The feasibility of waste heat recovery and energy efficiency assessment in a steel plant

by

Minxing Si

A thesis submitted to the Faculty of Graduate Studies of

the University of Manitoba

in partial fulfilment of the requirements of the degree of

Master of Natural Resources
Management

The Clayton H. Riddell Faculty of Environment, Earth and Resources
Natural Resources Institute
University of Manitoba
Winnipeg, Manitoba
R3T 2N2

UNIVERSITY OF MANITOBA

FACULTY OF GRADUATE STUDIES
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Abstract

Gerdau Manitoba Mill (Gerdau) at Selkirk, Manitoba is one of the biggest energy consumers in the province of Manitoba. This research analysis undertaken at Gerdau evaluated opportunities for energy efficiency, including the following six areas: 1) recovering waste heat to preheat billets, 2) upgrading the charge end in the reheat furnace, 3) recovering waste heat to preheat combustion air in the ladle preheater, 4) replacing direct-fired natural gas heaters with indirect-fired natural gas heaters, 5) Oxyfuel combustion, and 6) "tap to tap time" control in the eccentric bottom tapping (EBT) furnace in the melt shop. As part of this research, end-user distribution was analyzed and energy losses were assessed. An end-use analysis found that the melt shop that includes the EBT furnace is the biggest consumer of electricity consumption (kWh) and electric demand (kVa), which accounted for 68.7% and 73.6 % respectively. The 2010 delay time in the power-off time of EBT furnace at Gerdau was found to be 762.3 hr/yr. Further research to analyze the cause of each downtime at Gerdau is recommended to determine how these unplanned downtime can be reduced in the EBT furnace.

The reheat furnace is the biggest natural gas consumer at Gerdau with 437,563 MCF in 2010. Flue gas losses from the reheat furnace are the biggest energy losses in the gross heat distribution with 26,874,657 Btu/hr. Energy losses from hearth and roof by heat transmission are the biggest energy losses in the net heat distribution during operation, which accounted for 8.9%. The average thermal efficiency in the reheat furnace at Gerdau is 58.9% ± 3.6%. Compared to peak capacity, idle and partial operations of the reheat furnace and idling were found to be less efficient.

The opportunities that are considered feasible and recommended to Gerdau are: 1) recovering waste heat to preheat billets, 2) upgrading the charge end in the reheat furnace, 3) recovering waste heat to preheat combustion air in the ladle preheater, 4) replacing direct-fired natural gas heaters with indirect-fired natural gas heaters. These are both good for the environment, reducing fuel use and emissions and providing a good payback period and annual savings. Many opportunities are available for reducing energy as provided in Table A, which shows emissions reductions, costs, energy savings and

payback. Oxyfuel combustion is not deemed feasible without considering productivity improvement as oxygen cost is more than natural gas saving.

A number of incentive programs, including those from Manitoba Hydro, are applicable to Gerdau. However, a number of barriers to accessing these, particularly as regards tax incentive programs, should be explored to see if these barriers can be overcome.

Table A: Summary of project identified at Gerdau in the performance optimization program

	Environment		Economic			
Project name	CO_2 reduction (ton/yr)	Fuel saving (MM Btu/yr)	Annual saving /cost ($/yr)	Initial Cost ($)	Payback period (yr)	Feasibility (Y/N)
Preheating billets to 600 °F*	2,999	57,175	$ 468,838	$ 1,250,000	3.0	Y
Upgrading charge end	441	8490	$ 69,620	$ 200,000	2.9	Y
Recovering waste heat in the ladle preheater	1,081	20,800	$ 170,560	$ 144,017	0.8	Y
Replacing direct-fired natural gas heaters**	284	5,472	$ 44,870	$ 200,000	4.5	Y
Oxyfuel	9,670	535,468.8	$ (3,167,557.9)	----	----	N
* Initial cost is estimated based on preheating section is 150 feet long. Preheating billets to 600 °F, 400 °F and 200 °F is estimated to result in annual energy saving of 22.4%, 14.4% and 4.8%, respectively.						
** Replacing direct-fired natural gas is to comply with Canada's natural gas installation code, the energy saving depends on operating capacity.						

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Glossary of Terms

EBT - Eccentric Bottom Tapping

BOF – Basic Oxygen Furnace

EAF – Electric Arc Furnace

Gerdau – Gerdau Manitoba Mill

GMRM – Gerdau Metallics Raw Materials

GHG – Greenhouse Gas

GLSNA – Gerdau Long Steel North America

IEA – International Energy Agency

IPCC – Intergovernmental Panel on Climate Change

NSSI – North Star Steel Iowa plant

PHAST – Process Heating Assessment and Survey Tool

RET – Renewable Energy Technology

TCI – TC Industry

WCI – Western Climate Initiative

Chapter 1 Introduction

1.1 Background

Steel is a critical material for a nation's development being a major raw material for wide variety of infrastructure in buildings, energy, transportation, and water supply. As steel is continuously recyclable, it is a highly desirable environmental material. However, the steel industry is one of the most energy - intensive industries in the world, as it requires high temperatures to melt, and also a significant contributor of greenhouse gas (GHG) emissions. Globally, steel production amounts to approximately 1.6 billion tons CO_2 per year, accounting for 7% of global anthropogenic emissions (Kim & Worrell, 2002). The total GHG emissions are categorized into two sources: 1) process related emissions, such as steel liquid decarburization, electrode graphite consumption, etc. and, 2) energy related emissions, such as burning natural gas and energy consumption (Kirschen, Risonarta, & Pfeifer, 2009). In the iron and steel sector, there are many opportunities to improve energy efficiency and reduce GHG emissions, including enhancing continuous production processes, waste energy recovery, and changing from primary to secondary production routes (Bernstein et al., 2007; Gale & Freund, 2000).

The Canadian steel industry accounted for 2% of Canada's primary energy consumption, and 7.5% of industrial energy demand (The Canadian Industry Program for Energy Conservation, 2002). The annual sale of steel sector is more than $14 billion with 30,000 direct jobs in Canada (Canadian Steel Producers Association, 2008). In Canada, steel is produced at 13 plants in five provinces (Albert, Saskatchewan, Manitoba, Ontario and Quebec). This research 1) analyzes the feasibility of waste heat recovery to preheat billets and 2) assesses energy efficiency opportunities at a steel plant, Gerdau Manitoba Mill (Gerdau) at Selkirk, Manitoba.

1.2 Company background

Gerdau Long Steel North America (GLSNA) is the second largest mini-mill (scrap–based electric arc furnace) steel producer and steel recycler in North America. The annual manufacturing capacity of GLSNA is over 12 million tons of finished steel products (Gerdau, 2010a). Gerdau accounted for 3% of GLSNA's production (Gerdau, 2010a). Gerdau has served the industrial sector of Manitoba for over 100 years. It is one of the biggest energy consumers in Manitoba using natural gas and electricity. In 2010, natural gas and electricity consumption at Gerdau were 650,752,545 cubic feet and 253, 078,005 kWh, respectively (Gerdau, 2010b).

In the first step of the Gerdau process, scrap metal is melted into liquid steel in the eccentric bottom tapping (EBT) furnace at 2600 °F – 2800 °F, then the liquid steel is sent to the ladle furnace where steel is homogenized, desulphurized and dephosphorized. The deoxidized, clean molten steel is then delivered to the tundish where the liquid steel supplies the continuous casting machine. The steel is casted directly into semi-finished shapes (slabs and billets). The semi-finished products are then stored at ambient outdoor temperature (36 °F) (Natural Resources Canada, 2009) at the billet bay before being transported to a reheat furnace where they are heated up to 2200 °F (Gerdau, 2008). The reheat furnace is 74 feet long and currently individual billets need to be reheated in the furnace for approximately two hours. Finally, semi-finished products are transported to the rolling mill and rolled into the finished products (Gerdau, 2009a) (Figure 1).

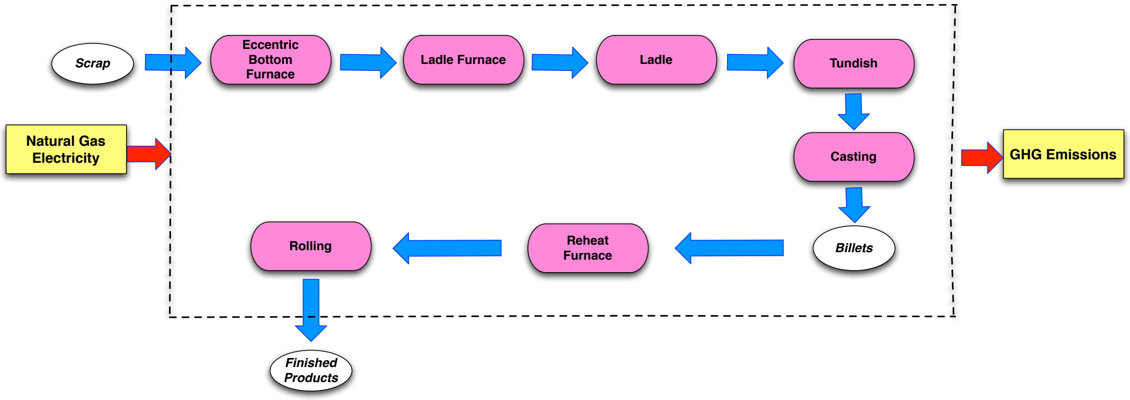

Figure 1: Simplified production process in Gerdau

1.3 Purpose and objective

The purpose of this research is to analyze the feasibility of waste heat recovery and assess energy efficiency in the reheat furnace and other areas in Gerdau at Selkirk, Manitoba. This research seeks to find solutions to real world.

The main objectives of this research are:

- To analyze energy end-user distribution at Gerdau for energy saving calculation;
- To collect waste heat data at billet bay to analyze energy recovery feasibility; and
- To assess energy efficiency to identify energy efficiency potential.

1.4 Benefits of research

This research provides the following environmental and economic benefits for sustainability. This research was able to accomplish the following:

- Determined the size needs for a preheating box. Although previous research discussed the feasibility of preheating technology, an analysis of the requirements for the size of the preheating box and the rate of heat transfer through preheating had never been determined prior to this research.

- Compared two tools, Process Heating Assessment and Survey Tool (PHAST) and Renewable Energy Technology Screen (RETScreen), to evaluate their ability to determine energy efficiency and emissions in the steel industry.
- Identified barriers to energy efficiency and proposed recommendations for balancing environmental and economic benefits for sustainable development.

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Chapter 2: Literature review

2.1 Introduction

Crude steel production has reached 1.7 billion tons in 2010 and increased by 15% in comparison with production in 2009 (World Steel Association, 2011). The total emissions of steel production were estimated to be 1.6 million tons CO_2 per year, including process related emissions and energy related emissions, and it accounted for about 7% of global anthropogenic emissions (Kim & Worrell, 2002). In 2010, Canada's steel production was 13 million tons (World Steel Association, 2010), Gerdau accounted for 2.7% of Canada's steel production (Gerdau, 2010). The total emissions of Gerdau in 2010 were 46,141 CO_2-eq ton, including 33,752 CO_2-eq ton from stationary combustion emissions (natural gas) and 12,389 CO_2-eq ton from process emissions (Gerdau, 2010). Reducing energy consumption in steel industry becomes an important step for sustainable development.

2.2 Climate change

Evidence strongly indicates that increasing GHG in atmosphere results in climate change (Tans, 2009). Unfortunately, CO_2 emissions are long–lived GHG emissions. About 20% of CO_2 emissions today will remain in atmosphere more than 1000 years (Reisinger, 2009). National Oceanic & Atmospheric Administration stated that CO_2 concentration increased dramatically from 2000 to 2009 (figure 2) (Tans, 2009). Even under the most ambitious scenario that CO_2 emissions will reach its peak around 2015 and decline to zero by 2100 in the fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2007), the global temperature is predicted to increase by 2 to 2.4 °C from its pre-industrial level. This temperature shift will result in 20% to 30% of all species having a higher risk of extinction (IPCC, 2007). Some key ecosystems, such as coral reefs and Arctic sea ice, are faced with significant challenges in the next decades, (Eisenman & Wettlaufer, 2009; Fischlin et al., 2007; Reisinger, 2009; Silverman, Lazar, Cao, Caldeira, & Erez, 2009). Therefore, GHG emissions require further reduction.

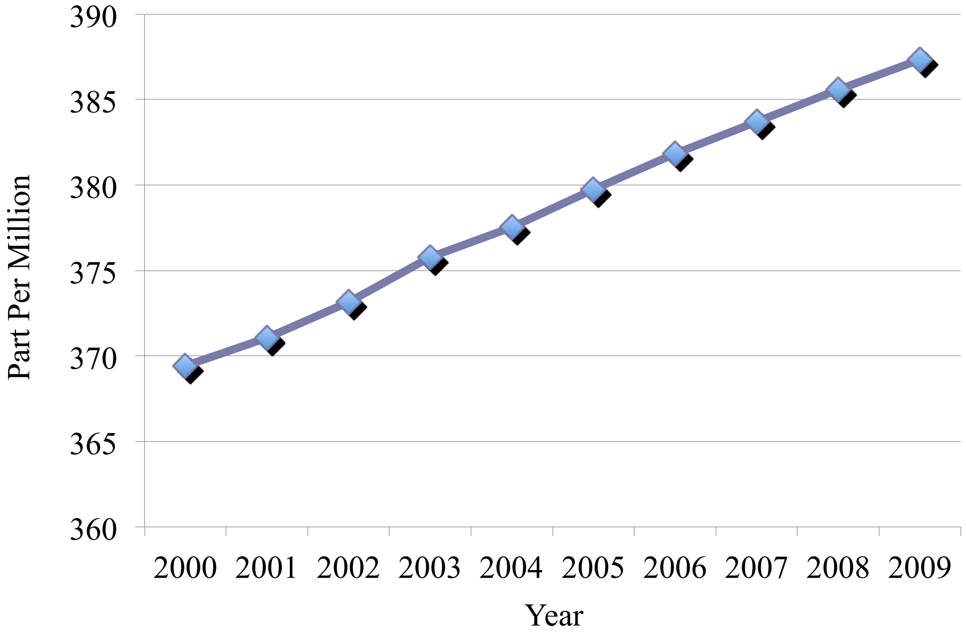

Figure 2: Recent yearly mean CO_2 at Mauna Loa

Source: Adapted from Tans, 2009

The line with square symbols represents the yearly mean values of carbon dioxide after correction for the average seasonal cycle.

2.3 Industry and climate change

Industry accounts for almost 40% of worldwide energy consumption, contributing almost 45% of global GHG emissions (Fisher et al., 2007). See Figure 3 that shows GHG emissions by sectors. These GHG emissions are from three sources: 1) energy generation by fossil fuels, either directly by industry for heat and power generation or indirectly in the generation of purchased electricity and steam; 2) the non-energy uses of fossil fuels in industrial production process, and 3) the non-fossil fuel sources (Worrell, Bernstein, Roy, Price, & Harnisch, 2009). A few energy intensive industries, other than power generation, are the main sources of GHG emissions. Those energy - intensive industries are: cement, oil refining and petrochemicals, aluminum, and iron and steel manufacturing industries (Gale & Freund, 2000). In 2004, those energy - intensive industries accounted for approximately 85% of industrial sector's energy consumption globally (Bernstein, et al., 2007). Moreover, production processes in those most energy - intensive industries also emit other GHGs, other than CO_2, such as N_2O and methane.

