 1990 because of long term commitments to energy efficiency improvement.

The steel industry uses energy both to supply heat and power for plant operations and as a raw material for the production of blast furnace coke. According to the most recent Manufacturing Energy Consumption Survey (MECS), the U.S. steel industry consumed about 2.0 quads (quadrillion Btu, or 10^{15} Btu) of energy in 1998 (including electricity losses incurred during the distribution, generation, and transmission of electricity). This represents about 1.5% of domestic energy use and about 6.7% of all U.S. manufacturing energy use (EIA, 2004).

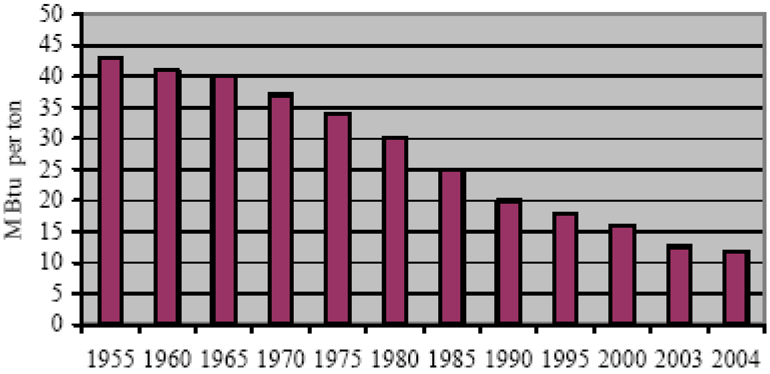

Figure 2.1 Energy Consumption per ton Shipped in U.S Steel Industry

Source: AISI, 2006

There are two different forms of steel production: production of primary steel using iron ore and scraps, and the production of secondary steel using scraps only (Worrell et al., 1997: 728). The primary (integrated) steel production consists of a number of process including iron ore preparation (sintering), coke making, iron making (blast furnace), steelmaking (Basic Oxygen Furnace, BOF), integrated casting, integrated hot rolling and integrated cold rolling. Secondary steel production consists of a steel making Electric Arc Furnace (EAF), casting and rolling. While primary steel production requires more fuel than electricity, secondary steel process using EAF requires more electricity than fuel.

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[1] 10^6 British Thermal Unit (Btu)

The iron-making process, the most energy intensive step in primary steel production, consumed 13.7 GJ/ton of fuel and 0.08 GJ/ton of electricity in 1994 in the U.S. On the other hand, the electric arc furnace, the most energy intensive process in secondary steel production, used 0.17 GJ/ton of fuel and 1.73 GJ/ton of electricity (Worrell et al., 1999).

Energy efficient technologies and measures for the steel and iron industry, in table 2.2, are drawn from the IAC database and LBNL's report (Worrell et al., 1999). The three criteria described in the previous section are applied to the IAC database and a criterion of 0.3 or more of fuel savings (GJ/tonne crude steel) is applied to Worrell et al.'s LBNL report (1999). It should be noted that the energy saving rate and payback period in the table is based on the assessment of a particular steel manufacturing facility; figures may vary depending on the system configuration. It should also be noted that the percentage of energy conserved is calculated by dividing saved energy by the total energy consumption for the IAC database.

Table 2.2 Energy Efficiency Technologies and Measures in Steel Industry

Energy efficiency technologies and measures	Conserved Energy Source	Energy Conserved (%)	Capital Cost (Simple Payback Period ,Year)	CO_2 Emission Reduction
Combustion system				
Furnace, ovens and directly fired operations				
Use insulation in furnaces	Electricity	20.6	\$790 (0.2)	93.2TC (20.6%)
Pulverized coal injection to 130kg/thm (blast furnace)*	Fuel	0.69GJ/tonne crude steel	\$6.24/tonne crude steel	11.42kgC/t
Injection of natural gas (blast furnace)*	Fuel	0.80GJ/tonne crude steel	\$4.46/tonne crude steel	13.45kgC/t
BOF gas and sensible heat recovery*	Fuel	0.92GJ/tonne crude steel	\$22/tonne crude steel	22kgC/t
Cokeless ironmaking†	Fuel	30	-	
DC-Arc furnace (EAF)*	Electricity	0.32GJ/tonne crude steel	\$3.90/tonne crude steel	14.42kgC/t
Scrap preheating, post combustion-Shaft furnace (FUCHS)*	Electricity Fuel	0.43GJ/tonne crude steel - 0.70GJ/tonne crude steel	\$6.0/tonne crude steel	9.62kgC/t
This slab casting (secondary casting)*	Electricity Fuel	0.57GJ/tonne 2.86GJ/tonne (fuel)	\$134.29/tonne crude steel	64.68kgC/t
Boilers				
Analyze flue gas for proper air/fuel ratio	Natural gas	10.6~17.0	\$16,564~50,000 (~3.0)	41.5~771TC (6~8%)

Fuel switching				
Replace electrically-operated equipment with fossil fuel equipment	Electricity	10.4	$65,000 (0.6)	248TC (13%)
Convert combustion equipment to burn natural gas	Fuel oil	32.9	$6,000 (~0)	562TC (36%)
Thermal system				
Steam				
Repair or replace steam traps	Fuel oil	14.3	$30 (~0)	131TC (28%)
Insulate steam and hot water lines	Fuel oil	13.8	$2,625 (0.2)	48TC (9%)
Heat recovery				
Use waste heat from hot flue gases to preheat combustion air	Natural gas	10.4~25.7	$8,250~88,000 (0.2~2.3)	24~530TC (5~16%)
Use waste heat from hot flue gases to generate steam	Natural gas	13.7	$25,000 (0.3)	375TC (11%)
Use heat in flue gases to preheat products or materials	Natural gas	11.2	$246,784 (1.7)	462TC (12%)
Use waste heat from flue gases to heat space conditioning air	Electricity	15.4	$3,577 (0.2)	280TC (32%)
Recover waste heat from equipment	Natural gas	12.3~15.1	$190,000~195,000 (1.5~2.0)	210~421TC (5%)
Insulate bare equipment	Natural gas	10.9	$5,181 (0.4)	41TC (6%)
Electrical power				
Cogeneration				
Use a fossil fuel engine to cogenerate electricity or motive power; and utilize heat	Electricity	14.6	$770,000 (1.8)	998TC (34%)
Motor system				
Air compressor				
Eliminate or reduce compressed air used for cooling, agitating liquids, moving products, or drying	Electricity	11.2~15.2	$660~1,580 (~0)	28~62TC (12~20%)
Eliminate leaks in inert gas and compressed air	Electricity	17.9	$9,300 (0.1)	299TC (19%)

lines/valves				
Other equipment				
Replace hydraulic/pneumatic equipment with electric equipment	Electricity	12.4~13.6	$18,900 (0.6)	109TC (14%)

Source: IAC database, Worrell et al. (2005) and EERE (2006a)
Note: Energy saving rate and payback period may vary based on the condition of individual plant. Carbon equivalent is obtained for IAC database using CO2 emission coefficient of 0.165TC/MWh for electricity (EIA, 2002a), 14.47 MTC/Quadrillion Btu for natural gas and 19.95 MTC/quadrillion Btu for fuel oil (EIA, 2002b). TC=ton of carbon equivalent.
* denotes energy efficiency measures identified by Worrell et al. (2005) at LBNL.
† denotes energy efficiency technology or measure identified in Energy Efficiency and Renewable Energy (EERE) at DOE (2006a).

Insulation of furnace

Ceramic low-thermal mass insulation materials (LTM) can reduce heat losses through the walls further than conventional insulations materials. A survey of steel reheating furnaces in the steel industry in four countries showed that approximately 30% of the furnaces had ceramic fiber linings (Flanagan, 1993, cited from Worrell, 1999).

Pulverized coal injection to 130 kg/t hot metal

The increase of hot metal from 2 kg/t to 130 kg/t hot metal in the blast furnace led to fuel savings of 0.77 GJ/t hot metal with capital cost of $7/t hot metal (Farla et al., 1998 cited from Worrell et al., 1999). The CO_2emission reduction is estimated to be 11.42kgC/t (Worrell et al., 1999).

Injection of natural gas to furnace

This measure is only applied to a portion of medium and small sized furnaces, defined as those with production rates of 1.3-2.3 Mt/year (Worrell et al., 1999). Natural gas injection can be used as an alternative to coal injection which is most commonly used today. The potential CO_2 emission reduction is substantial amounting to 13.45kgC/t (Worrell et al., 1999).

Basic Oxygen Furnace (BOF) gas and sensible heat recovery (suppressed combustion)

In the BOF process, crude steel is produced from molten iron and scrap along with other additives (manganese and fluxes). This is the most energy-saving process, making the BOF process a net energy producer. By reducing the amount of air entering over the converter, the CO is not converted to CO_2. The sensible heat of the off-gas is first recovered in waste heat boilers, generating high pressure steam (Worrell et al., 1999). The fuel saving is estimated to be 0.92GJ/tonne of crude steel. Material savings is another benefit of suppressed combustion. The BOF gas recovery technology reduces dust emissions, and since this dust contains high metal content, about 50% can be recycled in the sinter plant. Carbon dioxide emission reduction is estimated to be 22kgC/t (Worrell et al., 1999).

Cokeless ironmaking

The Mesabi Nugget developed a cokeless ironmaking technology, which turns iron ore into high quality iron nuggets in a rotary hearth furnace. The pilot plant produced 9,500 metric tons of iron nuggets superior in quality to direct reduced iron (DRI) and similar to blast furnace pig iron which is used most often. The iron nugget has 96-98 % purity reducing energy use by 30% and emissions by over 40% (EERE, 2006a: 20).