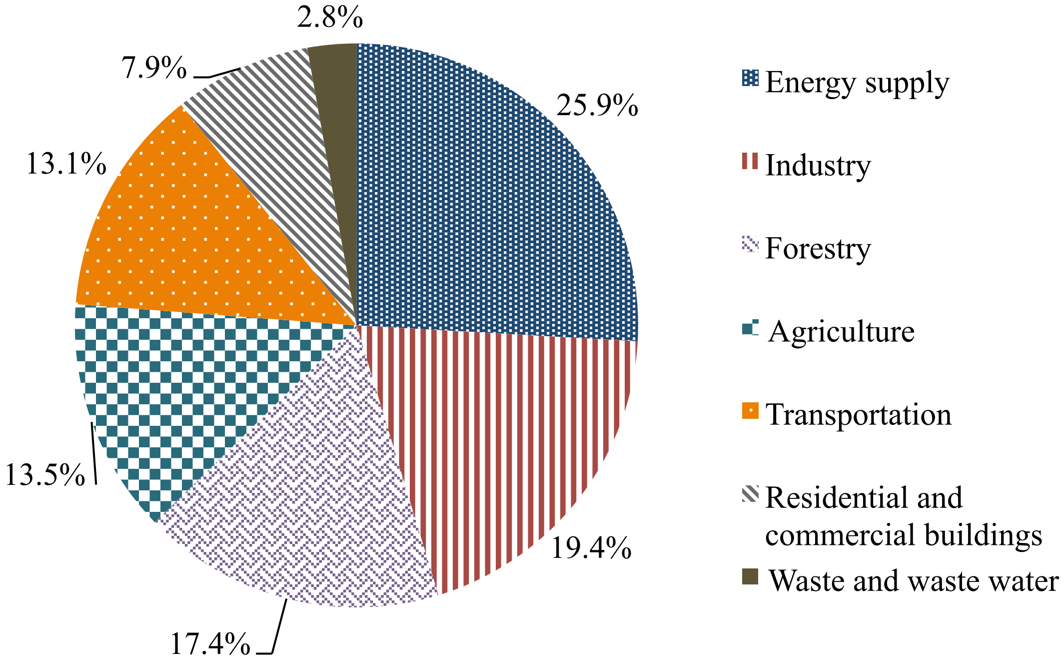

Figure 3: Greenhouse gas emissions from all sources in 2004

Source: Fisher et al., 2007

In steel production, CO_2 emissions vary as a result of production routes, energy efficiencies, fuel mixes as well as types of energy generation. There are three main routes of steel production (figure 4).

In *primary steel route (integrated route)*, iron ore or coal is reduced to pig iron in a blast furnace requiring coke, injected coal and prepared iron ore in the form of sinter or pellets. In the second step of this route, pig iron is processed into steel in a basic oxygen furnace (BOF). As large amounts of heat is produced in BOF, recycled steel (scrap) can be fed into BOF as a substitute for pig iron to reduce energy consumption (Schumacher & Sands, 2007).

In the *secondary steel route*, scrap steel is melted into liquid steel in an electric-arc furnace (EAF), and then liquid steel is used to produce crude steel and is further processed. Scrap-based EAF is often referred to as a mini mill. Compared with *primary steel route*, scrap-based steel production has less energy consumption and GHG emissions.

The third route is called *direct reduction process.* By using natural gas, direct reduction iron is processed into sponge iron that serves as a substitute for scrap and a source for steel production in an EAF. International Energy Agency (IEA, 2006) estimated that this production process could result in up to 50% CO_2 emissions reduction in contrast to the *primary steel route.*

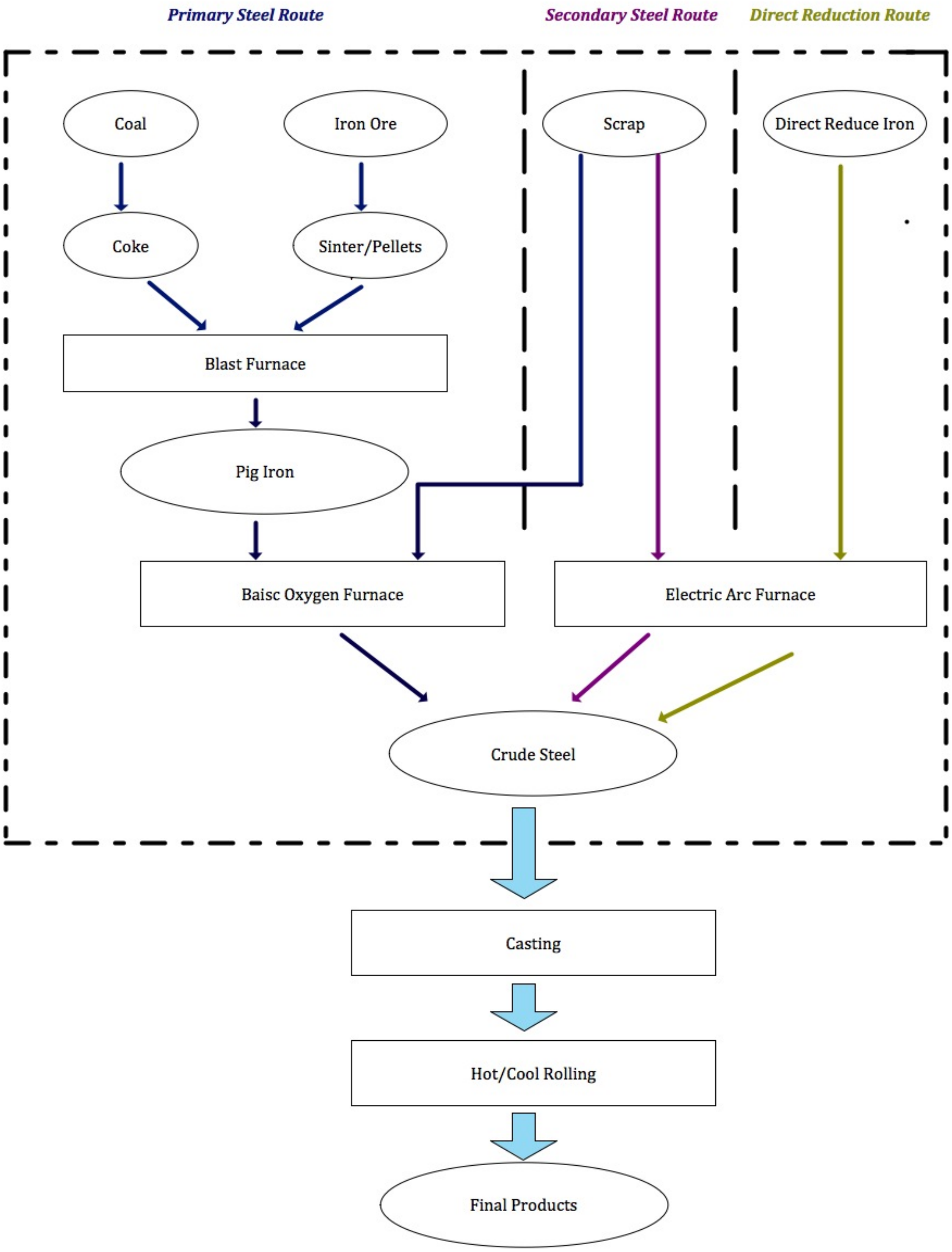

Figure 4: Simplified steel production routes

Source: Schumacher & Sands, 2007; Tanaka, 2008

2.4 The long-term strategies

Fuel switching, renewable energy and material efficiency are looked at as long term strategies of GHG reduction for industry (U.S. Energy Information Administration, 2009). Switching to renewable energy from fossil fuel can reduce GHG emissions significantly during energy generation. U.S. Energy Information Administration (2009) estimated that CO_2 emissions from fossil fuels fell by 6.1% in 2009 and CO_2 emission reduction from coal-fired generation fell by more than 10% compared to the emissions in 2008 due to increasing renewable-energy generation (U.S. Energy Information Administration, 2009). However, renewable energy technologies still have many uncertainties, such as reliability, security and cost.

2.5 A short- to mid- term strategy: energy efficiency

Energy efficiency is the most important way to reduce industrial GHG emissions in the short- to mid-term in comparison with fuel switching, renewable energy and material efficiency. Energy efficiency was recommended as the first of the seven solutions for G20 actions for green global recovery by Edenhofer & Stern (2009). However, current energy efficiency achievements have to go far in order to stabilize atmospheric concentrations of GHG at certain levels that will prevent dangerous anthropogenic interference with the climate system (Ürge-Vorsatz & Metz, 2009a, 2009b). Fisher et al. (2007) stated that drastic CO_2 reduction targets of 60 to 80% in 2050 (compared to today’s emission) require increased rates of energy intensity and carbon intensity improvement by 2-3 times the historical levels. This will demand dramatic improvement of energy efficiency.

In addition, there is a significant opportunity for reducing energy use and CO_2 emissions in industry. IEA (2006, P.230) reported

"*The energy intensity of most industrial processes is at least 50% higher than the theoretical minimum determined by the laws of thermodynamics. Many processes have very low energy efficiency and average energy use is much higher than the best available technology would permit*".

Numerous researchers have discussed the need for energy efficiency improvement in different industrial sectors and in different countries. For example, Anand, Vrat and Dahiya (2006) indicated that CO_2 emission would be reduced by approximately 40% from the India cement industry by using energy efficiency processes. Mukherjee (2008) measured energy efficiency for manufacturing sector and concluded that energy intensive industries have lower energy efficiency and lots of potential for improvement.

In the iron and steel production sector, there are many options to improve energy efficiency and reduce GHG emissions. For example, enhancing continuous production processes, waste energy recovery, changing from primary to secondary production routes and scrap preheating (Bernstein, et al., 2007; Gale & Freund, 2000). Worrell, Price and Martin (2001) provided a report of potential energy saving and CO_2 reduction from steelmaking in the U.S.. They proposed 47 energy efficiency practices and technologies. Among those technologies, flue gas control and monitoring were estimated to be able to produce 2.6 MM Btu/ton fuel savings and waste heat recovery from cooling water was able to produce 0.03 MM Btu/ton energy savings. De Beer, Harnisch and Kerssemeeckers (2000) estimated that by 2020, the global energy efficiency would be improved 29% in comparison with existing technologies, such as near net shape casting. Chan et al. (2010) reported that hot charging rolling can achieve 30-50% total energy savings. Oxy-fuel burner is considered to be the most cost effective measure in steel sector when taking productivity benefits into consideration, which has cost saving of US $1/ton (Worrell et al., 2003).

In addition, empirical research has found numerical temperature control in reheat furnace increases the combustion efficiency and reduces flue gas losses. Until now, a distributed control system is widely used in industry. However, the overall performance of a distributed control system is not satisfied (Lennartson et al., 1996; Wang et al., 2003). Due to the complexity of the reheating process, mathematical models cannot describe this process accurately (Ko et al., 2000). In contrast, several articles pointed out that some control systems combining human experience and pyrology mechanism have better performance when they were applied in the complex reheating process in steel sector (Li & Guan, 2001; Wang et al., 2003). From a technology point of view, as steel production needs very high temperature and pressure, the opportunities for continuous energy efficiency improvements are much more limited compared with those production processes that require moderate temperature and pressure, such as the pulp and paper industry (Worrell et al., 2001).

2.6 Energy recovery

Energy recovery is one of the main methods of energy efficiency improvement for industry to reduce energy consumption and GHG emissions. The history of waste energy recovery can be tracked back to the 19th century. Since the 1920s, development of energy recovery technologies has surged. Unfortunately, applications of proven technologies of waste energy recovery have not yet been extensively implemented due to economical, societal, and political barriers (Bergmeier, 2003). Therefore, even though technologies of energy recovery are available, there are still large potential for their application, which have not yet been realized in industries (Bergmeier, 2003).

Energy can be recovered in its three forms: heat, power, and fuel. Heat is used, generated and discarded in almost all industrial productions. Discarded heat can be reused in other processes or to preheat incoming water and combustion air through process integration (Martin et al., 2000). Martin et al. (2000) reported that cost effective energy savings of 5% to 40% by heat recovery were found in process integration analysis in almost all industries.

Power can be recovered to produce electricity by using pressure recovery turbines. It is globally used in blast furnaces by the iron and steel industry. The blast furnace gas from a top pressure furnace can be depressurized by turbines to produce electrical energy by means of a generator. By using this system, the power output of the top gas pressure recovery turbine can cover about 30% of electricity necessary for all equipment attached to the blast furnace including air blowers (Cao, Tan, & Zhang, 2004). In addition, power recovery is also used in the production process of other industries, such as a fluid catalytic cracker, natural gas grids, etc.(Leonard & Keith, 2007; Siddiqui, Marnay, Firestone, & Zhou, 2007).

Alternatively, combined heat and power (CHP or cogeneration) systems produce both electricity and useful heat. A cogeneration system has a number of attractive attributes, other than its ability to provide heat and power. These include increased efficiency, reduced waste and reduced emissions. Normally, cogeneration involves using energy loss in power production to generate heat for industrial processes and district heating. The overall system efficiency is improved, and more useful energy is produced per unit of fuel. This, in turn, reduces total greenhouse gas and other pollution emissions. However, in Canada, there are many barriers for CHP further development, such as lack of recognitions of environmental, social and economics benefits and uncompleted policy at federal and provincial levels (Laurin et al., 2004). Laurin et al. (2004) estimated that the installed CHP system was 20% to 40% energy saving over stand-alone system, and reduced GHG emissions by almost 30 million tons in Canada.

2.7 Energy recovery in the steel sector

The iron and steel industry have a long history of energy recovery. In the earlier 19th century, iron and steel industries, as pioneers of industries, developed and installed techniques of waste energy recovery (Bergmeier, 2003). Until now, energy recovery in steel production has been implemented in many companies, and produced significant economical and environmental benefits. For instance, North Star Steel's Wilton Iowa plant (which was later acquired by GLSNA in 2004) had completed some heat recovery projects in 2004. Among those successful projects, change to the reheat discharge skid base produced 17,600 MM Btu/yr. Another project changing combustion air temperature for reheat furnace of this plant produced annual energy savings of 61,860 MM Btu (U.S. Department of Energy, 2006). Through heat recovery by installing gas hoods on a converter furnace, Shijiazhuang Iron & Steel Co., Ltd recovered steam of 148,000 ton/yr with energy savings of $900,000/yr, the pay back period was 10 months, and reduced CO_2 emissions 148,000 tons per year (United Nations Environment Programme, 2006). Chan et al. (2010) pointed out that recuperator installation is one of the most effective approaches of energy efficiency in reheating process in steel production; generally, it can achieve 10% heat recovery for reheat furnace.

2.8 Conclusion

Manufacturing industries are the biggest GHG emitters, contributing approximately 30% of global energy consumption (IEA, 2008). The literature shows that the steel sector is a large contributor to GHG. Energy efficiency offers great potential to reduce GHG and decreases our dependence on fossil fuel consumption for steel industry. As a result, they should focus on energy efficiency improvements.

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Chapter 3: Research method

3.1 Research method

By undertaking energy audits, it was possible to analyze energy consumption data to determine feasibility of energy savings. The feasibility of waste heat recovery to preheat billets was analyzed with RETScreen and the energy efficiency in the reheat furnace was assessed with PHAST. The research undertook the following steps:

Step 1. To determine end-user energy distribution, historical energy consumption data was collected by reviewing monthly energy bills.

Step 2. To identify energy losses in the reheat furnace, structural data for reheat furnace was measured, including its dimensions, layer information, opening areas and wall information.

Step 3. To quantify energy losses in the reheat furnace, production data was collected, including flue gas temperature, waste gas temperature, furnace temperature, water temperature, discharge temperature, inside temperature and opening cycle and time of charge and discharge ends at full production (85 ton/hr), partial production (65 ton/hr) and idling (0 ton/hr). The temperatures for different variables were read every five minutes and averaged over the three days during normal production levels for this analysis.

Step 4. To evaluate the gross heat required in the reheat furnace, the gross heat required was calculated by equation 1:

$$H_{(G)} = H_{(\text{four layers})} \times A_{(\text{four layers})} + H_{(\text{three layers})} \times A_{(\text{three layers})} + H_{(\text{one layer})} + A_{(\text{one layer})} \quad (1)$$

Equation 1: The actual gross heat required in the reheat furnace

Where

$H_{(G)}$ = gross heat required (Btu)

$H_{(\text{four layers})}$ = four layer's heat required (Btu)

$A_{(\text{four layers})}$ = percentage of the area with four layers (%)

$H_{(\text{three layers})}$ = three layer's heat required (Btu)

$A_{(\text{three layers})}$ = percentage of the area with three layers (%)

$H_{(\text{one layer})}$ = one lay's heat required (Btu)

$A_{(\text{one layer})}$ = percentage of the area with one layers (%)

Step 5. To compare energy efficiency and energy losses in various operations, energy losses during full production, partial production and idling were calculated by PHAST. PHAST is developed by the U.S. Department of Energy. Industries can survey heating equipment that consumes steam, electricity, or natural gas by this tool and identify the energy losses and energy efficiency potential. It provides different scenarios of preliminary projections for energy efficiency projects.

The PHAST computer model analyzed energy efficiency of reheat furnace considering all the necessary factors including: 1) heat absorbed by cooling water, 2) heat transmission through wall, hearth and roof, 3) heat radiation through opening areas (charge end and discharge end), 4) heat losses by flue gas, and 5) atmosphere losses by air leaking into furnace. The rate and amount of heat losses in each category were analyzed by inputting the following factors:

- Water losses: water flow rate, temperature difference between water in and out, etc.
- Wall, hearth and roof losses: outside area of furnace, thickness and thermal properties of refractories and insulation, surface temperature, etc.
- Opening losses: area of opening and by furnace inside temperature.
- Flue gas losses: flue gas temperature, combustion air temperature and oxygen in flue gas.
- Atmosphere losses: temperature difference between in and out atmosphere and atmosphere flow rate.

Step 6. To evaluate the feasibility of preheating billets by recovered energy, the recoverable heat scenario was calculated by RETScreen. Energy savings potential, initial cost, CO_2 emission reduction and payback period were determined using RETScreen. *Method one* in the section of *Energy Efficiency: heat recovery* in RETScreen was used to evaluate the feasibility of energy recovery.

RETScreen is a clean energy project analysis software. It is developed by Natural Resource Canada. The software has been used worldwide to evaluate energy production, energy project cost and saving, GHG emissions reductions, financial viability and so on. For instance, Bakos, Sourcos and Tsagas (2002) evaluated the feasibility of integrated photovoltaic system in a grid-connected building by RETScreen. Thompson and Duggirala (2009) analyzed the feasibility of renewable energy at an off-grid community in Canada by RETScreen. The amount of recoverable heat was calculated by equation 2

$$Q = m \times Cp \times \Delta T \times \eta \qquad (2)$$

Equation 2: The amount of recoverable heat

Where:

Q = quantity of recoverable heat in kcal

m = annual outputs

Cp = specific heat of the substance in Btu/lb_m ^{o}F

ΔT = temperature difference of billets between before and after preheating

η = heat recovery factor

(Natural Resources Canada, 2009a; United Nations Environment Programme, 2006)

Step 7. To determined heat transfer rate in billets, the Lumped Capacitance method was applied to calculate billet heating time in the preheating box.

Biot number was used to validate the approach of the Lumped Capacitance method. The Biot number was calculated by equation 3

$$Bi = \frac{hL_c}{k} \qquad (3)$$

Equation 3: Biot number calculation

where

Bi = Biot number

V = volume, 0.64 feet (width) × 0.64 feet (height) × 23 feet (length)

A_s = area exposed to hot air, 0.64 feet × 0.64 feet ×2+3 ×0.64 feet × 23 feet

L_C = characteristic length = V/A

h = convection coefficient, 20 W/m^2.K

k = thermal conductivity, 43 W/m.K

The heating time is calculated by equation 4:

$$\frac{\theta}{\theta_i} = \frac{T_{(t)} - T_a}{T_i - T_a} = \exp\left[-\left(\frac{hA_s}{\rho Vc}\right)t\right] \qquad (4)$$

Equation 4: The heating time in billets

where:

$T(t)$ = reached temperature, 600 °F

Ta = surrounding temperature, 1500 °F

Ti = body temperature, 36 °F

ρ = density, 487 lb/ft^3

c = heat capacity of steel, 0.11 Btu/lb$_m$ ^{o}F

t = heat time (seconds)

Step 8: To calculate the annual energy savings of energy efficiency potential, equation 5 was applied.

$$S_a = S_E \times R_F \quad (5)$$

Equation 5: The calculation of annual energy savings

Where

S_a = annual energy savings (\$/yr)

S_E = annual energy savings (MM Btu/yr)

R_F = fuel rate (\$/MM Btu). In this study, natural gas rate is considered to be \$8.2/MM Btu.

Step 9. To calculate the simple payback period of energy efficiency potential, equation 6 was applied.

$$Y_S = \frac{C_p}{S_a} \quad (6)$$

Equation 6: The calculation of simple payback period

Where

Y_s = simple payback period (yr)

C_p = project costs ($)

S_a = annual energy savings ($/yr)

Step 10. To calculate the CO_2 emission reductions of energy efficiency improvement, equation 7 was applied.

$$E_R = S_E \times F_E \quad (7)$$

Equation 7: The calculation of CO_2 reduction

Where

E_R = amount of CO_2 reductions per year (ton/yr)

S_E = annual energy savings (MM Btu/yr)

F_E = emission factor of natural gas is 0.052 ton CO_2/MM Btu

Step 11. To calculate the productivity benefits by oxyfuel combustion, equation 8 was applied.

$$B_p = P_i \times P_b \times P_p \quad (8)$$

Equation 8: The calculation of productivity benefits by oxyfuel combustion

Where

B_p = productivity benefits by production improvement ($/yr)

P_i = production improvement (ton/yr)

P_b = billet's price (\$/ton)

P_p = Net profit margin (%)

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Chapter 4 End-user energy distribution

To identify the major energy consumers at Gerdau, energy distribution of end users was conducted considering electricity and natural gas energy distribution. Energy end users at Gerdau include 1) melt shop furnace where steel scraps are melted into liquid steel, 2) melt shop mechanical which refers to materials handling between furnaces, 3) reheat furnace where semi-finished products are reheated up to 2200 °F, 4) utilities which refers to lighting and other non-production energy consumption, 5) Number 4 & 5 rolling mill where semi-finished products are rolled into finished products (figure 5). No. 1, 2, and 3 mills were decommissioned and 6) two internal suppliers, Gerdau Metallics Raw Materials (GMRM) and TC Industry (TCI). GMRM is a division of Gerdau Corporation and prepares scrap metals for Gerdau. TCI is another manufacturing facility that is tied to the steel mill energy consumption. TCI performs commercial heat-treating, annealing and quench and temper of commercial size bars plates and rounds of carbon steel.

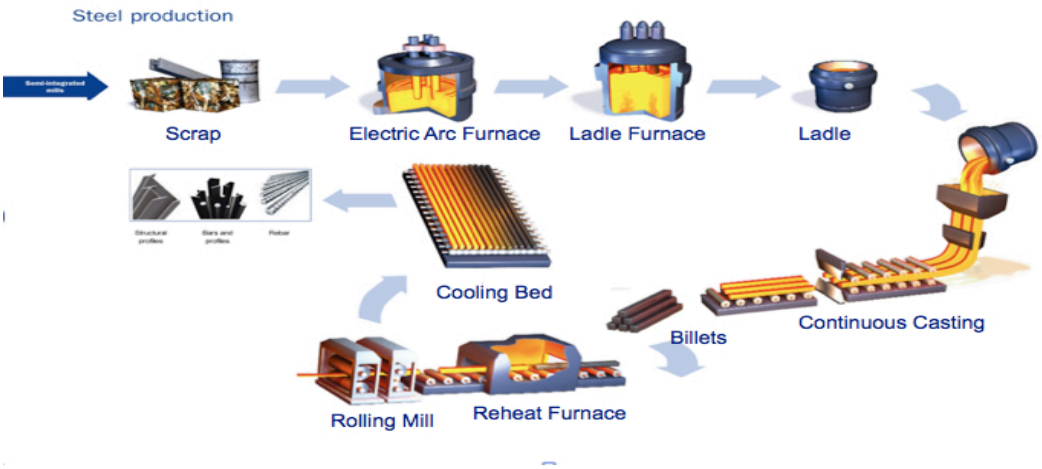

Figure 5: Production Process at the Gerdau

Source: Gerdau, 2009b.

The electricity end-user distribution analysis considers electricity energy consumption (kWh) and demand (kVa). Electricity consumption (kWh) refers to the electricity use in kilowatt-hours, which is calculated by multiplying the wattage of equipment by the number of hours they are in use. Electricity demand (kVa) charge is based on the peak of electrical use recorded over 15 minutes during the billing period, which are typically charged for commercial and industrial customers.

4.1 Trends in energy consumption from 1999 - 2011

The energy consumption from 1999 to 2011 is shown in figure 6 to 8. During this period, the average and standard deviation of electricity consumption (kWh), electrical demand (kVa) and natural consumption (MCF) were 253,329,412 kWh ± 39,461,808 (kWh), 553,873 kVa ± 25,234 kVa and 728,304 MCF ± 89,288, respectively. This history shows that electricity consumption (kWh) was highest at 2007 reaching 276,460,783 kWh, but the highest electrical demand (kVa) was 622,653 kVa in 2010. The natural gas consumption (MCF) was highest at 2004 with 795,148 MCF. 2009 was the lowest year of electricity consumption (kWh) and natural gas consumption (MCF) due to Gerdau being at low production that year.