DC-Arc furnace

DC arc furnaces use direct current (DC) instead of conventional alternating current (AC). DC furnaces can power consumption up to 0.32GJ/tonne of crude steel. As well, it reduces tap-to-tap time and electrode consumption (down to 1.2-1.6kg/steel), increases refractory life, and improves stability (Worrell et al., 1999). It can be applied to large furnaces (80-130t heat size) but small furnaces are expected to remain AC systems. The disadvantage of a DC furnace is the up to 10-35% higher capital cost (Worrell et al., 1999). The reduction of carbon dioxide emissions is estimated to 14.42kgC/t.

Scrap preheating, post combustion-Shaft furnace (FUCHS)

Scrap preheating is a technology that can reduce the power consumption in EAF though using the waste heat of the furnace to preheat the scrap charge. One of the scrap preheating systems is a FUCHS shaft furnace, which consists of a vertical shaft that channels the off-gases to preheat the scrap. The potential power savings of this system is estimated to 100-120kWh/t. In addition, it can reduce electrode consumption, improve yield of 0.25-2%, and increase productivity up to 20%. Carbon dioxide emission reduction is estimated to 9.62kgC/t (Worrell et al., 1999).

Thin slab casting

Thin slab casting is a technology that integrates casting and hot rolling in one process. Electricity savings and fuel savings are estimated to be 0.57GJ/tonne crude steel and 2.86GJ/tonne crude steel respectively. Carbon emission reduction is substantial amounting to 64.68kgC/t (Worrell et al., 1999).

Analyze flue gas for proper fuel/air ratio (ARC 2.1233)

Adjusting the combustion system air-fuel ratio, as needed, to reduce the amount of excess air passing through the boilers and thus improve the combustion efficiency of the system. To determine the percent excess air or excess fuel at which a combustion system operates, the perfect or ideal air-fuel ratio (known as stoichiometric air-fuel ratio) is needed. When burned, it consumes all the fuel and air without any excess of either left over. If an insufficient amount of air is supplied to the burner, unburned fuel, soot, smoke, and carbon monoxide exhausts from the boiler. This results in heat transfer surface fouling, pollution, lower combustion efficiency, flame instability and a potential for explosion. To avoid inefficient and unsafe conditions, boilers normally operate at an excess air level. According to the IAC database, the average payback period is only 0.3 years (IAC, 2006)

Maintenance of Steam Traps (ARC 2.2113)

A steam trap holds steam in the steam coil until it gives up its latent heat and condenses. In a flash tank system without a steam trap (or a malfunctioning trap), the steam in the process heating coil would have a shorter residence time and not completely condense. The uncondensed high-quality steam would be then lost out of the steam discharge pipe on the flash tank. Comparing the temperature on each side of the trap can easily check steam trap operation. If the trap is working properly, there will be a large temperature difference between the two sides of the trap. A clear sign that a trap is not working is the presence of steam downstream of the trap. Nonworking steam traps allow steam to be wasted, resulting in a higher steam production requirement from the boiler to meet the system needs. It is not uncommon that, over time, steam traps wear and no longer function properly. The average payback period for the implemented maintenance of steam trap is 0.1 years (IAC, 2006).

Use Waste Heat from Hot Flue Gases to Preheat Combustion Air: Recuperation (ARC 2.2411)

It is possible to recover a high percentage of the heat from the gas that goes through the stack, and use it to preheat the combustion air, thus lowering natural gas consumption for the furnace. The heat from the stack gas will be recovered by either a recuperator or a regenerator heat exchanger. Usage of either one of these depends on if there are contaminants in the exhaust gas, if there are, it is necessary to use a regenerator (IAC, 2006).

Cogeneration (ARC 2.341)

Modern cogeneration systems are gas based, using either a simple cycle system (gas turbine with waste heat recovery boiler), a Cheng cycle or STIG (with steam injection in the gas turbine), or a combined cycle integrating a gas turbine with a steam cycle for larger systems. In particular, the latter is used to ‘re-power’ exiting steam turbine systems. Integrated steel plants produce significant levels of off-gases (coke oven gas, blast furnace gas, and basic oxygen furnace-gas). The steel and iron facility can use these gases to re-power the steam turbine, which may increase electricity generation to 1.1GJ/t for crude steel (Worrell et al., 1999).

Eliminate Incorrect Uses of Compressed Air (ARC 2.4232)

Compressed air generation is one of the most expensive utilities in an industrial facility. When used wisely, compressed air can provide a safe and reliable source of power to key industrial processes. Users should always consider other cost-effective forms of power to accomplish the required tasks and eliminate unproductive demands. Inappropriate uses of compressed air include any application that can be done more effectively or more efficiently by a method other than compressed air (IAC, 2006).

2.3.2 Petroleum refining industry

The petroleum refining industry is one of the largest energy consuming industries in the United States. In 2001, total final energy consumption is estimated at 3,025 TBtu. Primary energy consumption is estimated at 3,369 TBtu (Worrell & Galitsky, 2005). As shown in figure 2.1, refinery gas, natural gas and coke are the main fuels in the petroleum refining industry. Since refinery gas and coke are byproducts of the different process, natural gas and electricity represents the largest share of the purchased fuels in refineries. It is noteworthy that the relatively small share of electricity consumption is due to the fact that the refinery industry uses large amounts of self-produced electricity. In addition, the refinery industry is an energy intensive industry spending over $ 7 billion on energy purchase in the same year (Worrell & Galitsky, 2005).

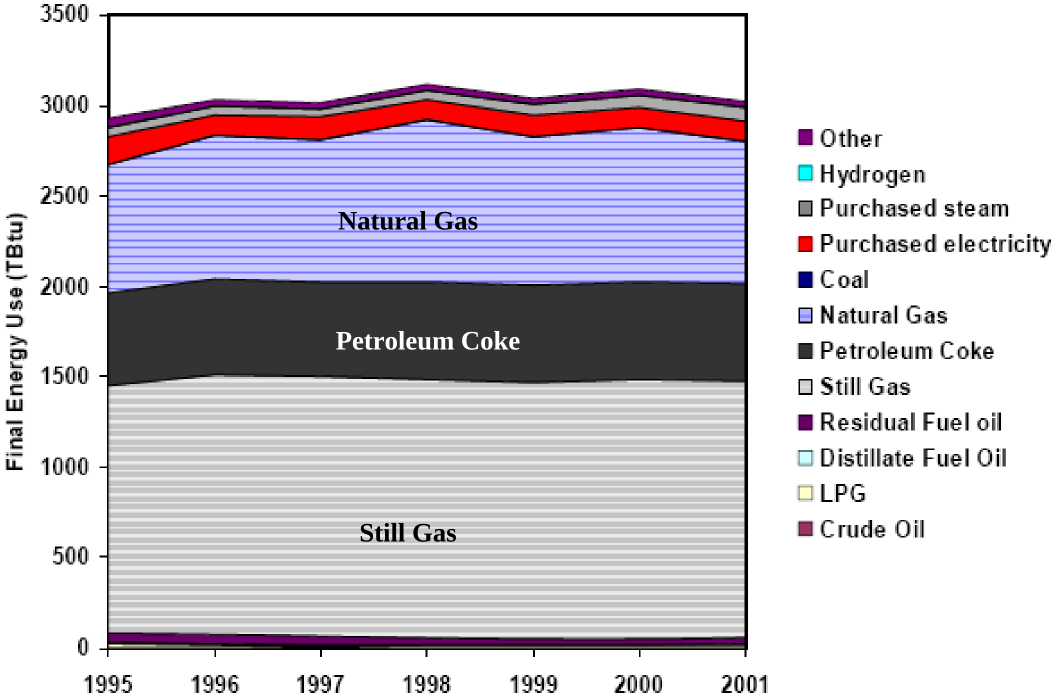


Figure 2.2 Annual Final Energy Consumption of U.S. Petroleum Refineries for the Period of 1995-2001

Source: Energy Efficient Improvements and Cost Saving Opportunities for Petroleum Refineries (Worrell & Galitsky, 2005, Originally from Energy Information Administration).
Note: The order in the legend corresponds with the order of fuels in the graph.

There is great energy saving potential in the refinery industry while maintaining or enhancing the productivity of the U.S. petroleum refining plant. According to Worrell et al. (2005), most petroleum refineries can economically improve energy efficiency by 10-20 %. The major areas for energy efficiency improvement are utilities (30%), fired heaters (20%), process optimization (15%), heat exchangers (15%), motor and motor applications (10%) and other area (10%) (Worrell et al., 2005). Table 2.3 shows the energy efficient technologies and measures in the petroleum refining industry identified by the IAC database and LBNL, which are classified based on the industrial process area.

It should be noted that while the percentage of energy savings for the IAC database represents the ratio of amount of energy conserved to the total energy consumption, rate of energy conserved (%) for LBNL represents the energy saving potential for the specific process. For example, improved insulation of boilers, boiler maintenance, improved insulation of steam distribution systems, steam trap maintenance and recovery of condensate are identified as energy saving technologies and measures in the steam generation, particularly boiler and distribution systems. The percentage of energy saving for these technologies and measures indicates the energy savings in the boiler system and steam distribution system. In the same manner, the percentage of energy conserved from adequate operation and maintenance and correcting sizing of the pumps represents the electricity savings for pumping.