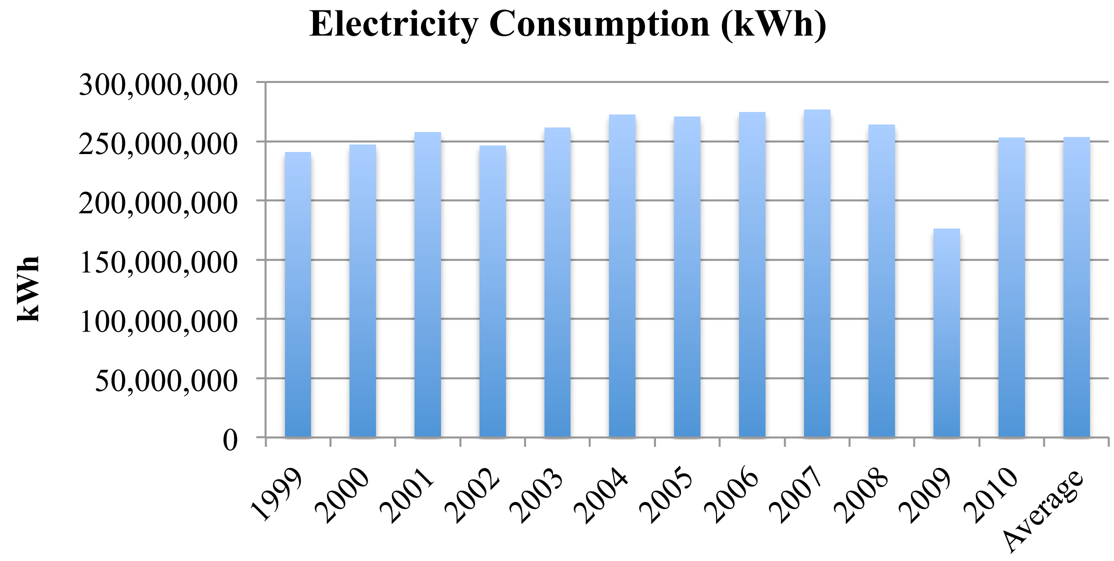

Figure 6: Electricity consumption (kWh) from 1999 to 2010

Source: Manitoba Hydro, 2011

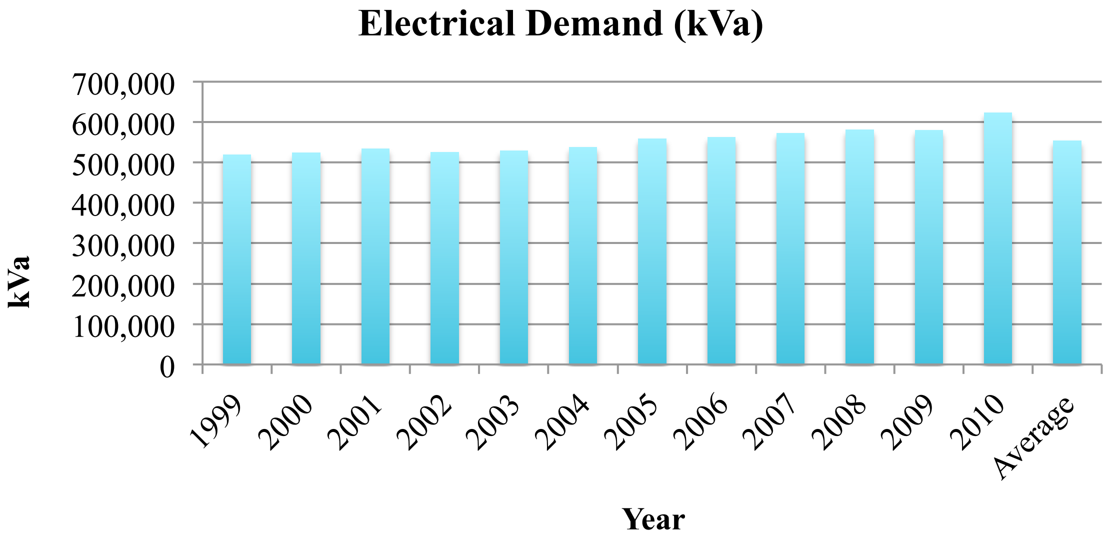

Figure 7: Electrical demand (kVa) from 1999 to 2010

Source: Manitoba's Hydro, 2011

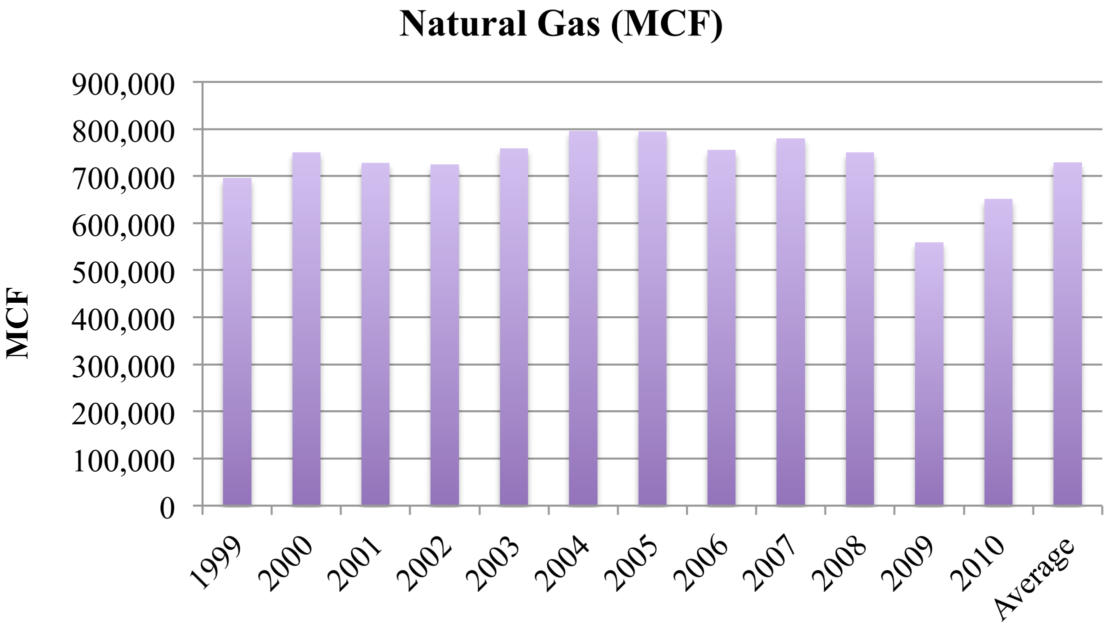

Figure 8: Natural gas consumption (MCF) from 1999 to 2010

Source: Manitoba Hydro, 2011

4.2 Energy use per production unit

From 1999 to 2010, energy use per production unit is shown in figure 9 and 10. The average specific electricity use is 722.2 kWh/ton ± 29.9 kWh/ton and the average specific natural gas use is 2084.4 ft^3/ton ± 166.5 ft^3/ton. The 2009 year stands out as a highly inefficient energy use with much higher at 50.1 kWh/ton than the average. 2009 was a low production year, possibly with a lot of downtime.

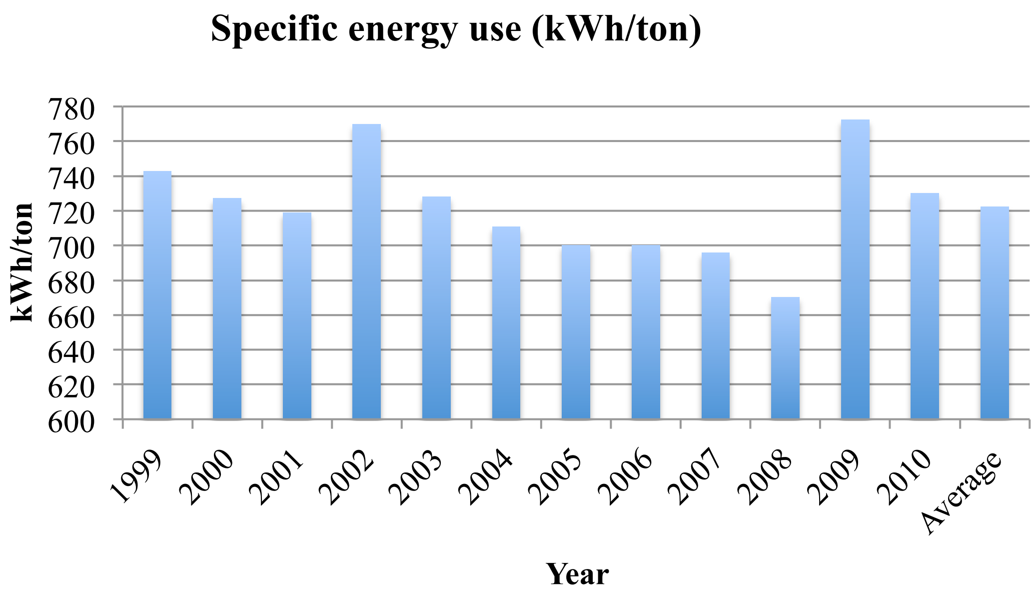

Figure 9: Specific energy use (kWh/ton) at Gerdau from 1999 to 2010

Source: Gerdau, 2011a

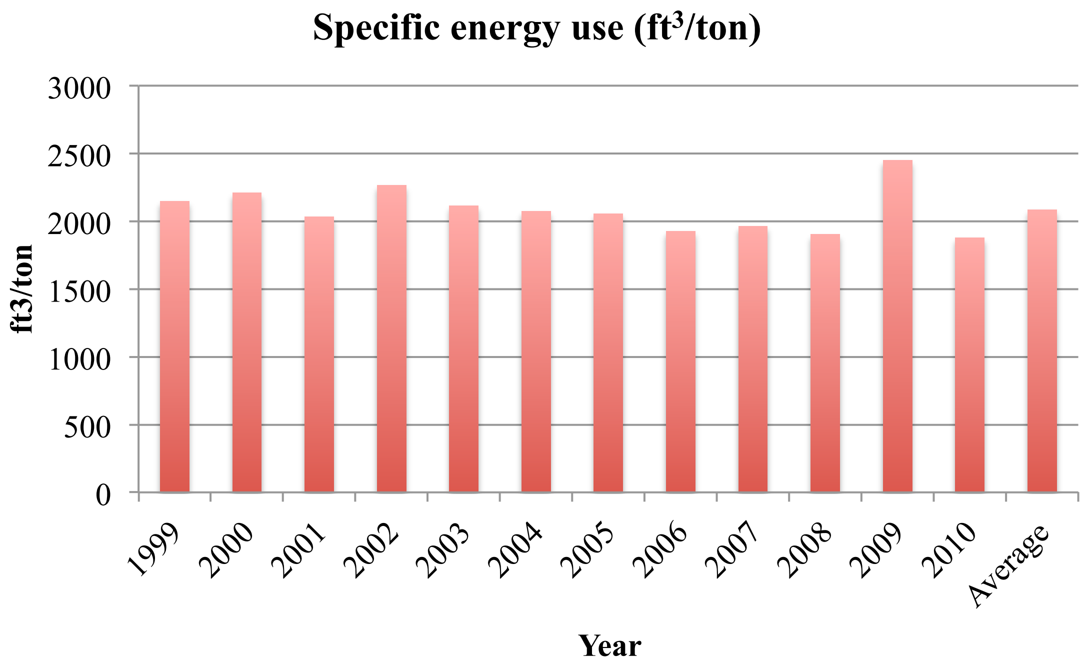

Figure 10: Specific energy use (ft^3/ton) at Gerdau from 1999 to 2010

Source: Gerdau, 2011a

4.3 Electrical energy (kWh) 2010

Gerdau is a mini-mill steel producer being the biggest electrical consumer on the site (figure 11). This melt shop furnace with its EBT furnace accounted for 68.7% electrical energy consumption using 173,756,546 kWh (table 1). The 4 & 5 mills, which are the workshops for rolling semi-finished products, accounted for 12.9% of electrical consumption in Gerdau. Only slightly less at 11.9%, melt shop mechanical is the third largest electricity consumer. GMRM accounted for 2.7% of electrical consumption. TCI contributed 1.7% of electrical consumption.

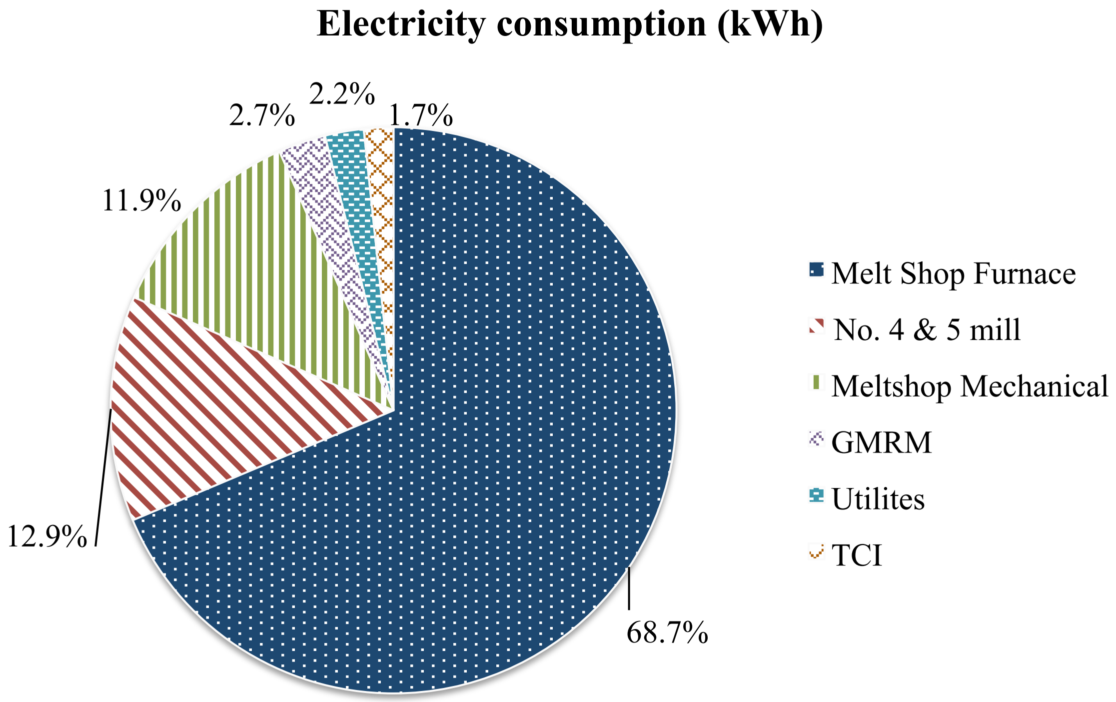

Figure 11: Electrical end-user energy distribution at Gerdau

Source: Gerdau, 2011b

Table 1: Electrical end-user energy distribution at Gerdau

End-user	Electricity consumption (kWh)	Percentage (%)
Melt Shop Furnace	173,756,546	68.7%
No. 4 & 5 mill	32,593,995	12.9%
Melt Shop Mechanic	30,004,953	11.9%
GMRM	6,858,174	2.7%
Utilities	5,612,369	2.2%
TCI	4,251,968	1.7%
Total*	253,078,004	100%

Source: Gerdau, 2011b; Manitoba Hydro, 2011
* The total consumption is from Manitoba Hydro's record. The breakdown of energy consumption is from the accounting department at Gerdau

4.4 Electrical demand (kVa) 2010

Electrical demand at Gerdau is high and fairly constant over time. Gerdau's steel making operation typically works 48 weeks at 24 hours every day, seven days a week. Thus, the electrical demand is significant due to almost continuous production. Gerdau's electricity bills, showed the peak demand to be 52,000 kVa per month. The total billed demand was 622,563 kVa in 2010 (table 2). The melt shop furnace accounted for 73.6% of annual electrical demand with 458,045 kVa (figure 12).

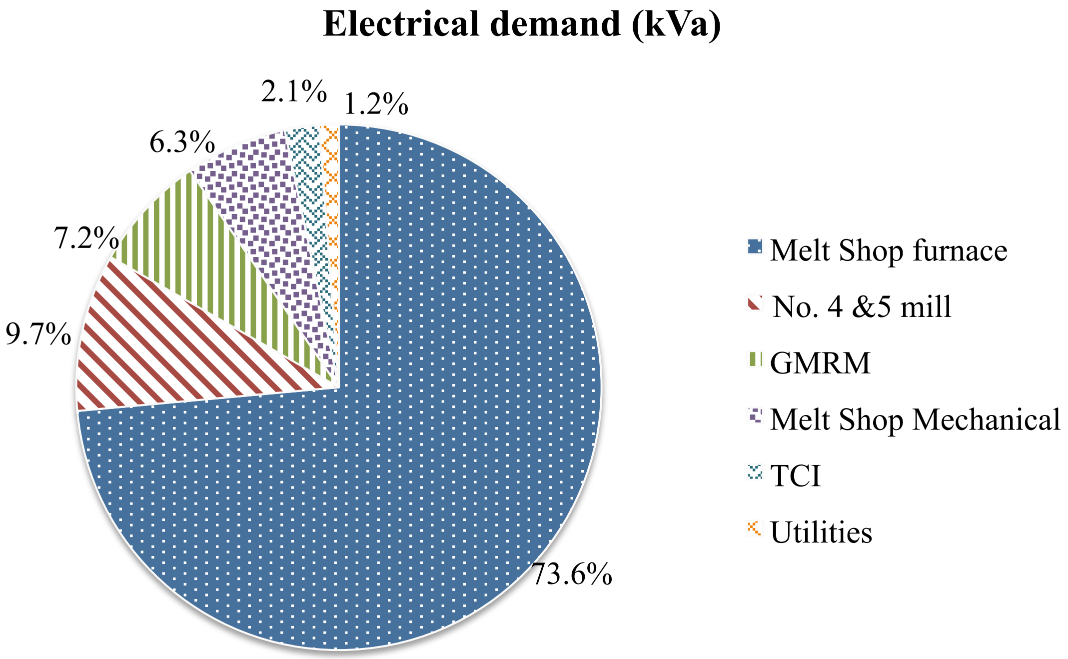

Figure 12: Electrical demand at Gerdau in 2010

Source: Gerdau, 2011b

Table 2: Electrical demand at Gerdau in 2010

End-user	Electrical Demand (kVa)	Percentage
Melt Shop Furnace	458,045	73.6%
No. 4 & 5 Mill	60,316	9.7%
GMRM	44,591	7.2%
Melt Shop Mechanical	39,107	6.3%
TCI	13,163	2.1%
Utilities	7,432	1.2%
Total*	622,653	100%

Source: Gerdau, 2011b; Manitoba Hydro, 2011
* The total consumption is from Manitoba Hydro's record. The breakdown of energy consumption is from the accounting department at Gerdau

4.5 Natural gas 2010

The main natural gas consumer at Gerdau was the reheat process, which accounted for 67.2% of the total natural gas consumption (figure 13). The melt shop was the second largest natural gas consumer on site with 113,510 MCF. The melt shop building heating, water heating and other make-up air heating consumed 64,023 MCF in 2010. The internal supplier TCI also consumed 35,653 MCF (table 3).

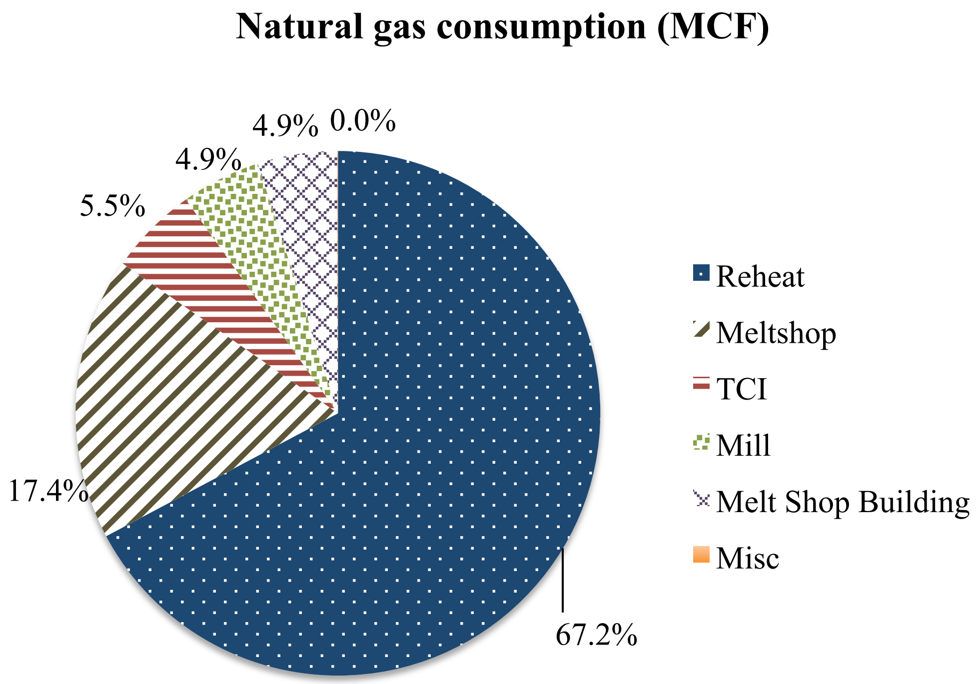

Figure 13: Natural gas end-user energy distribution at Gerdau in 2010

Source: Gerdau, 2011b

Table 3: Natural gas end-user energy distribution at Gerdau in 2010

End-user	Consumption (MCF)	Percentage
Reheat	437,563	67.2%
Melt Shop	113,510	17.4%
Melt Shop Building	31,887	5.5%
No.4 & 5 mill	31,887	4.9%
TCI	35,653	4.9%
Misc	249	0.0%
Total*	650,749	100%

Source: Gerdau, 2011b; Manitoba Hydro, 2011
* The total consumption is from Manitoba Hydro's record. The breakdown of energy consumption is from the accounting department at Gerdau

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Chapter 5 Energy losses in reheat furnace

5.1 Introduction

The reheat furnace in Gerdau is a walking hearth design manufactured by Salem Industries Canada Ltd. The furnace was installed in 1974, a recuperator was added in 1984 and a new hearth design was installed in 1999. From the end-user energy distribution analysis, it was determined that the reheat process is the biggest natural gas consumer on site. In order to evaluate the feasible of waste heat recovery in the reheat furnace, it is necessary to identify where energy is lost in the reheat furnace. Therefore, this chapter identifies the energy losses in the reheat furnace by the PHAST. The energy losses in the reheat furnace from each daily shift and each product may vary slightly based on the combustion air temperature, flue gas temperature, billet temperature and operational production or idling.

As Gerdau has a wide range of finished products including 6 ¾” 7 ⅝”, 8”, 10” billet, etc. it was necessary to choose a single product for analysis. This chapter takes one of the products, the 7 ⅝” billet, to analyze energy losses in the reheat furnace at the production rate of 85 ton/hr (figure 14). The 7 ⅝” billet was chosen because it is the most common product at Gerdau.

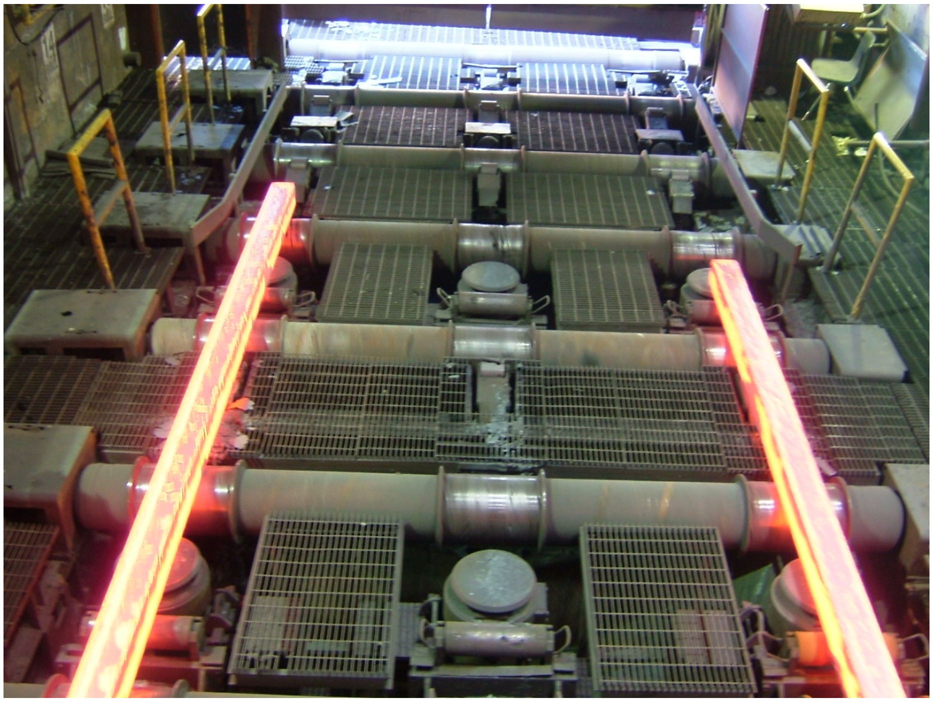


Figure 14: Billets after the casting process

The production data on the date of April 9 2010 was applied. The temperatures for the different variables were recorded every five minutes from 7:00 -16:00, including combustion air temperature, flue gas temperature, furnace temperature, inside temperature and water temperature. All the temperatures were averaged for the analysis. The reheat furnace structure is shown in figure 15 and 16. Please note that the charge end in the reheat furnace has a curtain (figure 17), with a fixed opening area. Discharge end has a door, billets are dropped out of the furnace every 10 seconds, so this opening cycle is variable.

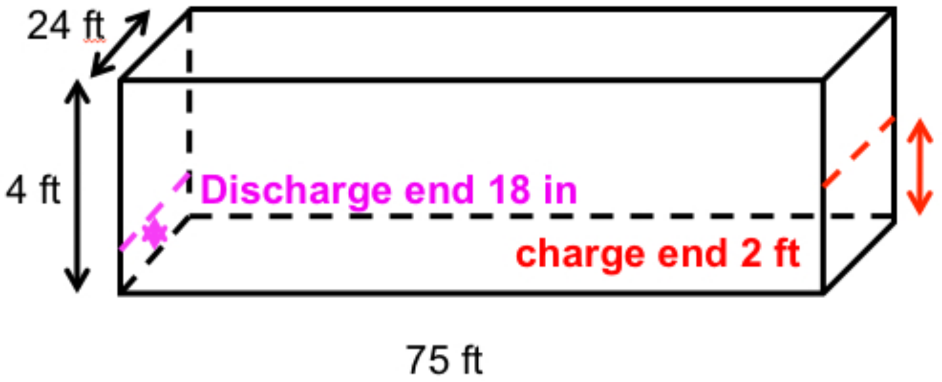


Figure 15: Simplified reheat furnace structure at Gerdau

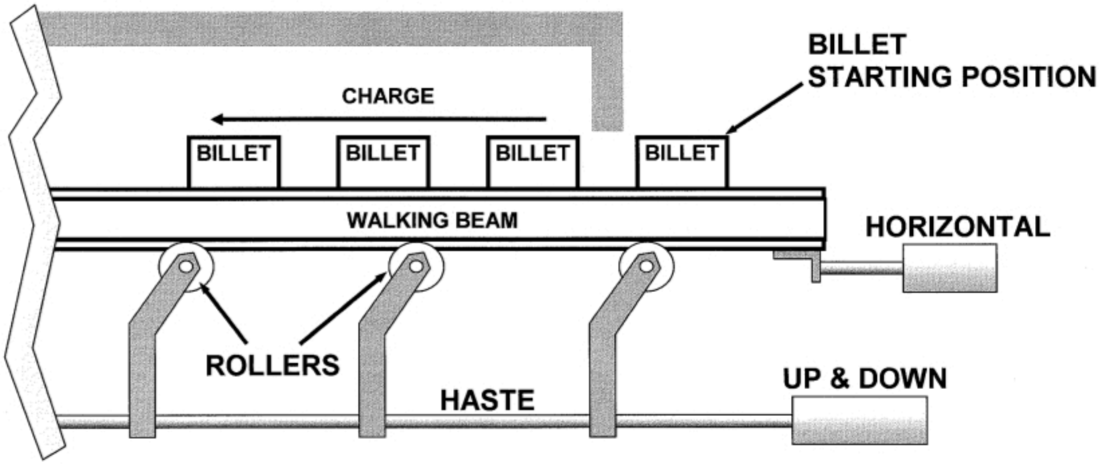


Figure 16: Inside structure in the reheat furnace

Source: Hoppe, no date

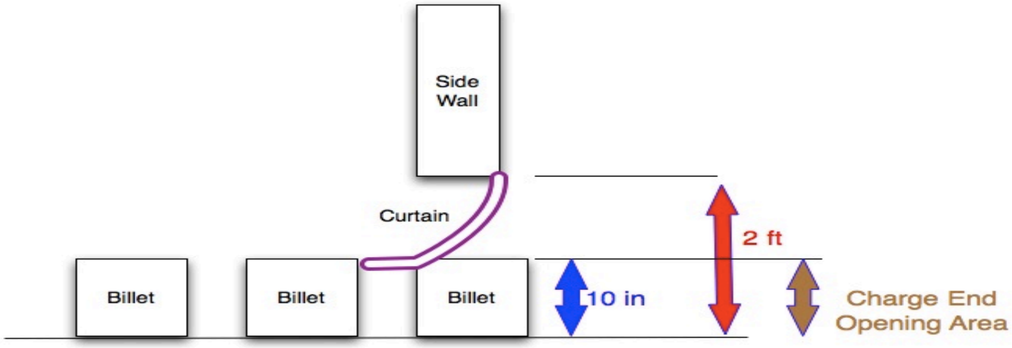


Figure 17: Simplified charge end in the reheat furnace at Gerdau

5.2 Assumptions

5.2.1 Wall, hearth and roof temperature

The wall, hearth and roof temperatures are highly variable. Many factors can impact them, such as billet types, flue gas temperature, idling production, operational production, etc. In this analysis, the wall, hearth and roof temperatures from a Gerdau consulting report (RHI Refractories, 2008) were applied. Based on the previous hand held pyrometer survey, the wall temperatures were found to vary from 450°F to 550 °F, depending on the wall location (RHI Refractories, 2008). 450°F was assumed for this study as the temperature of most wall area are approximately 450°F. Therefore wall temperature variation during operational production is considered to be within 20% in this study.

5.2.2 Atmosphere losses

Atmosphere losses depend on atmosphere flow rate, which is represented by standard cubic feet per hour (SCFH) in PHAST. SCFH refers to the volumetric flow rate of the atmosphere corrected to standardized conditions of temperature, pressure and relative humidity. The atmospheric flow rate from Gerdau consulting report was applied, namely 1,365,335 scfh (Hotwork Combustion Technology, 2006).

5.2.3 Heat storage

Heat storage represents the total heat storage in furnace walls (refractory and insulation) from the old condition (idling production) to the hot condition (operational production). The quantity of heat storage is a function of type of insulating materials and the numbers of layers in furnaces.

In the heat storage section of the model, PHAST only allows one input for the furnace end information. However, the reheat furnace at Gerdau has two ends, the discharge end (drop-out end) and the charge end. Gerdau takes measures at both of these ends. The layer materials and layer thickness for discharge end and charge end are different for the reheat furnace at Gerdau. The input of the end area was calculated manually by averaging the area of both ends.

In addition, the reheat furnace's bottom layer materials are variable (Appendix I). 76.7% of the bottom areas have three layers, namely: 1) didurit 70 CD, 2) green lite HS IFB, and 3) Skamolex V-1100. Another 9% of the bottom areas have only one layer of didurit 70 CD, while 14.4 % of the bottom has four layers, namely: 1) HP cast ultra, 2) didurit 70 CD, 3) green lite HS IFB, and 4) Skamolex V-1100 or 27 S. However, a limitation of PHAST is that users cannot input layer information according to its percentage of the area as there is only inputs for one layer. The actual gross heat required was calculated by equation 1:

$$H_{(G)} = H_{(\text{four layers})} \times A_{(\text{four layers})} + H_{(\text{three layers})} \times A_{(\text{three layers})} + H_{(\text{one layer})} + A_{(\text{one layer})}$$

(1)

Where

$H_{(G)}$ = gross heat required (Btu)

$H_{(\text{four layers})}$ = four layer's heat required (Btu)

$A_{(\text{four layers})}$ = percentage of the area with four layers (%)

$H_{(\text{three layers})}$ = three layer's heat required (Btu)

$A_{(\text{three layers})}$ = percentage of the area with three layers (%)

$H_{(one\ layer)}$ = one lay's heat required (Btu)

$A_{(one\ layer)}$ = percentage of the area with one layers (%)

Gross Heat Required (Btu) represents total heat storage in furnace walls (insulation and refractory) when the furnace is heated from cold condition to hot (at operating temperature). It is gross heat required after considering effect of available heat from the heating system. The three layers' heat required was calculated by PHAST.

The results from equation 1 show that the actual gross heat storage was 194,632,279 Btu. The three layer's heat storage calculated by PHAST was 187,146,423 Btu. With only 4% difference, the PHAST calculation with three layers were considered to be sufficiently accurate to apply to determine the gross heat storage. The layer thickness and materials are provided in table 4 according to the diagram of the reheat furnace (Appendix I).

Table 4: Simplified layer information in the reheat furnace

Location	NO. of layers	Material	Thickness (in)
Top	1	Ceramic fibre foamfrax grade	2
	2	Hi temp insulating firebrick	9
Side	1	Ceramic fibre foamfrax grade	2
	2	Hi temp insulating firebrick	13.5
End	1	Ceramic fibre block	12
Bottom	1	Hi-density castable	9
	2	Hi temp insulating firebrick	4.5
	3	Hi temp insulating firebrick	5.5

Source: the diagram of the reheat furnace at Gerdau (Appendix I)

5.3 Results

According to PHAST, flue gas losses account for 29.5% of energy losses, exhausting 26,874,657 Btu/hr (figure 18, table 5). Energy distribution in the reheat furnace is shown in figure 19.

Hearth and roof losses, defined as other losses in PHAST, are the biggest energy loss in the net heat distribution with 8.9% with 5,687,690 Btu/hr (figure 20, table 6). Water is used for cooling products at the discharge end in the reheat furnace. The temperature of water is measured by the temperature gauge, the water losses only account for 0.2% in the net heat distribution. Gerdau does not have any fixture, basket or tray for materials handling, so there are no material handling losses in the reheat furnace. The detailed input data is in the Appendix I.