Table 2.3 Energy Efficiency Technologies and Measures in Petroleum Refining Industry

Energy efficiency technologies and measures	Conserved Energy Source	Energy Conserved (%)	Capital Cost (Simple Payback Period, Year)	CO_2 Emission Reduction
Combustion system				
Boilers				
Improved insulation*	Fuel	6~26	-	
Boiler maintenance*	Fuel	10	(0)	
Fuel Switching				
Replace fossil fuel with electrical equipment (convert gas fired hydrogen compressor to electric motor drive)	Natural gas	10.0	$962,500 (2.6)	1,404TC (5%)
Install equipment to utilize waste fuel (recovery of flare gas)	Natural gas	32.4	$120,000 (1.2)	418TC (13%)
Thermal system				
Steam				
Improved insulation*	Fuel	3~13	(1.1)	
Steam trap maintenance*	Fuel	10~15	(0.5)	
Condensate return*	Fuel	10	(1.1)	
Progressive crude distillation*	Fuel	35	-	
Heat recovery				
Air preheating* for process heater	Fuel	8~18	(2.5)	
Motor system				
Pumps				
Operation and maintenance of pumps*	Electricity	2~7% of pumping electricity	(1)	

Correct sizing of pump (matching pump to intended duty)*	Electricity	15~25 of pumping electricity	(~1.0)	

Source: IAC database and Worrell and Galitsky (2005)
Note: Energy saving rate and payback period may vary based on the condition of individual plant. Carbon equivalent is obtained for IAC database using CO2 emission coefficient of 0.165TC/MWh for electricity (EIA, 2002a), 14.47 MTC/Quadrillion Btu for natural gas and 19.95 MTC/quadrillion Btu for fuel oil (EIA, 2002b). TC=ton of carbon equivalent.
* denotes energy efficiency measures identified by Worrell and Galitsky (2005).

Improve insulation in boilers
According to Worrell & Galitsky (2005), savings of 6-26% can be achieved if the improved insulation is combined with improved heater circuit controls. This improved control is required to maintain the output temperature range of the old firebrick system. As a result of the ceramic fiber’s lower heat capacity, the output temperature is more vulnerable to temperature fluctuations in the heating elements (Caffal, 1995 cited from Worrell et al., 2005).

Boiler maintenance
A simple maintenance program can result in substantial reduction of energy use and emissions. Appropriate measures are needed to control fouling of the fireside of the boiler tube or scaling on the waterside of the boiler (especially for coal-fed boilers), which reduces the heat transfer performance leading to energy loss and tube failure. According to Worrell & Galitsky (2005), a soot layer of 0.03 inches (0.8mm) reduces heat transfer by 9.5%, while a 0.18 inch (4.5mm) soot layer reduces heat transfer by 69%. For scaling, 0.04 inches (1mm) of buildup can increase fuel consumption by 2%.

Flare gas recovery
Reduction of flaring can be achieved by improved recovery systems, including installing recovery compressors and collection and storage tanks. This technology is commercially available. John Zink Co., the installer of the recovery system, reports that the payback period of recovery systems may be as short as one year (Worrell & Galitsky, 2005: 34-35).

Improve insulation of steam distribution system
Improving the insulation of the steam distribution system has substantial potential for energy savings and CO_2 emissions reductions as shown in figure 2.3 and 2.4. In order to improve steam insulation, insulating material should be used properly. Crucial factors in choosing insulating material include: low thermal conductivity, dimensional stability under temperature change, resistance to water absorption, and resistance to combustion (Worrell & Galitsky, 2005). In addition, tolerance of large temperature variations and system vibration, and compressive strength where insulation is load bearing are important factors that should be taken into account for certain applications (Worrell & Galitsky, 2005).

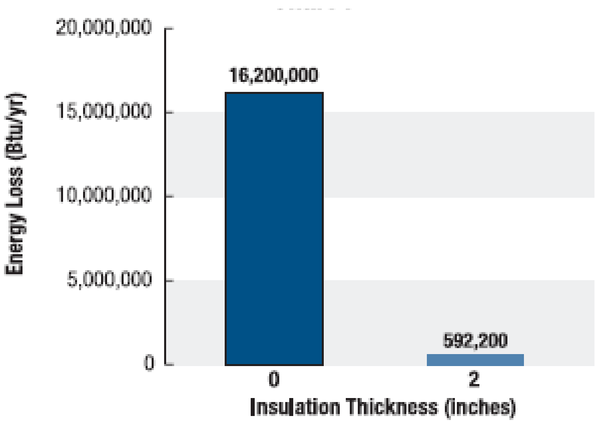


Figure 2.3 Thermal energy loss for bare versus insulted 4-inch pipe

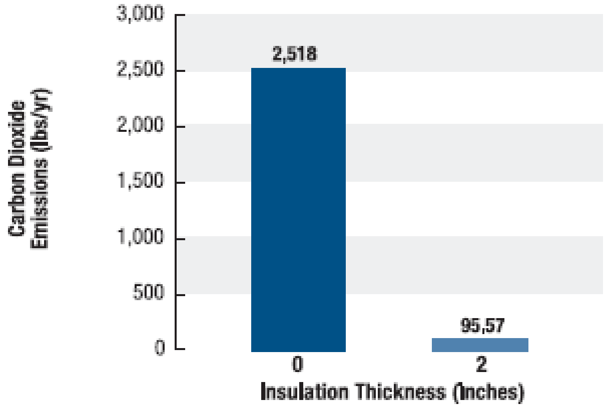


Figure 2.4 Carbon dioxide (CO_2) comparison for bare versus insulated 4-inch pipe

Note: data for 4-inch carbon steel pipe at 350F
Source: NAIMA 3E Plus Computer Program, Cited from ITP (2003)

Steam trap maintenance

A single program of checking steam traps to ensure that they perform properly can save substantial amounts of energy. Energy savings for a regular monitoring of steam trap and follow up maintenance is estimated at up to 10% with 0.5 years of payback period (Worrell & Galitsky, 2005). According to the EERE's report (2002), effective management of a steam trap program can save typical fuel of 3.0% for the steam trap system managed informally and 7.2% for the steam trap system that lacks proper management. The payback period for improving steam trap management program was reported to be 8 months. In addition, steam trap performance has a variety of effects on the steam system, including improved end-use equipment performance, better steam quality and a decreased risk of water hammering (EERE, 2002a).

Progressive crude distillation

The Crude Distillation Unit (CDU) is the major energy consuming process in the petroleum refining industry. Technip and Elf (France) developed an energy efficient design for a CDU, by redesigning the crude preheater and the distillation column (Worrell & Galitsky, 2005). The crude preheat train was separated in several steps to recover fractions at different temperatures. The distillation tower was re-designed to work at low pressure and the outputs were changed to link to the other processes in the refinery and product mix of the refinery (Worrell & Galitsky, 2005). The design resulted in reduced fuel consumption of up to 35%, compared to conventional CDU, and heat integration (reducing the net steam production of the CDU) (Technip, 2000 cited in Worrell & Galitsky, 2005).

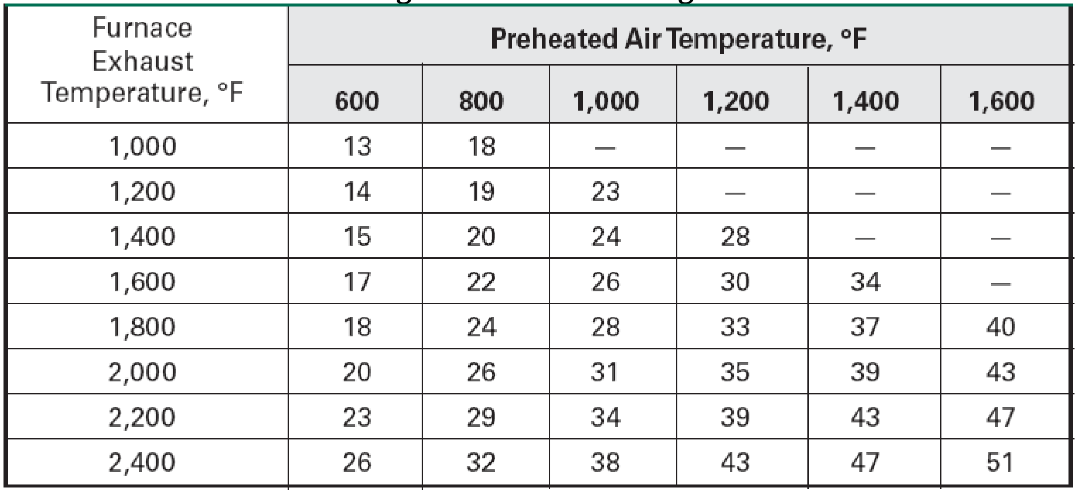
Return condensate

Optimizing condensate return for the reuse of boiler feed water can save substantial energy and improve boiler system efficiency. The maximum energy savings are estimated at 10% with a payback period of 1.1 years (Worrell et al., 2005). According to the EERE in US DOE (2002a), about 2% of typical fuel use can be saved by optimizing condensate return. An aditional benefit of condensate recovery is the reduction of the blowdown flow rate because boiler feed water quality has been increased (Worrell et al., 2005).

Air preheating

Flue gases from the furnace can be used to preheat the combustion air going to the burners. A heat exchanger, placed in the exhaust stack or ductwork, can extract a large portion of thermal energy in the flue gases and transfer it to the incoming combustion air (OIT, 2002). According to Worrell & Galitsky (2005), every 35º F drop in the exit flue gas temperature increases the thermal efficiency of the furnace by 1%. Typical fuel saving range between 8 and 18% and the typical payback period for combustion air preheating in a refinery is estimated at 2.5 years (Worrell & Galitsky, 2005). Fuel savings for different fuel gas temperature and preheated air temperature is estimated in the table 2.4, which can be used to estimate possible reductions in energy costs.

Table 2.4 Percent Fuel Savings Gained from Using Preheated Combustion Air



Furnace Exhaust Temperature, °F	Preheated Air Temperature, °F					
	600	800	1,000	1,200	1,400	1,600
1,000	13	18	—	—	—	—
1,200	14	19	23	—	—	—
1,400	15	20	24	28	—	—
1,600	17	22	26	30	34	—
1,800	18	24	28	33	37	40
2,000	20	26	31	35	39	43
2,200	23	29	34	39	43	47
2,400	26	32	38	43	47	51

Source: OIT (2002)

Operation and maintenance (O&M) of pumps

Proper maintenance of a pump system includes: replacement of worn impellers; bearing inspection and repair; bearing lubrication replacement; inspection and replacement of packing seals; inspection and replacement of mechanical seals; wear ring and impeller replacement and pump/motor alignment check (Worrell & Galitsky, 2005: 59-60). Typical energy savings for pumping operations and maintenance are estimated to be between 2-7% of pumping electricity use for petroleum refining industry. The payback period is about one year (Worrell & Galitsky, 2005: 60).