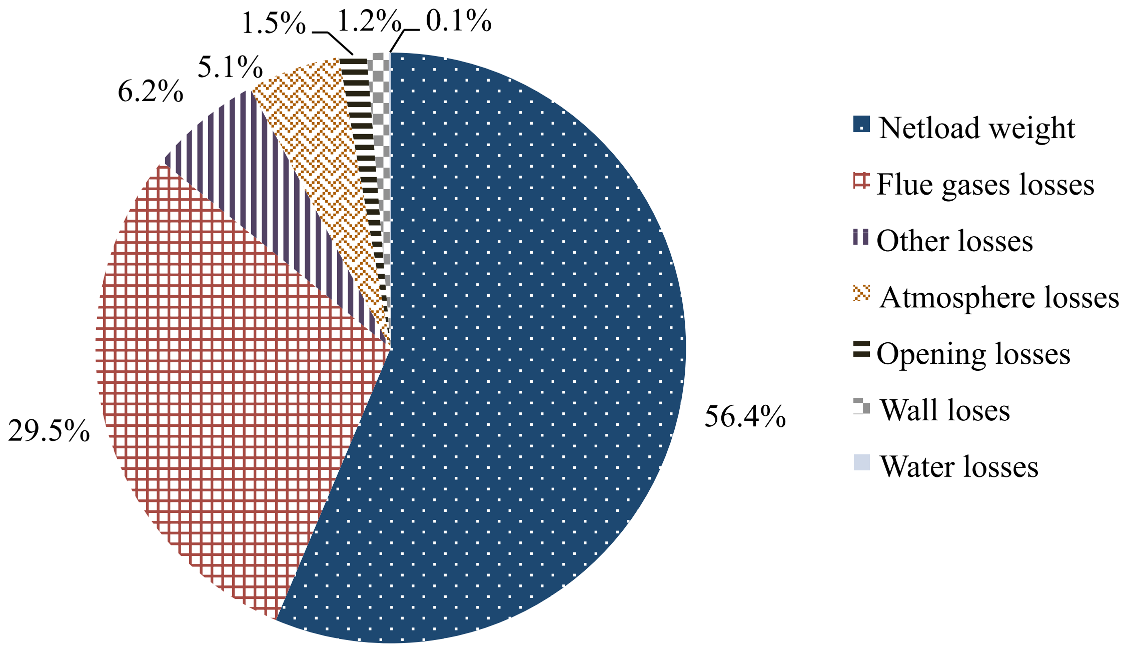


Figure 18: Gross heat distribution in the reheat furnace calculated by PHAST

Table 5: Gross heat distribution in the reheat furnace calculated by PHAST

Area of Heat Consumption	Heat distribution (Btu/hr)	Percentage
Net load weight	51,331,500	56.4%
Flue gas losses	26,874,657	29.5%
Other losses (Hearth & Roof)	5,687,690	6.2%
Atmosphere losses	4,669,446	5.1%
Opening losses	1,354,155	1.5%
Wall losses	1,078,934	1.2%
Water losses	104,151	0.1%
Fixture losses	0	0.0%
Total	91,100,533	100%

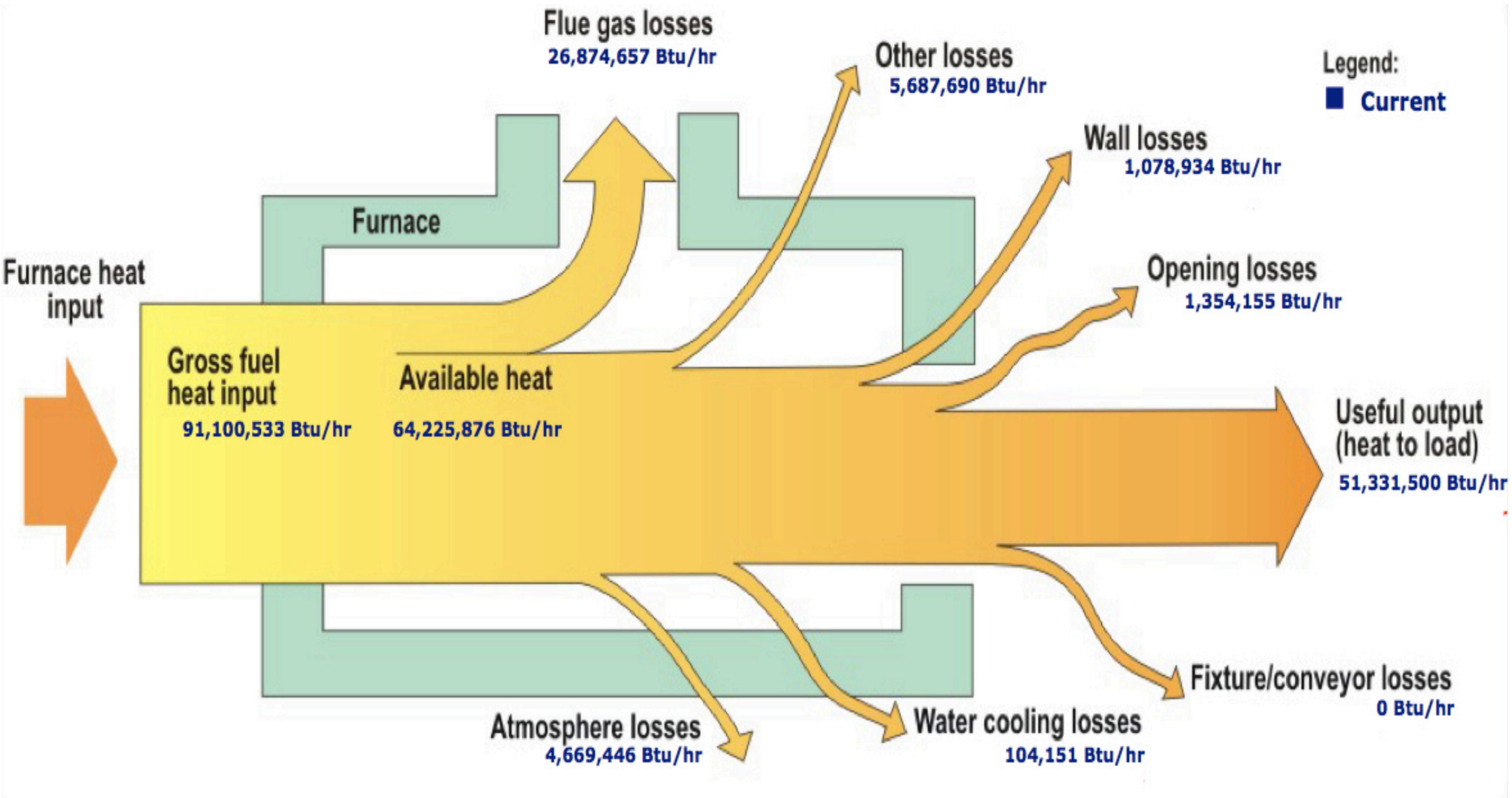


Figure 19: Energy losses in the reheat furnace at 85 ton production rate

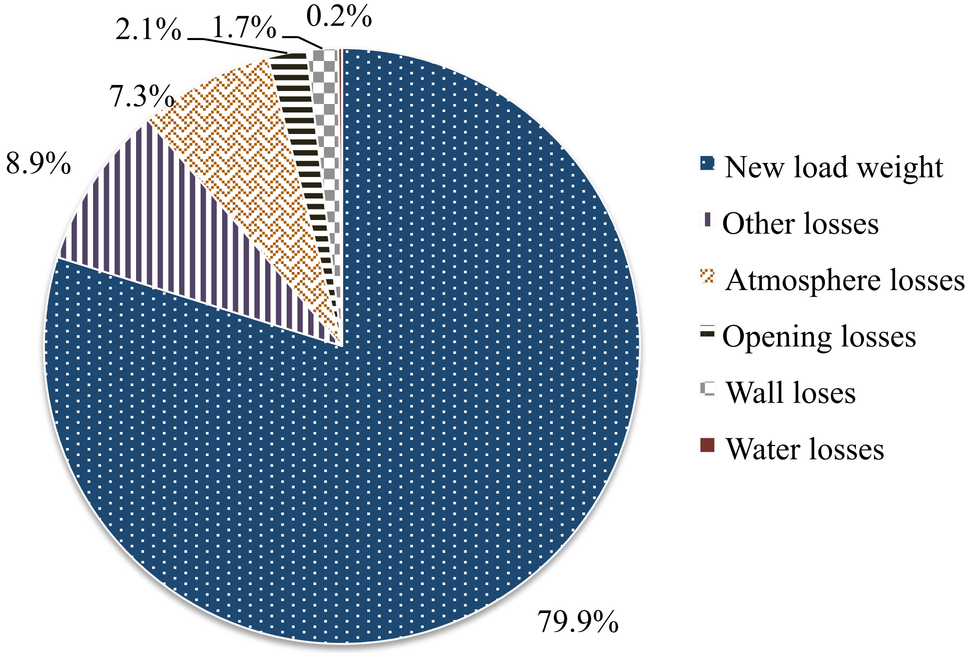


Figure 20: Net heat distribution in the reheat furnace calculated by PHAST

Table 6: Net heat distribution in the reheat furnace calculated by PHAST

Area of Heat Consumption	Heat distribution (Btu/hr)	Percentage
Net load weight	51,331,500	79.8%
Other losses (Hearth & Roof)	5,687,690	8.9%
Atmosphere losses	4,669,446	7.3%
Opening losses	1,354,155	2.1%
Wall losses	1,078,934	1.7%
Water losses	104,151	0.2%
Fixture losses	0	0.0%
Total	64,225,876	100%

5.4 Conclusion

Flue gas was the biggest energy loss at 26,874,657 Btu/hr. However, flue gas losses are easy to recover compared to losses in other production processes. The waste heat from the flue gases can be reused for preheating billets and incoming water. Wall, hearth and roof losses are the second biggest energy losses in the reheat furnace of 6,766,624 Btu/hr. Those losses are caused by heat conduction through wall, hearth and roof. To reduce heat conduction losses, Gerdau can add or upgrade high-tech materials of refractoriness and further insulate the furnace.

Reference

RHI Canada Inc. (2008). *Reheat furnace fibre veneer.* Unpublished raw data.

Hoppe, B. (No date). Combustion training (Internal training material). Unpublished raw data.

Chapter 6 Sensitivity analysis of production dates, production rates and billet types

Energy losses may vary with products and production rates in the reheat furnace. The chapter compares the energy losses among different production dates, production rates and billet types to determine if 7 ⅝” billets can represent the overall performance in the reheat furnace by undertaking a sensitivity analysis of production dates, production rates and billet types.

6.1 Introduction

The analysis of energy losses by PHAST considers: 1) heat absorbed by cooling water, 2) heat transmission through wall, hearth and roof, 3) heat radiation through opening areas (charge end and discharge end), 4) heat losses by flue gas and atmosphere infiltration. The rate and amount of heat losses in each category depend on many factors including:

- Water losses: determined by water flow rate, temperature difference between water in and out. In this study, water flow rate, water in and out temperature are considered as the same in production.
- Wall, hearth and roof losses: determined by outside area of furnace, thickness and thermal properties of refractories and insulation, surface temperature, etc. Surface temperature of wall is the only variable among different production cases. The temperature can be read by a pyrometer. However, surface temperature is highly variable. Each point in the wall will be different at the same time; every single time will have difference as well. In this study, we used RHI Refractories’ report (2008) as a reference for the wall, hearth and roof temperature.

- Opening losses: determined by the area of opening and by furnace zone temperatures.
- Flue gas losses: determined by the flue gas temperature, combustion air temperature and oxygen in flue gas.
- Atmosphere losses: determined by the temperature difference between in and out atmosphere and atmosphere flow rate around the furnace.

Therefore, the main energy losses in different production are furnace temperature, flue gas temperature and combustion air temperature.

6.2 Method

A sensitivity analysis was undertaken for:

1) Production dates by comparing furnace temperature, flue gas temperature and combustion air temperature on different production dates for one billet type- the 7 ⅝" billet. The production dates were 7:00 – 16:00 on April 9 2010, 0:55 – 5:00 on June 13 2010 and 7:00 – 11:15 on June 14 2010 (table 7).

Table 7: Temperature comparison among different production periods

Billet type	Production rate	Production date	Shift
7 ⅝"	85 tons/hr	April 9 2010	7:00-16:00
7 ⅝"	85 tons/hr	June 13 2010	0:55-5:00
7 ⅝"	85 tons/hr	June 14 2010	7:00-11:15

2) Production rate by comparing furnace temperature, flue gas temperature and combustion air temperature on different production rates for one billet type- the 7 ⅝” billet. Production rate were 85 tons/hr, 65 tons/hr, 90 tons/hr and 80 tons/hr (table 8).

Table 8: Temperature comparison among different production rate

Billet type	Production rate	Production date	Shift
7 ⅝”	85 tons/hr	April 9 2010	7:00-16:00
7 ⅝”	65 tons/hr	June 13 2010	20:15-23:50
7 ⅝”	90 tons/hr	Jan 27 2010	0:00-2:35
7 ⅝”	80 tons/hr	Feb 5 2010	19:00-3:20

3) Billet types by comparing flue gas losses, atmosphere losses and opening losses on different billet types (6 ¾” 7 ⅝”, 8”, 10” and 10 × 16 slab) at 85 tons/hr production (table 9).

Table 9: Energy losses comparison in the reheat furnace 85 ton/hr and 65 ton/hr

Billet Type	Production Rate	Production Data	Shift
7 ⅝”	85 ton/hr	April 9 2010	7:00-19:00
6 ¾”	85 ton/hr	Aug 5 2006	19:00-7:00
10”	85 ton/hr	Aug 20 2006	7:00-19:00
8”	85 ton/hr	Sept 10 2006	19:00 -7:00
10 × 16 Slab	85 ton/hr	Sept 27 2006	19:00 -7:00

All temperatures were read every five minutes. All the observed temperatures were averaged for comparison. If differences were within 10% of each other, there was not considered to be significant variation.

6.3 Findings

Furnace temperature, flue gas temperature and combustion air temperature have slight differences among these three production periods when the production rate was 85 ton/hr. Compared with production data on April 9 2010, the temperature difference of furnace, flue gas and combustion air at three production dates were up to 6 °F, 35 °F and 22 °F, which have 0.3%, 2% and 2.9% difference, respectively (table 10). The sensitivity analysis shows that temperature differences during different production periods at 85 ton/hr are fairly small, far below the 10% significant variant cutoff, so that the 7 ⅝" billet's production data on April 9 2010 is considered acceptable to be used as a reference for the further analysis of heat recovery.

Table 10: Sensitivity analysis of temperature among different production periods

Production date	Billet type	Furnace temp	Flue gas temp	Combustion air temp
April 9 2010	7 ⅝"	2329 °F	1471 °F	745 °F
June 13 2010	7 ⅝"	2335 °F	1499 °F	751 °F
June 14 2010	7 ⅝"	2335 °F	1506 °F	767 °F

Compared with temperature data on April 9 2010, the temperature difference of furnace, flue gas and combustion air at 65 ton/hr, 90 ton/hr and 80 ton/hr production rate were up to 5 °F, 26 °F and 47 °F, which have 0.2%, 1.7% and 6% difference (table 11). The sensitivity analysis shows that the temperature differences among different production rate are below the sensitivity analysis cutoff. 85 ton/hr production rate was considered a suitable rate to apply for further analysis of waste heat recovery as most of operations in the reheat furnace at Gerdau are at this peak production rate.