Correct sizing of pumps (matching pump to intended duty)

Pumps that are oversized can lead to unnecessary energy losses. Correcting for pump oversizing can save 15 to 25% of electricity consumption for pumping. In addition, pump load may be reduced by changing alternative pump configuration and improved O&M practices (Worrell & Galitsky, 2005).

2.3.3 Petrochemical industry

In 1998, the U.S. chemical industry (SIC 28) was the second largest consumer of energy in the manufacturing sector, using almost 7.3 quads of energy (including electricity losses), which represents 7% of all domestic energy use and over one-quarter of total U.S. manufacturing energy use (the largest industrial energy user is the petroleum refining industry) (ITP, 2004). In particular, this industry is the second largest consumer of natural gas accounting for over one-third of total US manufacturing use, and the largest consumer of liquefied petroleum gas (LPG), 95% of total manufacturing use (ITP, 2004: 2).

The petrochemical industry (SIC 2869) is a sub-sector of the chemical industry (SIC 28), which accounts for the largest primary energy consumption (33%) in the chemical industry followed by Industrial Inorganic chemicals not elsewhere classified (SIC 2819), plastic material and resins (SIC 2821), nitrogenous fertilizers (SIC 2873), industrial gases (SIC 2813) and alkalies and chlorine (SIC 2812) (see table 2.5).

Table 2.5 Primary Energy Use and Carbon Dioxide Emissions for Selected US Chemical Subsectors in 1994

Chemical Subsector	SIC code	Primary Energy (PJ)	CO_2 emissions form Energy Use (MtC)
Petrochemical Industry (Industrial Organics, nec)	2869	1,653	25
Industrial Inorganics, nec	2819	830	11
Plastic Materials and Resins	2821	518	7
Nitrogenous Fertilizers	2873	344	10
Industrial Gases	2813	364	4
Alkalies and Chlorine	2812	286	4
Others		1,146	16
Total Chemicals	28	5,141	77

Source: Worrell et al. (2000)

The petrochemical industry produces a wide variety of products, but the most energy is used for the production of some intermediate compounds. The key chemical products in petrochemical industry are ethylene, other steam cracking derivatives (propylene and butadiene) and methanol (Worrell et al., 2000). Table 2.5 shows the energy efficiency technologies and measures for the petrochemical industry identified in the IAC database. The percentage of energy conserved represents the ratio of energy savings to the total energy consumption.

Table 2.6 Energy Efficiency Technologies and Measures in Petrochemical Industry

Energy efficiency technologies and measures	Conserved Energy Source	Energy Conserved (%)	Capital Cost (Simple Payback Period, year)	CO_2 Emission Reduction

Combustion system				
Furnace, ovens and directly fired operations				
Improve combustion control capability (optimize the efficiency of hot air furnace at SAC unit*)	Natural gas	18.3	$240,000 (0.7)	853TC (14%)
Thermal systems				
Steam				
Repair or replace steam traps	Fuel oil	18.5	$500 (0.1)	16TC (13%)
Repair leaks in lines and valves	Natural gas	12.2	$13,000 (0.1)	583TC (10%)
Repair and eliminate steam leaks	Natural gas	11.2	$413,700 (~0)	36,480TC (8%)
Heat recovery				
Use hot process fluids to preheat incoming process fluids	Natural gas	9.0	$10,000 (0.7)	32TC (5%)
Electrical power				
Cogeneration				
Use waste heat to produce steam to drive a steam turbine generator	Electricity	50.0	$1,230,000 (1.9)	3,095TC (77%)

Source: IAC database
Note: Energy saving rate and payback period may vary based on the condition of individual plant. Carbon equivalent is obtained for IAC database using CO2 emission coefficient of 0.165TC/MWh for electricity (EIA, 2002a), 14.47 MTC/Quadrillion Btu for natural gas and 19.95 MTC/quadrillion Btu for fuel oil (EIA, 2002b). TC=ton of carbon equivalent.
* SAC: Sulphuric Acid Concentration

Improve combustion control capability (ARC 1116)

Process heating accounts for a large percentage of energy in most industrial systems—36% of the total energy used in industrial manufacturing applications (ITP, 2006a). Efficient process heating systems can contribute to saving natural gas and a reduction of emissions such as nitrogen oxide (NOx) and carbon dioxide (CO_2). There are a number of ways to save energy in a process heating system. One of the important methods is to control combustion more efficiently. According to Thekdi, energy saving potential for efficient combustion would be 5-25% and typical payback period would be less than 6 months with a short implementation period (less than 2 months). Typical activities are as follows:

- Maintain minimum required oxygen (typically 1-3 %) in combustion products from burners for fuel-fired process heating equipment or
- Control air-fuel ratio to eliminate formation of excess carbon monoxide (CO), typically more than 30-50 ppm, or unburned hydrocarbons eliminate or

- Eliminate or minimize air leakage into the direct-fired furnaces or ovens.

(Arvind Thekdi, from ITP, 2006a)

In July of 2006, EERE conducted an energy saving assessment for the three furnaces in Innovene Chocolate Bayou Plant which cracks petroleum and produces ethylene, propylene, butenes, Pygas, benzene, butadiene and polypropylene. The fuel savings are estimated to be 2,399MMBtu/yr, 3,123MMBtu/yr and 4,797MMBtu/yr respectively by adjusting the air/fuel ratio and reducing the oxygen level (EERE, 2006d).

Repair or replace steam traps (ARC 2113)

> "A steam trap holds steam in the steam coil until the steam gives up its latent heat and condenses. In a flash tank system without a steam trap (or a malfunctioning trap), the steam in the process heating coil would have a shorter residence time and not completely condense. The uncondensed high-quality steam would be then lost out of the steam discharge pipe on the flash tank. Comparing the temperature on each side of the trap can easily check steam trap operation. If the trap is working properly, there will be a large temperature difference between the two sides of the trap. A clear sign that a trap is not working is the presence of steam downstream of the trap. Nonworking steam traps allow steam to be wasted, resulting in higher steam production requirement from the boiler to meet the system needs. It is not uncommon that, over time, steam traps wear and no longer function properly" (IAC, 2006).

In steam systems that have not been maintained for 3 to 5 years, between 15% to 30% of the installed steam traps may have failed (ITP, 2006b). ITP recommends appropriate intervals for steam trap test:

- High-pressure (150 psig and above): Weekly to Monthly
- Medium-pressure (30 to 150 psig): Monthly to Quarterly
- Low-pressure (below 30 psig): Annually

Repair leaks in lines and valves (ARC 2133)

Any kind of leaks around valves and fittings in the lines may lead to a significant energy loss in manufacturing facilities. Depending on the nature of the substance in the lines, leaks may also result in a safety hazard (IAC, 2006). In table 2.6, repairing leaks in lines and vales in one of petrochemical facilities assessed by IAC led to the energy saving of 12.2% with a very short payback period.

Repair and eliminate steam leaks (ARC 2135)

> "Significant savings can be realized by locating and repairing leaks in live steam lines and in condensate return lines. Leaks in the steam lines allow steam to be wasted, resulting in higher steam production requirements from the boiler to meet the system needs. Condensate return lines that are leaky return less condensate to the boiler, increasing the quantity of required make-up water. Because make-up water is cooler than condensate

return water, more energy would be required to heat the boiler feedwater. Water treatment would also increase as the make-up water quantity increased. Leaks most often occur at the fittings in the steam and condensate pipe systems. Savings for this measure depend on the boiler efficiency, the annual hours during which the leaks occur, the boiler operating pressure, and the enthalpies of the steam and boiler feedwater" (IAC, 2006).

Use hot process fluids to preheat incoming process fluids (ARC 2444)

"Heat recovery systems are installed to make use of some of the energy which otherwise would be lost into the surroundings. Usually, the systems use a hot media leaving the process to preheat other, or sometimes the same, media entering the process. Thus energy otherwise lost, does useful work. Shell and tube heat exchangers are liquid-to-liquid heat transfer devices. Their primary application is to preheat domestic water for toilets and showers or to provide heated water for space heating or process purposes. The shell and tube heat exchanger is usually applied to a furnace process cooling water system, and is capable of producing hot water approaching 5 to 100F of the water temperature off the furnace" (IAC, 2006).

Use waste heat to produce steam to drive a steam turbine generator (ARC 3412)

Well designed cogeneration systems can save a significant amount of energy and reduce emissions. There are two types of heat-recovery system for cogeneration as shown in figure 2.5 and 2.6.

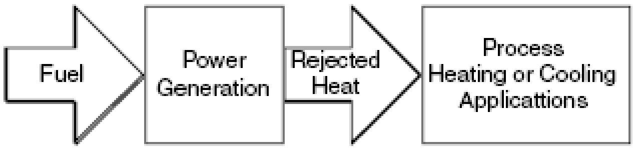


Figure 2.5 Topping-Cycle Schematic

In topping-cycle systems, fuel is first used to generate electricity. Waste heat from the prime mover (e.g., steam turbine, gas turbine, reciprocating engines, fuel cells, and microturbines) is then recovered and used for process heating or applications.

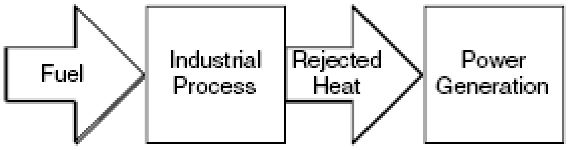


Figure 2.6 Bottoming-Cycle Schematic

On the other hand, in a bottoming-cycle system, high-temperature thermal energy is produced in boilers and first used for industrial applications. Waste heat recovered from the industrial process is then used to drive a turbine to produce electricity (ORNL, 2004).

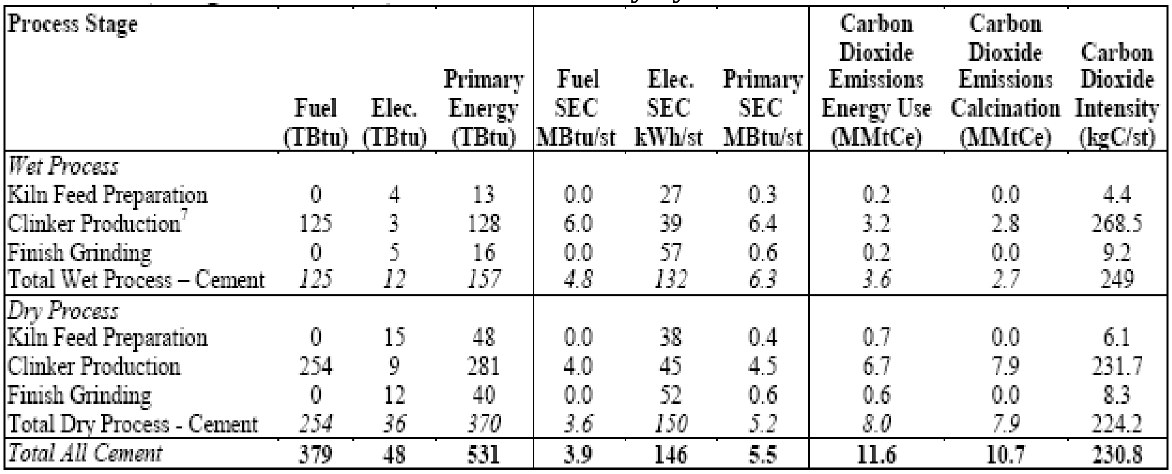
In the IAC recommendation database, about 50% of electricity is saved through using the waste process heat for electricity generation with a 1.9 year of payback period.

2.3.4 Cement industry

The U.S. cement industry consists of either portland cement plants that produce clinker and grind it to make finished cement, or clinker-grinding plants that intergrind clinker obtained elsewhere, with various addictives (Worrell & Galitsky, 2004). Portland and masonry cements are the chief types of products in the U.S. More than 90% of the cement produced in the U.S. in 1999 was Portland cement and masonry accounted for only 5% in the same year (Worrell & Galisky, 2004).

In 1999, the cement industry consumed 427 TBtu of final energy (about 2 % of total U.S. manufacturing energy use) and emitted 22.3 MtC of carbon dioxide (about 4 % of total U.S. manufacturing carbon emissions) (Worrell & Galitsky, 2004). As shown in table 2.7, clinker production is the most energy intensive stage, which consumes over 90% of the total industry energy, and is the largest CO_2 emitting process in cement production. There are two sources of carbon dioxide source in cement industry: the combustion of fossil fuels and the calcination of limestone. As shown in the table 2.7, in the production of clinker in the kiln, calcium carbonate (limestone) turns into calcium oxide (lime) and carbon dioxide (EERE, 2006b).

Table 2.7 1999 Energy Consumption and Specific Energy Consumption (SEC) in the U.S. Cement Industry by Process



Process Stage	Fuel (TBtu)	Elec. (TBtu)	Primary Energy (TBtu)	Fuel SEC MBtu/st	Elec. SEC kWh/st	Primary SEC MBtu/st	Carbon Dioxide Emissions Energy Use (MMtCe)	Carbon Dioxide Emissions Calcination (MMtCe)	Carbon Dioxide Intensity (kgC/st)
Wet Process									
Kiln Feed Preparation	0	4	13	0.0	27	0.3	0.2	0.0	4.4
Clinker Production[7]	125	3	128	6.0	39	6.4	3.2	2.8	268.5
Finish Grinding	0	5	16	0.0	57	0.6	0.2	0.0	9.2
Total Wet Process – Cement	*125*	*12*	*157*	*4.8*	*132*	*6.3*	*3.6*	*2.7*	249
Dry Process									
Kiln Feed Preparation	0	15	48	0.0	38	0.4	0.7	0.0	6.1
Clinker Production	254	9	281	4.0	45	4.5	6.7	7.9	231.7
Finish Grinding	0	12	40	0.0	52	0.6	0.6	0.0	8.3
Total Dry Process - Cement	*254*	*36*	*370*	*3.6*	*150*	*5.2*	*8.0*	*7.9*	224.2
Total All Cement	**379**	**48**	**531**	**3.9**	**146**	**5.5**	**11.6**	**10.7**	**230.8**

Source: (Worrell & Galitsky, 2004)

Note: “st” denotes “short ton,” a United States unit of weight equivalent to 2,000 pounds.

Energy efficient measures and technologies in the cement industry are identified from two sources. One is from IAC database which assessed 147 energy efficient measures and technologies in the cement industry and the other is Worrell & Galitsky’ study on energy efficiency technologies and measures for the U.S. cement industry published by Lawrence Berkeley National Laboratory (LBNL) in 2004. Since the energy saving rate is calculated differently, different criteria were used for selecting measures from the LBNL study: technology with energy savings of more than 0.2 MBtu/ton for fuel saving and 5.0 kWh/ton for electricity savings. The result is summarized in table 2.8 below.

Table 2.8 Energy Efficiency Technologies and Measures in Cement Industry

Energy efficiency technologies and measures	Conserved Energy Source	Energy Conserved (%)	Capital Cost (Simple Payback Period, year)	CO_2 Emission Reduction
Combustion systems				
Furnaces, ovens and directly fired operations				
Kiln combustion system improvement*	Fuel	~10% or 0.1~0.39 MBtu/ton (D)	(2~3)	2~7.8 TC/10^3ton
Indirect firing*	Fuel	0.13~0.19MBtu/ton (D)	$5,000,000 for annual production capacity of 680,000 tons	2.6~3.8 TC/10^3ton
Kiln shell heat loss reduction*	Fuel	0.1~0.34 MBtu/ton (D)	$0.23/annual ton clinker capacity (1)	2~6.8 TC/10^3ton
Thermal systems				
Cooling				
Conversion to grate cooler*	Fuel	8% (or 0.23 MBtu/ton) (D)	(1~2)	4.6 TC/10^3ton
Electrical power				
Install a cogeneration system†	Electricity	44%†	$12,540,000 (2.6)	9,823TC (67%)
Install a cogeneration system*	Electricity	18kWh/ton (D)		2.97 TC/10^3ton
Motor systems				
Motors				
High efficiency motors*	Electricity	8%	$0.2/annual ton cement capacity (~1)	N/A
Adjustable or variable speed drives*	Electricity	15~44%, or 7 kWh/ton cement	$75/kW for over 300kW, $120~140 for the range of 30~300kW (2~3)	1.16 TC/10^3ton

Source: IAC database and Worrell and Glaisky (2004)
Note: Energy saving rate and payback period may vary based on the condition of individual plant.

Carbon equivalent is obtained by using CO2 emission coefficient of 0.165TC/MWh for electricity (EIA, 2002a), 14.47 MTC/Quadrillion Btu for natural gas and 19.95 MTC/quadrillion Btu for fuel oil (EIA, 2002b). TC=ton of carbon equivalent.
* denotes energy efficiency measures identified by Worrell and Galitsky (2004) at LBNL.
† denotes energy efficiency measures identified by IAC.
D: Dry process

Kiln combustion system improvement
Clinker is produced by pyro-processing in large kilns. The kiln system evaporates the water in the raw material, calcine the carbonate constituents (calcination), and forms cement minerals (clinkerization). In the U.S., while many different fuels can be used in the kiln, coal has been the primary fuel since the1970s (Worrell and Galitsky, 2004: 5). Since clinker production is the most energy intensive process, the efficiency improvement measures in the kiln such as optimization of combustion and heat containment can contribute significant energy savings and emission reductions. In particular, fuel combustion systems in kilns can address inefficiencies associated with poorly adjusted firinig, incomplete fuel burn-out with high CO formation, and combustion with excess air (Worrell and Glitsky, 2004: 24).

Improved combustion systems in kilns aims to optimize the shape of the flame, the mixing of combustion air and fuel and reduce the use of excess air (Worrell & Galitsky, 2004: 24). There are some empirical data showing the effectiveness of the measures adopted in the cement production facility to increase efficiency of kiln combustion system. One technique developed in UK for flame control resulted in fuel savings of 2-10% depending on kiln type (Worrell and Galitsky, 2004: 24).

A recent technology has demonstrated the improvement of gas flame quality while reducing NOx emissions. Originally developed at the University of Adelaide (Australia), the Gyro-Therm technology can be applied to gas burner or gas/coal dual fuel. A demonstration project at an Adelaide Brighton plant in Australia found average fuel saving between 5 and 10% as well as an increase in output of 10% (CADDET, 1997. cited from Worrell and Glaitsky, 2004: 24). Another demonstration project at the Ash Gorve plant in the U.S. found fuel savings between 2.7% and 5.7% with increases in output between 5 and 9% (CADDET, 1998. cited from Worrell and Galitsky, 2004: 24).

Kiln shell heat loss reduction
There can be considerable heat losses through the shell of cement kiln, especially in the burning zone. Use of high temperature insulating linings for the kiln refractory bricks can reduce heat losses substantially (Worrell & Galitsky, 2004: 25). The coating helps to reduce heat loss and to protect the burning zone refractory zones. It is suggested that the high-temperature insulating linings for the kiln refractories can reduce fuel use by 0.1-0.34 MBtu/ton (Worrell and Galitsky, 2004, 25). The payback period is estimated to be one year.