Table 11: Sensitivity analysis of temperature among different production rate

Production rate	Billet type	Furnace Temp	Flue Gas Temp	Combustion air temp
85 tons/hr	7 ⅝”	2329 °F	1471 °F	745 °F
65 tons/hr	7 ⅝”	2334 °F	1496 °F	754 °F
90 tons/hr	7 ⅝”	2331 °F	1499 °F	707 °F
80 tons/hr	7 ⅝”	2331 °F	1499 °F	736 °F

The differences of energy losses among each type come from flue gas losses, opening losses and atmosphere losses. The furnace had highest thermal efficiency when it reheated 10 × 16 slab, which was 62.5% (table 12). The average thermal efficiency was 58.9%. The flue gas losses were found to impact the overall thermal efficiency significantly. The efficiency difference between the 7 ⅝” and the average efficiency of the reheat furnace is 2.5%. The sensitivity analysis of thermal efficiency in the reheat furnace shows that thermal efficiency is fairly constant in the reheat furnace. The efficiency of 7 ⅝” billet should be able to fairly represent the overall thermal efficiency of the reheat furnace for other semi-finished products because thermal efficiencies do not have significant differences.

Table 12: Sensitivity analysis of efficiency among different types of billets

Billet type/Energy losses (Btu/hr)	10 × 16 slab	7 ⅝”	6 ¾”	8"	10"
Flue Gas Losses	21,335,709	26,874,657	24,195,256	26,421,138	25,548,048
Atmosphere Losses	1,283,415	4,669,446	2,102,616	3,140,740	3,249,497
Opening Losses	1,270,594	1,354,155	1,298,634	1,346,393	1,340,594
Thermal Efficiency	62.5%	56.4%	59.8%	57.6%	58.1%

In addition, the energy efficiency was calculated when the production rate was 65 ton/hr by PHAST to compare energy efficiency between partial production and full production (table 13). The energy intensity in the reheat furnace increased by 7.7%, and the overall thermal efficiency in the reheat furnace decreased to 52.3% during 65 ton/hr.

Table 13: Energy efficiency comparison in the reheat furnace between 85 ton/hr and 65 ton/hr

	85 ton/hr	65 ton/hr
Net Heat Required (Btu/hr)	64,225,876	52,557,476
Gross Heat Required (Btu/hr)	91,100,533	75,039,229
Energy Used (Btu/lb)	535.9	577.2
Thermal Efficiency (%)	56.4	52.3

6.4 Conclusion

The thermal efficiency of the reheat furnace at Gerdau does not significantly vary with the different billet types and different production rates (table 10,table 11). Due to the constant temperature in the furnace, the thermal efficiency keeps a stable level of 58.9% when production is operational. Therefore, a 7 ⅝” billet at 85 ton/hr rate was chosen as a reference for the design of unfired hot charged box, which can be applied to other products. This sensitivity analysis found that production periods, production date and billet types do not affect energy efficiency to any large degree.

Reference

RHI Canada Inc. (2008). *Reheat furnace fibre veneer.* Unpublished raw data.

Chapter 7 Energy losses comparison between operational production and idling

7.1 Introduction

Energy distribution of idling in the reheat furnace may be different with operational production and so requires investigation. In Gerdau, 70% of production time is operational and 30% of production time is idle. This chapter compares the energy losses between operational and idling production.

7.2 Method

To compare energy losses between operational production and idling, the following steps were carried out:

Step 1: Collected production data of 7 ⅝” billet on April 9 2010 (7:00 – 16:00) to analyze energy losses while production was operational.

Step 2: Collected production data on Jan 27 2010 (2:30-7:00) for idling production.

Step 3: Loaded production data of operational production and idling into PHAST to analyze energy losses during operational production and idling.

7.3 Findings

The flue gas losses were found to decrease dramatically when the production was idling. Hearth and roof losses (other losses) became the biggest energy loss during idling, which accounted for 44.5% (figure 21).

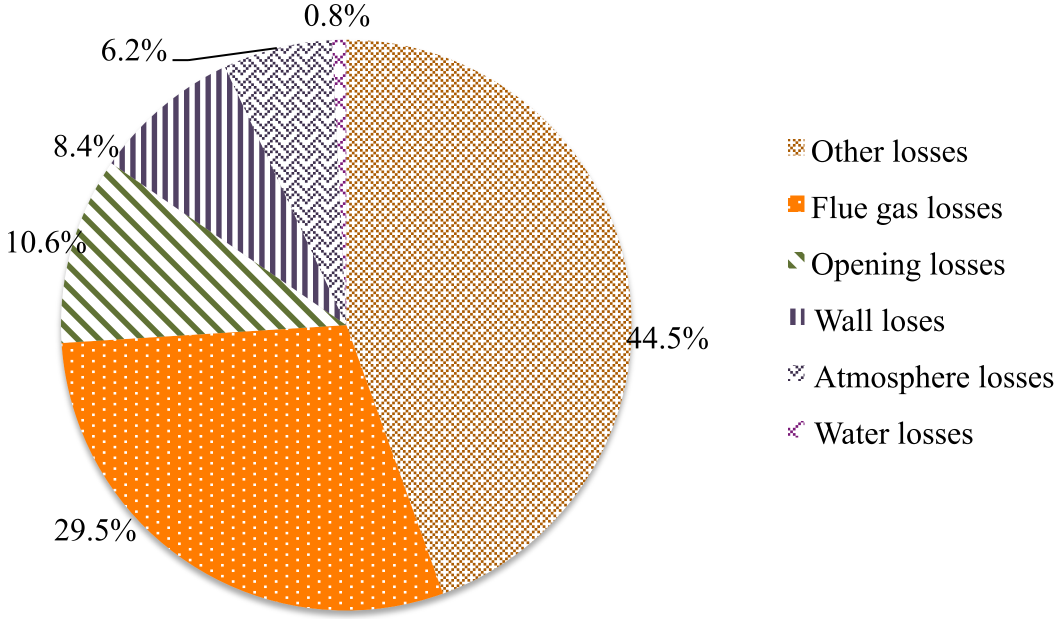


Figure 21: Gross heat distribution when production is idling

When production is idle, flue gas temperature drops to 800 °F, which reduces flue gas losses by 86%, compared with peak production. On the other hand, the inside furnace temperature remains at 2,186 °F, heat transmission from hearth and roof became the biggest energy losses with 5,687,690 Btu/hr (figure 22). The atmosphere losses are 791,894 Btu/hr during idling.

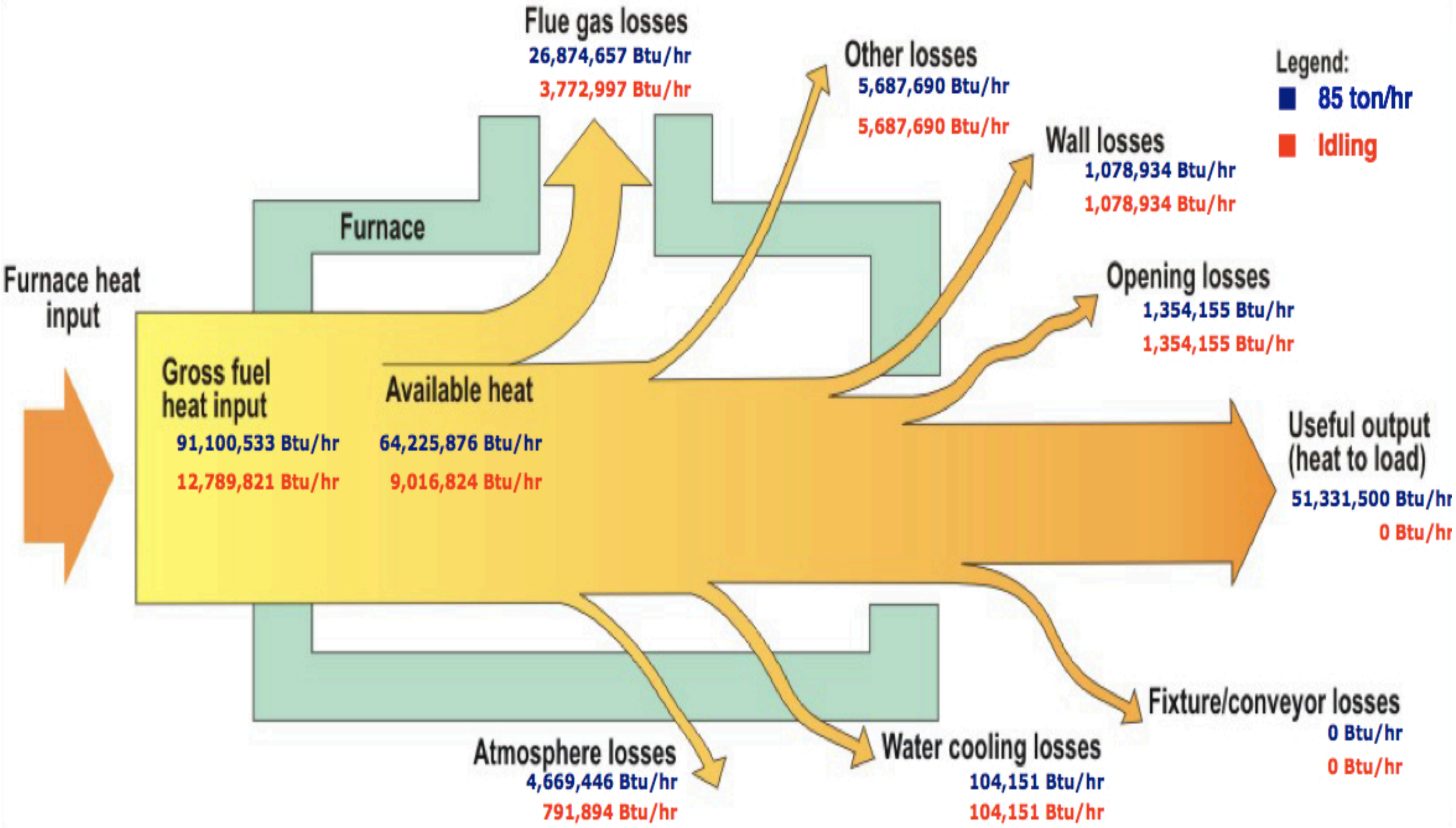


Figure 22: Comparison energy losses between idling and peak production

7.4 Conclusion

Wall, hearth and roof losses are relatively constant regardless of operation or idling. Some materials of refractories and insulation can be considered in order to reduce those heat conduction. In 2009, Gerdau implemented a project of adding another layer of insulating material in the roof and wall for the entire furnace. The total area covered by insulating materials was more than 2000 ft^2. Monitoring should be done to evaluate the project benefits. When production is idling, air infiltration is still happening, cold air leaks into the furnace through the opening areas. Cold air is heated to flue gas temperature in the furnace, and then exits through the flue system, wasting amount of fuel. Pressure control needs to be considered in order to prevent heat leakage into atmosphere.

Chapter 8 The feasibility of preheating billets at Gerdau

The temperature of billets goes from 2200 °F to ambient temperature during storage at billet bay, and then are transported to the reheat furnace to be heated up to 2200 °F. This section explores the feasibility of recovering waste heat by preheating billets using RETScreen. The energy loss chapter, chapter 5, reported that: more than 20 millions Btu/hr losses were from flue gas. This flue gas energy could be recovered.

A similar preheating project was done for North Star Steel's Iowa plant (NSSI) (which was later acquired by GLSNA in 2004), a mini-mill steel producer that uses EAF steelmaking and 100% recycled steel scrap (U.S.Department of Energy, 2003). In 2001, the annual production was 300,000 tons in NSSI and the total energy cost were $8.7 million for fiscal year 2000-2001. The preheating project in NSSI was estimated to have annual energy savings of 14,080 MM Btu at a cost of $153,846 in 2001. The present value of cost is $179,958 as calculated by inflation calculator (CUPA, 2011).

8.1 Method

Software RETScreen was used to determine the feasibility of preheating billets. RETScreen is an energy project analysis software. It was developed by Natural Resource Canada. The software has been used worldwide to evaluate energy production, energy project cost and saving, GHG emissions reductions, and financial viability etc.

8.1.1 The amount of recoverable heat

The amount of recoverable heat was calculated by equation 1

$$\boldsymbol{Q = m \times Cp \times \Delta T} \quad (1)$$

M= 714,818,033 lb (average annual production from 2005-2010)

Cp= 0.1 btu/lb*F

The flue gases temperature is 1000 °F - 1500 °F, preheating billets from ambient temperature 36.1 °F at billet bay to an estimated 600 °F.

ΔT= 563.9 °F

The amount of recoverable heat = 40,308.6 MM Btu

8.1.2 Other conditions

Other inputs to RETScreen are based on the production data in Gerdau (table 14).

- Fuel rate applied was the average rate from 2005-2010.
- Duty cycle refers to the percentage of time that the load is running during operating time.
- Season efficiency refers to thermal efficiency in the reheat furnace. According to the calculation by PHAST, thermal efficiency in the reheat furnace is about 56.4% (Natural Resources Canada, 2009).

Table 14: RETScreen data input

Indicators	Conditions
Fuel Rate	$ 8.2 MM btu
Heat Load	90 MM btu/hr
Duty Cycle	50 %
Operation	8016 hr/year
Seasonal efficiency	56.4%
Recoverable efficiency	80%
Initial cost	$ 1,250,000
Annual Maintenance cost	$ 50,000

The heat load and operation conditions applied in RETScreen were obtained from an internal Gerdau report (table 15) (Manuliak, 2007).

Table 15: Heat load tests in the reheat furnace

Case	Fuel consumption (MM btu/ton)	Production (t/hr)	Fuel Usage (MM btu/hr)
1	1.1	86	94.6
2	1.0	90	90.0
3	1.0	90	90.0
4	1.0	90	90.0
5	1.2	77	92.4
6	1.1	83	91.3
7	1.0	90	90.0
8	1.0	80	80.0
9	1.0	80	80.0

Source: Manuliak, 2007

The costs for this project, defined as initial costs, consider labor costs and costs required to bring the project to a commercial statue, including construction, installation, equipment and material costs.

To estimate the initial costs for the preheating section the feasibility study of preheating billet in NSSI figures were applied considering inflation (U.S. Department of Energy, 2003) and the different scale, as well as upgrading handling systems.

The initial costs are estimated at $1,250,000 based on the project of installation of ceramic fibre veneer in 2009 at Gerdau, including

1) Materials: $600,000 (RHI Canada Inc., 2009)
    - Insulation & Refractory: Ceramic fiber block and insulating firebrick
2) Structural works: $400,000 (RHI Canada Inc., 2009)
    - Construction
    - Installation
3) Upgrading handling system: $100,000 (interviews, 2011)
4) Labors: $100,000 (interviews, 2011)
5) Other: $50,000 (interviews, 2011)

The project life chosen was 20 years with 5% inflation rate.

8.2 Findings

Preheating billets to 600 °F will decrease energy consumption by 57,175.3 MM Btu /year, according to the RETScreen analysis. The annual natural gas saving is estimated to be $468,838 when the rate is $8.2 MM Btu/hr GHG reduction is 2,999 ton CO_2-eq per year. The project simple payback is estimated to be 3.0 years (figure 23).