Conversion to grate cooler
Modern reciprocating coolers have a higher degree of heat recovery than older variants, increasing heat recovery efficiency to 65% or higher, while reducing fluctuations in

recuperation efficiency. The advantage of the grate cooler are its large capacity (allowing large kiln capacities) and efficient heat recovery (the temperature of the clinker heaving the cooler can be as low as 83ºC, instead of 120~130 ºC, which is expected from planetary coolers (Worrell & Galitsky, 2004: 27). Grate coolers are widely used in large-scale kilns. In particular, it is economically attractive for the plants more than 500 tonnes per day. The energy savings are estimated to be up to 8% of the fuel consumption in the kiln and the payback period is between one and two years.

Heat recovery for cogeneration

There are a variety of sources of useful energy that can be converted into power in the cement industry: waste gas discharged from the kiln exit gases, the clinker cooler system, and the kiln pre-heater system. Among them, only in long-dry kilns is the temperature of the exhaust gas sufficiently high, to cost-effectively recover the heat though power generation. Cogeneration systems can either be direct gas turbines that utilize the waste heat, or the installation of a waste heat boiler system that runs a steam turbine system (Worrell & Galitsky, 2004: 29). Steam turbine systems are largely installed in many plants worldwide because of their economic attractiveness. According to the LBNL report, the energy savings of heat recovery for cogeneration is 18 kWh/ton of cement and the payback period is about 3 years.

High efficiency motors and drives

Motors and drives are used throughout the cement plant to drive fans (preheater, cooler, alkali bypass), rotate the kiln, transport materials and, most importantly, for grinding. Power savings through replacing old motors with high-efficiency motors may vary considerably on a plant-by-plant basis, ranging from 3% to 8%. The LBNL report estimates that electricity can be saved up to 5kWh/ton of cement and the payback period is less than one year (Worrell & Galitsky, 2004: 33).

Adjustable or variable speed drives

Drives are the largest power consumers in cement production. The energy efficiency of a drive system can be improved by reducing energy losses or by increasing the efficiency of the motor—the latter is described above. Decreasing throttling can reduce energy losses in the system and coupling losses through the installation of adjustable speed drives (ASD). In particular, load varies substantially in cement plants, energy savings are likely by operating the drives appropriately for various load conditions. Energy savings depends on the flow pattern and loads, ranging from 7 to 60%. ASD system is widely used in cement plants, especially applied for fans in the kiln, cooler, preheater, separator and mills, and for various dives (Worrell and Galitsky, 2004: 33). In addition, ASD can contribute to system control and reliability (ITP, 2004).

2.3.5 Pulp and paper industry

The U.S. pulp and paper industry consists of three primary types of producers: 1) *pulp mills*, which produce pulp from wood or other materials, primarily wastepaper; 2) *paper mills*, which produce paper from wood pulp and other fiber pulp; and 3) *paperboard mills*, which manufacture paperboard products from wood pulp and other fiber pulp (Martin et al., 2000).

There are three main pulping processes: mechanical, chemical and semi-chemical. Among them, sulphate pulp, or Kraft chemical pulp, is the dominant pulping process in the world, accounting for about 70% of world pulp production (CADDET, 2001). The chemical pulping process is the most common method for pulping wood, accounting for 82% of the wood pulp produced in the U.S. in 1994. Kraft pulping process is a dominant chemical pulp making process, accounting for over 95% of the chemical pulp production in 1994 (Martin et al., 2000). This process consists of several sub-processes: i) cooking process which includes chip preheating, steaming, impregnation and digestion; ii) oxygen delignification; iii) bleaching process; iv) drying process where the pulp is dried before transported to paper mill; and v) recovery process

The energy use in pulp production varies widely between mills, due to the equipment installed and the grades of pulp produced. For the production of bleached Kraft pulp, typical steam demand is between 10-14 GJ/ADMT[2] excluding steam for electricity production. In addition, lime kilns consume fuel amounting to about 1.5-2.5 GJ/ADMT (CADDET, 2001). The evaporation plant is the largest steam consumer in the mill, followed by drying and digester. In a Kraft pulp mill, cooking, evaporating and drying processes account for 60-80% of the steam demand for process heating (CADDET, 2001). Energy use in paper and paperboard production also varies with respect to the types of system and final products. In stock preparation process, electricity is mainly used because steam demand could be reduced to zero in a properly designed paper mill. According to CADDET (2001), in the stock preparation, the surface-sized uncoated fine paper is the largest electricity consumer, amounting to 250 kWh/tonne in 1995, followed by newspaper and paperboard. In many non-integrated-mills, the paper machine accounts for both the largest electricity consumption and the largest steam consumption. The table shows the energy consumption in paper machine.

Table 2.9 Energy Consumption in a Paper Machine

	Process heat (GJ/tonne)		Electric power (kWh/tonne)	
	1980	1995	1980	1995
Paperboard	6.9	5.8	994	554
Surface-sized, uncoated fine paper	8.5	7.1	525	420
Newspaper	6.0	5.3	563	585

---

[2] ADMT is an abbreviation of "Air-dried metric tones," which is used a measure of pulp and paper mill output.

Tissue	5-25	600-1,100

Source: CADDET
Note: The figures for 1980 represent average Swedish mills while the figures for 1995 represents a modernized mill that is not an average mill. The higher figures for tissue represent though-air-drying (TAD).

The energy efficient technologies and measures are based on the IAC database, LBNL report (2000) and CADDET analysis paper (2001). The LBNL report mostly focuses on state-of-the-art technologies that are currently implemented in the pulp and paper industry worldwide, while advanced technologies in the early stage of commercialization are not included. The LBNL (2000) report mainly focuses on retrofit measures. The three criteria described in the previous section are applied to the IAC database for selection. The percentage of energy conserved for the IAC database represents the ratio of energy saving to total energy consumption in a typical cement plant.

Table 2.10 Energy Efficiency Technologies and Measures in Pulp and Paper Industry

Energy efficiency technologies and measures	Conserved Energy Source	Energy Conserved	Capital Cost (Simple Payback Period, year)	CO_2 Emission Reduction
Combustion system				
Boiler maintenance[‡]	Fuel	10% (1.26 GJ/t)	(~0)	24TC/10^3t
Replace electrically-operated equipment with fossil fuel equipment	Electricity	20.3%	$21,794 (0.4)	73TC (34%)
Power boiler condensing economizer**	Natural gas	10%	$4,000,000 (1)	
Thermal system				
Steam trap maintenance[‡]	Fuel	1.79 GJ/t	(0.2)	34TC/10^3t
Energy efficient dryer[†]		50%	-	
Pre-evaporator*	Fuel	25% of steam (1GJ/ADMT)	-	
Continuous digester modification[‡]	Fuel	0.97GJ/t	(0.3)	18TC/10^3t
Batch digester modification[‡]	Fuel	3.20 GJ/t	(0.5)	61TC/10^3t
Electrical power				
Cogeneration: burn fossil fuel to produce steam to drive a steam generator and use steam exhaust for heat	Electricity	38.1%	1,200,000 (2.5)	1,483TC (69%)
Cogeneration: Combined Cycle Gas Turbine	Electricity	44.1%	(1.8)	618TC (30%)

Generator (CCGT)				

Source: IAC database, EERE (2006a), LBNL (2000) and EERE (2006c)
Note: Energy saving rate and payback period may vary based on the condition of individual plant. Carbon equivalent is obtained by using CO2 emission coefficient of 0.165TC/MWh for electricity (EIA, 2002a), 14.47 MTC/Quadrillion Btu for natural gas and 19.95 MTC/quadrillion Btu for fuel oil (EIA, 2002b). TC=ton of carbon equivalent.
† denotes energy efficient technology or measures are from EERE (2006a)
* denotes energy efficient technology or measures identified by CADDET (2001)
‡ denotes energy efficient technology or measures identified by LBNL (2000)
****** denotes energy efficiency technology and measure identified by EERE (2006c).

Boiler maintenance

A simple and proper boiler maintenance program can save substantial amount of energy as already described in previous section. According to Marten et al. (2000), in the absence of a good maintenance system, the burners and condensate return system can wear or get out of adjustment. With a proper boiler maintenance program, they estimate a 10% possible energy savings over 20% of all boilers in the pulp and paper industry in the U.S. Energy savings and carbon savings are estimated to 1.26 GJ/t and 11.3 kgC/t respectively. This measure is assumed to be accomplished for an additional $0.06/tonne paper with no additional start-up cost, which means the payback period is virtually zero (Martin et al., 2000).

Replace Electronically-Operated Equipment with Fossil Fuel Equipment

The cost of operating equipment with electricity can be 4 to 5 times the cost of using natural gas. In this regard, this recommendation should be taken into consideration whenever there are major pieces of equipment in operation that use electricity. Natural gas is one of the cleanest burning alternative fuels available, so this makes it a good choice for protecting the environment if the equipment is run by natural gas. Implementation of this measure would require purchasing natural gas burning equipment to replace the electric based equipment currently in use (IAC, 2006). According to the IAC assessment, this measure can save 20.3 percent of total energy consumption and the payback period is less than six months.

Power Boiler Condensing Economizer

EERE is conducting an Energy Saving Assessment (ESA) program as a part of the Energy Saving Now initiative. The purpose of this program is to identify immediate opportunities to save energy and money, primarily by focusing on steam and process heating systems. The final assessment report was completed for the Boise Alabama Operations Paper Mill located in Jackson, Alabama in 2006. One of the recommendations for this plant is installing a power boiler condensing economizer. According to the energy assessment, boiler efficiency can be improved by approximately 10% with the installation of a condensing economizer. The economic saving opportunity is estimated to $4,000,000/year while the gross cost of the system is estimated to approximately $4,000,000 which includes economizer and heat recovery system. The technology has been proved in small natural gas fired gas heaters, small natural gas fired water heaters, and small natural gas fired boilers. The technology has not been proven in industrial boilers but the benefits are considered significant. It is estimated that this system can reduce natural gas consumption by 10% (EERE, 2006c).

Steam trap maintenance

Steam traps remove condensed steam and non-condensable gases without losing any live steam. If not properly monitored, steam traps can vent a significant amount of useful steam. Simple inspection and maintenance can save a significant amount of energy for very little money. According to Martin et al. (2000), if the steam traps are not regularly monitored, 15-20% of the traps can be malfunctioning. Energy savings for a regular system of steam trap checks and follow-up maintenance is conservatively estimated at 10% or 1.79 GJ/t, which can be applied for 50% of steam trap systems in the pulp and paper industry. Carbon savings are estimated to 16.1 kgC/t in the industry (Martin et al., 2000).

Energy efficient dryer (evaporator)

Merrill's molded pulp products dryer uses superheated steam and oxygen suppression to improve molded pulp product drying. As water evaporates from the product, the vapor is superheated by indirect integral heaters, raising the temperature within the dryer. This allows faster drying at lower temperatures than conventional air dryer. It reduces energy use by 50% as well as scorching, burning, and discoloration of molded pulp products (EERE, 2006a: 10).

Pre-evaporator

Steam consumption in the evaporation plant could be reduced by connecting a flash steam pre-evaporator to the digester. According to CADDET (2001), 25% of the evaporation steam demand could be saved (about 1 GJ/ADMT).

Continuous digester modification

In the impregnation process in the cooking plant, cooking chemicals (sodium hydroxdide and sodium suphide) are added and absorbed by pre-steamed wood chips. In the digester, the wood chips and pulping liquors are heated to reaction temperature (about 160-170ºC). The cooking time is usually 2-4 hours (CADDET, 2001). In a continuous cooking system, the chips and white liquor are fed into the top of the digester in a continuous flow. Thus, unlike a batch digester, there is a continuous stream of chips into the digester and continuous exit stream of pulp (Martin el al., 2000). Indirect steam heaters or/and direct heating system with live steam are used for heating in digesters (CADDET, 2001). The continuous digest process is a more efficient technology than the batch digester. As of 1988, 50% of chemical pulp in the U.S. was produced using continuous digesters (Martin et al., 2000). While installation of a continuous digester needs substantial up-front investment, modification of the continuous digesters is economically attractive and energy savings and carbon emission reduction are also substantial. Energy savings and carbon emission reduction are estimated to 0.97GJ/t and 2.63kgC/t respectively and the payback period is only 0.3 years (Martin et al., 2000). Modifications of the continuous digesters focus on reducing the amount of material that must be heated and increasing the level of heat recovery. Measures include minimizing the liquor to wood ratio, improving the recycling of waste heat, use of heat exchangers, improved steam recovery, and increased insulation (Martin et al., 2000).

Batch digester modification

For smaller mills, it may not be operationally efficient to switch to larger batch digester in the digesting operation. In addition, specialty mills or mills that produce variety of type of pulp are less suited for continuous digesters. In this circumstance, batch digesters make more sense. There are several approaches to reduce energy consumption in batch digesters such as the use of indirect heating and cold blow. In indirect heating cooking liquor is withdrawn from the digester through a center pipe, pumped through an external heat exchanger, and returned into the digester at two separate locations in the vessel, thereby reducing direct steam loads (Martin et al., 2000). Energy savings are estimated to 3.2 GJ/t and the simple payback period is 0.5 years. Carbon reduction is estimated to 2.59kgC/t (Martin et al., 2000).

Cogeneration

Heat and power demands in the pulp and paper industry are largely met by on-site production with internal fuels. While a modern commercial pulp mill could be self-sufficient in both steam and electricity, most integrated pulp and paper mills, and stand-alone paper mills, have, and will continue to have, a need to purchase fuel and power. In the U.S., 61% of the industry is self-sufficient with respect to fuel and 56% self-sufficient with respect to electricity.

3. Case Studies

3.1 Using coke oven gas in a blast furnace in steel making plant

Coke is the essential input in the steel industry and is produced by heating coal in coke ovens where coke is heated in the absence of oxygen to drive volatile matter from it. Coke oven gas (COG), a by-product of coke manufacturing, is used as a fuel in a number of steel making processes such as coke oven, boilers and reheat furnaces. Because of variation of needs for the energy, particularly electricity and steam, US steel (USS) had to flare some of the COG during periods of low energy demand (EERE, 2000). In order to save energy, particularly natural gas, and reduce costs, USS installed a system at their Mon Valley Steel Works in Pittsburgh, Pennsylvania, that enabled them to recover COG to fuel the blast furnace. In order to use COG to replace some of the natural gas used in blast furnace, USS made modifications to a number of systems.

USS already had a state-of-the-art COG processing and cleaning facility at their coke plant. The facility processes the COG until its content is approximately 50-60 % hydrogen (EERE, 2000). USS installed three 900 horsepower compressors and the associated piping to boost the incoming COG pressure from 10 psig to 55 psig for injection into the furnace. Since COG would be not sufficient to replace natural gas required into blast furnace, USS purchased instrumentation and equipment so that natural gas could be added to supplement the COG. USS modified the blast furnace tuyeres (nozzles) that allowed them to successfully use the COG. They also modified the interior of the tuyeres to withstand the additional heat and added nozzles to the blowpipes through which the COG and hot blast are injected (EERE, 2000).

As shown in Table 3.1, USS' project to use COG in their blast furnace resulted in substantial energy savings, fuel and electricity cost reductions and COG emissions reductions. It is estimated that the annual savings is over $6.1 million. With total project costs of about $6 million, the payback period for the project was under one year (EERE, 2000).

Table 3.1 Using Coke Oven Gas in a Blast Furnace at Mon Valley Steel Works

Technology: Recovery of coke oven gas to fuel blast furnace

Company: Mon Valley Steel Works, U.S. Steel (USS)

Location: Pittsburgh, PA, USA

Project Start Date: January 1, 1996

Technical

- Three 900 hp compressors and associated piping were installed to boost incoming coke oven gas pressure
- Plant added instrumentation and equipment so that natural gas could be added to supplement the coke oven gas

Energy

- Decrease in purchase of natural gas by about 2,440,000 MMBtus annually
- Lowers overall electricity costs

Environmental
- Reduction of COG flaring by using recovered exhaust
- Reduction of emissions pollutants

Economics
- Total energy savings achieved through purchasing less natural gas to fuel blast furnaces is about $6.1 million annually
- Project cost was about $6 million
- Simple payback of slightly less than one year

For more information

http://www.caddet.org/infostore/display.php?id=3450
http://www.usx.com/corp/ussteel

3.2 Compressed air system optimization at forging plant

The Interstate Forging plant forges metal components for a variety of industries such as aerospace, automotive, agriculture and construction etc. Compressed air is vital to the plant's production processes including grinding and pressing applications and drop-forge hammers. In particular, the forging hammers are the most important compressed air application, and require a consistent pressure level of 95 pounds per square inch gauge (psig) to achieve reliable production (EERE, 2003b).

Before the project, the plant operators tried to maintain a system pressure of 100 psig by running five compressors totaling 900 hp. Despite operating all five compressors and using a 2,500-gallon storage receiver, the system pressure fluctuated between 85 and 100 psig. The fluctuation of system pressure caused erratic operation of drop-forge hammers, reducing product quality and increasing cycle time (EERE, 2003b).

The plant operators tried to purchase additional compressor to address this pressure fluctuation. However, when they consulted with DOE Allied Partner Pneumatech/ConservAir, it was found out that the plant could establish and maintain the required system pressure by operating fewer compressors. The Pneumatech/ConserAir found out that the hammer's intermittent air demand and insufficient compressed air storage were the main causes of the pressure fluctuations. Another problem was a substantial air leakage rate of 20 percent of system output (EERE, 2003b).

In order to stabilize the system pressure, the plant operator installed a Pressure/Flow Controller (P/FL) to separate the demand side of system from the supply side. In addition, 5,000 gallons of compressed air storage was installed just upstream of the P/FL. The plant personnel also initiated an innovative leak detection and repair program, which included redesigning the shaft seals on the counterbalance cylinder as well as detecting and repairing the leaks in the distribution piping (EERE, 2003b).

The project enable the plant to maintain a adequate and stable pressure level with fewer compressors, which led to improved product quality and lower production downtime. The project also could yield annual energy savings of 820,000 kWh and reduce energy cost by $45,000/year. The total project cost is $67,000 and the payback period is just 1.5 years. In addition, as the plant no longer needed a new compressor, capital cost of approximately $60,000 for a new 200 hp unit could be avoided (EERE, 2003b).

Table 3.2 Compressed Air Syste Optimization at Forging Plant

Technology: Compressed Air System Optimization

Company: Interstate Forging, Citation Corporation

Location: Milwaukee, Wisconsin, US

Project Start Date: N/A

Technical
- Installation of Pressure/Flow Controller (P/FL)
- Installation of 5,000 gallons of compressed air storage
- Detection and repair of leaks
- Redesign of the shaft seals on the counterbalance cylinders

Energy
- Saves 820,000 kWh annually

Environmental
- CO2 emission reduction in response to electricity savings

Economics
- Saves $45,000 annually
- Project cost was about $67,000
- Simple payback of 1.5 year
- Avoids a $60,000 capital cost for new compressor
- Improves system performance and product quality

For more information
http://www1.eere.energy.gov/industry/bestpractices/publications.asp.

3.3 Compressed air system improvement in cement plant

Compressed air systems are widely used in the cement industry and consume significant portions of the total electricity use for the sector. Lehigh Cement Company implemented a system-level project that aimed the improvement of the compressed air system at its Tehachapi cement plant. The project included stabilization of system pressure, replacement of some worn compressors with more efficient units and reduction of compressed air leaks (EERE, 2003a).

Lehigh Southwest Cement uses compressed air to serve dust collectors, cylinders, air knives, and pneumatic clutches. Before the project, four rotary-screw compressors served the compressed air system. The system's pressure fluctuated between 85 and 120 psig and the plant faced periodic production shut down because of low pressure. Lehigh Southwest Cement worked with two U.S. Department of Energy Allied Partners on the project. Air Solutions of New Mexico reviewed the compressed air system and Accurate Air Engineering of California assisted in implementing the project. They identified a number of problems that could be improved: unstable pressure level; lower set points for loading and unloading the compressors than their design set points, which caused the compressor to operate at 15% to 20% below their maximum efficiency; cleanness of the intake air to the compressors; convoluted distribution piping system and leaks in worn hoses and sub-headers; and finally, complex piping room which exacerbated the system's pressure drop (EERE, 2003a).

In order to stabilize the system pressure, the plant installed a pressure/flow controller (P/FC) along with a 5,000-gallon storage receiver. The plant also disposed of the 220-hp compressor and installed two new 350-hp rotary-screw units. To improve the intake air conditions, the company built a filter wall, which includes several ventilation fans to reduce the amount of dust in the intake air and sealed all doors to the compressor room. In addition, to reduce the compressed air leaks, the company replaced nonfunctional condensate traps are replaced with high-efficiency drain traps, repaired broken solenoids on the dust collectors and located and repaired the largest leaks in the sub-headers, drop piping and hoses (EERE, 2003a).

As shown in Table 3.3, the Tehachapi plant's project resulted in significant energy savings and economic benefits. After the project, the plant can satisfy its compressed air demand with reduced compressor capacity. An additional $50,000 per year is saved because the plant no longer needs to rent a 300-hp compressor; another $59,000 per year is saved through lower maintenance costs. In addition, the plant has not experienced any production shut down that can be linked to the compressed air system. With incentives from Southern California Edison (SCE), $90,000, the total cost of the project was $327,000. The simple payback period was less than 20 months (EERE, 2003a).

Table 3.3 Compressed Air System Improvement at Lehigh Southwest Cement Plant

Technology: Compressed air system improvement

Company: Lehigh Southwest Cements, Lehigh Cement Company

Location: Tehachapi in California, USA

Project Start Date: 2001

Technical

- Installation of a pressure/flow controller (P/FC) along with a 5,000-gallon storage receiver
- Replacement of 220-hp compressor with 350-hp compressor
- Improvement of the intake air conditions and supply-side distribution piping
- Reconfiguration of compressor room piping
- Repair the malfunctioning aftercoolers
- Replacement of non-functional condensate traps with high efficiency drain traps

- Repair broken solenoids on the dust collectors
- Repair leaks in sub-headers, drop piping and hoses

Energy

- Reduces annual energy consumption by 900,000 kWh

Environmental

- Reduction of CO_2 emissions in response to energy savings but not analyzed quantitatively in this project

Economics

- Saves $90,000 in annual energy costs
- Reduces annual maintenance cost by $59,000
- Payback period of less than 20 months

For more information

http://www1.eere.energy.gov/industry/bestpractices/publications.asp.

3.4 Cogeneration with gas turbine at Cascades Inc.

Cascade plant at Kingsey Falls in Quebec, Canada, installed a gas turbine in cogeneration system to produce electricity and steam. Before the installation of this system, the plant used a conventional steam boiler plant to dry paper. The cogeneration system consists of two turbine-alternator groups of simple cycle system generating 16 MW of electric power at 13,800 volts. The turbine exhausts heat water to generate 40,920 kg/hour of saturated steam at 1,965 kpa. The energy efficiency increased from 30% to 80% and supplied energy for continuous paper production (CADDET, 2006).

The cogeneration system generates 140,000 MWh/year of electricity which is sold to Hydro-Quebec, and produces an additional 360,000,000 kg/year of steam. The fuel consumption is approximately 73,000,000 m^3/year of natural gas at standard pressure. The investment cost for the construction of the cogeneration plant was CAD 20,000,000. The fuel cost varies between CAD 11,500,000 and CAD 12,500,000/year (based on CAS 0.15/ m^3 for natural gas) and the maintenance cost is approximately CAD 650,000/year. The sale of electricity to Hydro-Quebec was 7,300,000 (CAD 0.052/kWh) and the production of steam from the cogeneration saved CAD 9,500,000 (CAD 26.5/1,000kg of steam). Under these conditions, the plant expects to recover its investment within five years (CADDET, 2006).

The use of natural gas and the efficiency of the gas turbine produces less emission than government standards: there are no SO_2 emissions; NOx emissions are 10 times less than the standards and the CO_2 emissions are reduced by 60% compared to a fuel oil boiler (CADDET, 2006).

Table 3.4 Cogeneration with Gas Turbine at Cascades Inc.

Technology: Cogeneration with gas turbines

Company: Cascades, Inc.

Location: Kingsey Falls, Quebec, Canada

Project Start Date: N/A

Technical

- Before the installation of this system, Cascades Inc. used a conventional steam boiler plant to dry paper
- Cogeneration system consists of two turbine-alternator groups of simple cycle system
- Turbines produce 16 MW of electric power at 13,800 volts
- Exhaust heats water to generate 40,920 kg/hour of saturated steam at 1,965 kpa

Energy

- Fuel consumption is approximately 73,000,000 m^3/year of natural gas at standard pressure
- Generates 140,000,000 kwh/year of electricity which is sold to Hydro-Quebec
- Produces an additional 360,000,000 kg/year of steam

Environmental

- No SO_2 (acid rain) emission
- Emission of NOx is 10 times less than government standards
- CO_2 emissions are reduced by 60% compared to a fuel oil boiler

Economics

- Investment cost for the construction of the cogeneration plant was CAD 20,000,000
- Operational cost varies between CAD 11,500,000 and CAD 12,500,000/year
- Maintenance cost is approximately CAD 650,000/year
- Sale of electricity to Hydro-Quebec corresponds to CAD 7,300,000
- Production of steam yields an approximate cost saving of CAD 9,500,000

For more information

http://www.caddet.org/infostore/display.php?section=7&id=1532

3.5 Boiler blowdown heat recovery project at Augusta Newsprint

The boiler blowdown process involves the periodic or continuous removal of water from a boiler to remove accumulated dissolved solids and/or sludges. In this process, water is discharged from the boiler to avoid negative impacts of dissolved solids or impurities on boiler efficiency and maintenance. While the blowdown process is essential for continued operation of any steam boiler, it represents an energy loss because boiler blowdown water is at about the same temperature as the steam produced. Much of this heat can be recovered by routing the blowdown liquid through a heat exchanger that preheats the boiler's makeup water (EERE, 2002b).

Augusta Newsprint mill produces up to 440,000 metric tons of standard newsprint each year from southern pine and recycled paper and magazines. The plant has two paper machines and employs 380 workers. As shown in Figure 3.1, Augusta plant personnel modified existing boiler blowdown system to recover the energy from the flash tank. A plate-and-tube heat exchanger and associated piping was installed (Figure 3.1). The hot boiler blowdown water, 380 ºF, was routed to the "hot side" of the heat exchanger to preheat the make up water passing through the other side of the heat exchanger (EERE, 2002b).

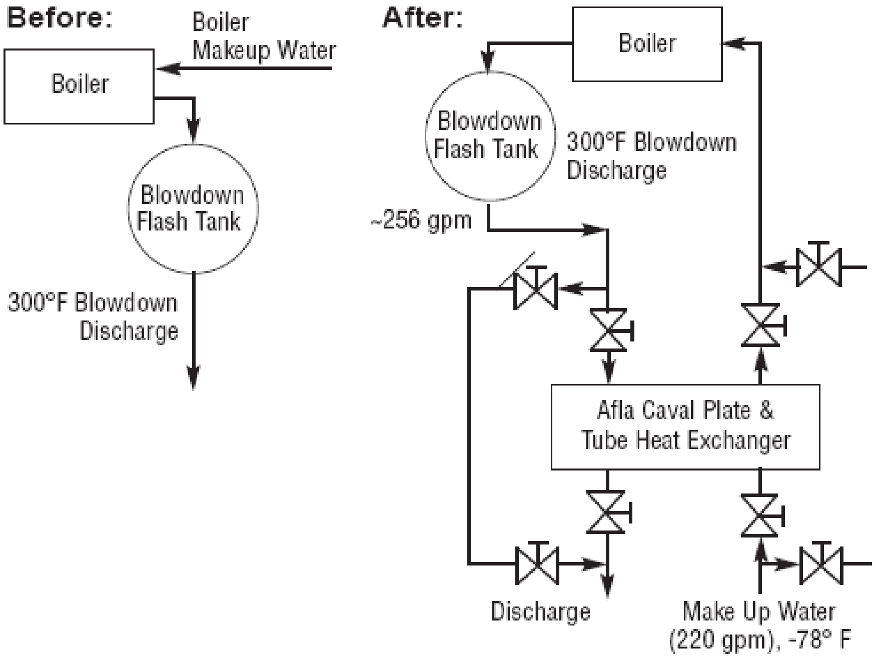


Figure 3.1 Blowdown System Before and After Installation

The blowdown heat recovery is estimated to save almost $31,000 in annual fuel cost by preheating the boiler feedwater by 17 ºF. The total cost of this project is $15,000 and the simple payback period is about 6 months. The total energy savings is expected to be 14,000 MBtu annually.

Table 3.5 Boiler Blowdown Heat Recovery at Augusta Newsprint

Technology: Boiler Blowdown Hear Recovery System

Company: Augusta Newsprint

Location: Augusta, GA, USA

Project Start Date: 2002

Technical

- Installation of a plate-and-tube heat exchanger and associated piping to preheat the boiler feedwater

Energy

- Annual fuel saving is 14,000 MBtu (based on feedwater flow of 220 gallon per minute, a temperature differential of 17 ºF and a fuel cost of $2.33 per 1,000 pounds of steam)

Environmental
- CO_2 emissions are reduced in response to the energy savings

Economics
- $31,000 annual savings in fuel costs
- 6-month simple payback period

For more information
http://www1.eere.energy.gov/industry/bestpractices/publications.asp.

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