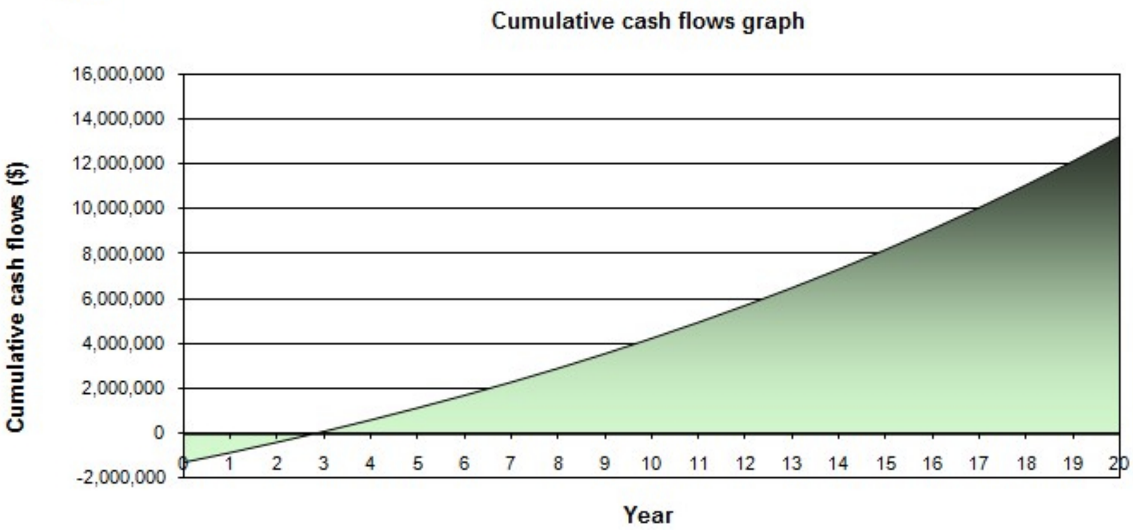


Figure 23: Financial analysis of preheating billets calculated by RETScreen

8.3 Conclusion

According to the calculation by RETScreen, preheating billets to 600 °F is considered economically feasible. The amount of recoverable heat in this calculation is only 19.3% of flue gas losses. Theoretically, the preheat temperature can be more than 600 °F, but practical limits to this are waste heat temperature and billets' transportation distance.

Energy price will impact the project payback period. If energy prices go up, the project will have a shorter payback period than 3.0 years. In addition, all energy efficiency projects have strengths, weaknesses, opportunities and threats that should be considered by Gerdau. Those concerns will be discussed in chapter 13 in this report.

References

Interviews. (2011). *Gerdau meeting.* Unpublished raw data.

Natural Resources Canada. (2009). *E-textbook/guides for waste heat recovery by RET Screen.* Retrieved from http://www.retscreen.net/ang/energy_efficiency_heat_recovery.php

Manuliak, D. (2007). *Reheat furnace audit for Gerdau steel Selkirk Manitoba* (Internal Report). Ontario: Furnace Automation Technology & Equipment Inc.

U.S. Department of Energy (2006). *Full PWA report: An assessment of energy, waste, and productivity improvements for North Star steel Iowa.* Retrieved from http://www1.eere.energy.gov/industry/bestpractices/case_studies.html#Plant-Wide_Assessment_Case_Studies_and_Summaries

Chapter 9 Unfired hot charge box design

9.1 Introduction

The steel reheating process is an energy-intensive step in the steelmaking mill process. Semi-finished products, billets and slabs, must achieve a uniform temperature distribution within reheat furnace for the rolling operation. At Gerdau, a single billet needs to stay in the reheat furnace for about two hours at a rate of 0.625 ft/min (figure 14 to 26).

A 7 ⅝” billet at 85 ton/hr production rate was used as an example to calculate the rate of heat transfer in the proposed unfired hot charge box.

Figure 24: Billets at billet bay

Figure 25: Steel reheating process in the reheat furnace

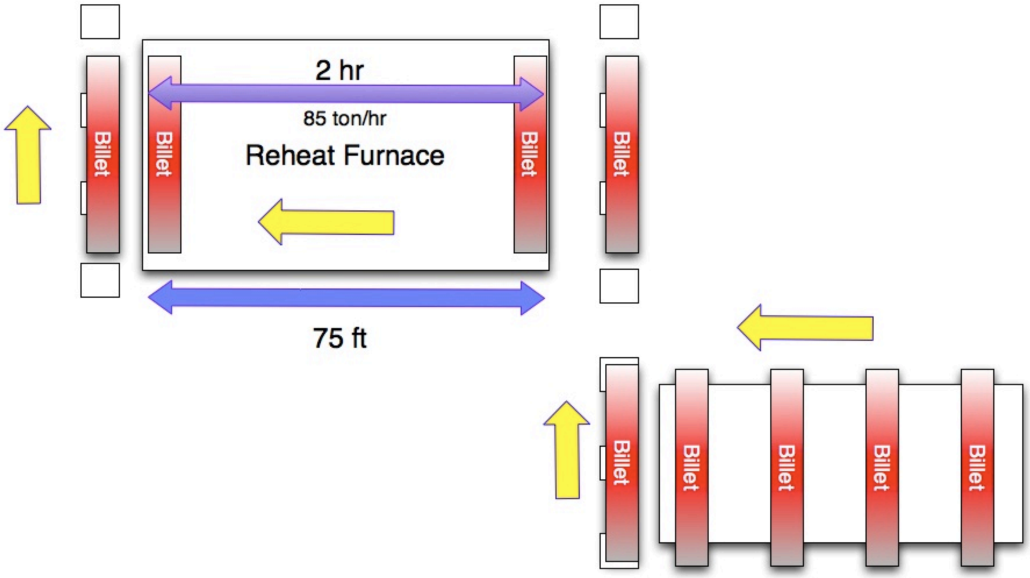


Figure 26: Preheating process at Gerdau

In order to keep the same production rate as the reheat furnace, the unfired hot charge box needs to heat the same weight of billets as the reheat furnace for the same time period. The heat is transferred in the unfired hot charge box by convection and conduction. One surface of a billet with ambient temperature is exposed to convection;

conduction will produce a change in the temperature distribution along the thickness of the billet.

9.2 Method

The Lump Capitance method is applied to determine the rate of heat transfer in billets. Biot number is calculated to validate the Lump Capitance Method by equation 3:

$$Bi = \frac{hL_c}{k} \quad (3)$$

Where

V = volume = 0.64 ft × 0.64 ft × 23 ft =9.42 ft^3

A_s = area exposed to hot air = 0.64 × 0.64 × 2+3 × 0.64 × 23=45 ft^2

L_C = characteristic length = V/A=9.42/45=0.21 ft=0.64 cm=0.064m

h = convection coefficient (W/m^2.K) , steel = 20 W/m^2.K

k = thermal conductivity (W/m.K), steel = 43 W/m.K

Bi (Biot number) = hL_C/k = 20 × 0.064/43 = 0.03

As the Biot number 0.03 < 0.1, Lump Capacitance method can be used in the heat transfer calculation (equation 4).

$$\frac{\theta}{\theta_i} = \frac{T_{(t)} - T_a}{T_i - T_a} = \exp\left[-\left(\frac{hA_s}{\rho Vc}\right)t\right] \quad (4)$$

Where

$T\,x,t(T)$ = reached temperature, 600 ^{o}F

T_a = surrounding temperature. Waste gas temperature 800 ^{o}F

T_i = body temperature: 36 ^{o}F

ρ= density = 7800 kg/m^3

c = *heat capacity of steel* = 440 J/kg.K

t = heat time

$$\frac{600-800}{36-800}=\exp\left[-\left(\frac{20}{7800\times 0.064\times 440}\right)t\right]$$

$0.263 = \exp(-9.1\times10^{-5}\times t)$

$=-1.335=-9.1\times10^{-5}\times t$

$t=14670s = 4$ hr

9.3 Results

To preheat the billet from 36 °F to 600 °F by waste heat, the heat transfer calculation estimates that four hours is required. As a result the length of unfired hot charge box or the distance of billet transportation from billet bay to the reheat furnace needs to be 150 feet (figure 27).

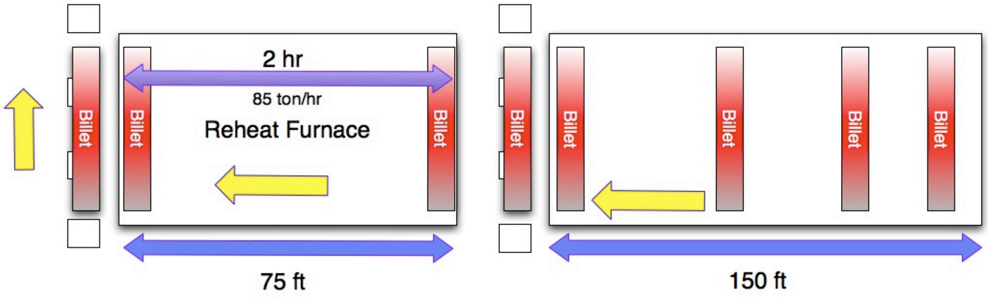


Figure 27: Proposed reheating process at Gerdau

After preheating billets from 36 °F to 600 °F, the heat required (Btu/hr) in the billet will be reduced by 22.3 % and the energy intensity (Btu/lb) will be reduced by 119.7 Btu/lb (table 16).

Table 16: Heat required comparison between 36 °F and 600 °F billet

Description	36 °F Billet	600 °F Billet	Energy Savings
Net heat required (Btu/hr)	64,225,876	49,869,376	14,356,500
Gross heat required (Btu/hr)	91,100,533	70,736,704	20,363,829
Energy Used (Btu/lb)	535.8	416.1	119.7

9.4 Discussion

In the Lump Capacitance method, the heating time depends on the difference between the temperature of the surrounding area (Ta) and the temperature that the billet must reach (Tx). Of course, the larger the difference, the shorter the heating time. The time for a solid to reach the surrounding temperature is infinite, or a very long time (figure 28). Therefore, a higher flue gas temperature will reduce the heating time in the box.

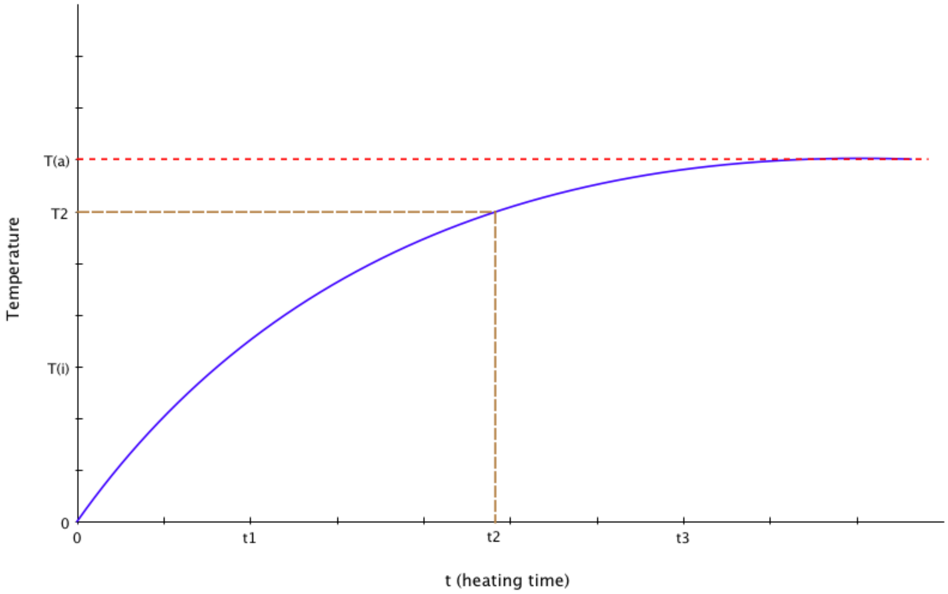


Figure 28: The principle of the Lump Capacitance method

9.4.1 Flue gas temperature

In this calculation, the ambient temperature of billet is considered to be 36 °F as the solid body temperature, based on the annual average temperature in Selkirk from NASA (Natural Resources Canada, 2009). Flue gas temperature in this box was assumed to be 800 °F, based on an assumption of 80% heat exchange efficiency and heat losses in the exchange system. This heat can either go through a heat exchange system, like recuperators or be charged into billets directly. Direct heat recovery to billets will use waste heat in the exhaust more efficiently than indirect heat recovery by a heat exchange system. In the daily production, the average flue gas temperature goes up to 1500 °F, which is much higher than 800 °F, making this temperature feasible. 800 °F was chosen because it is the minimum temperature of waste heat to have the billets reach 600 °F. If the flue gas of 1500 °F was used to preheat the billets to 600 °F, the preheating time will be reduced to 1.5 hr, which needs 55 feet long for billets' transportation (figure 29).

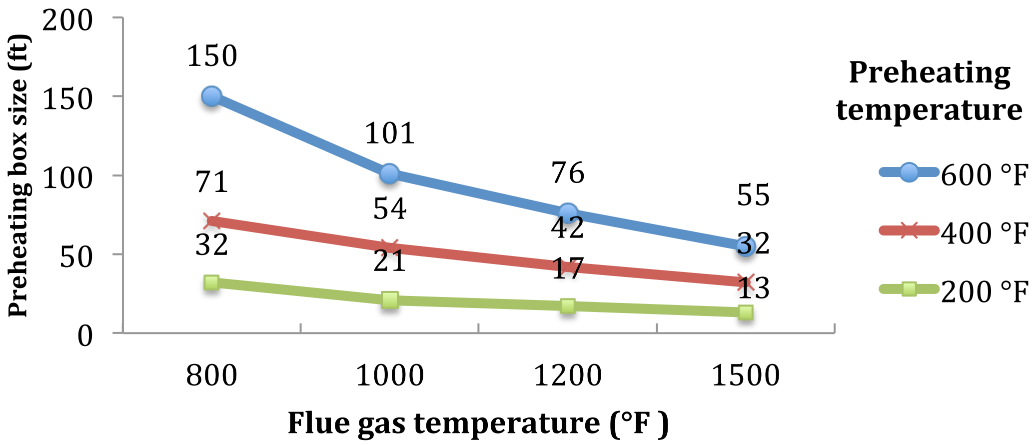


Figure 29: The size of the preheating box

9.4.2 Preheating temperature

In this analysis, the preheating temperature is 600 °F, which can save 22.4% of the energy consumption. If preheating temperature is lower than 600 °F, heating time is reduced dramatically. For instance, preheating billets to only 400 °F needs 1.9 hours when gas temperature is 800 °F, and it will generate 14.4% fuel savings calculated by PHAST (table 17).

Table 17: Energy savings by preheating billets

Billets temperature (°F)	Specific energy used (Btu/lb)	Energy saving (Btu/lb)	Energy saving (%)
Ambient	535.9	-----	-----
200 °F	510.2	25.7	4.8%
400 °F	458.7	77.2	14.4%
600 °F	416.1	119.8	22.4%

9.3.3 Box size

The length of the preheating box, or the handling distance from billets bay to the reheat furnace depends on the preheating temperature and the flue gas temperature (figure 25). The length of the preheating box can combine the actual handling distance and range from 13 feet to 150 feet on a theoretical basis. Considering the billet dimension is 0.64 feet (height) × 0.64 feet (width) × 23 feet (length), the width of the preheating box needs to be 24 feet. The height of preheating box could be 1 foot, which is high enough to storage a billet. Therefore, the dimension of preheating box could be 1 foot (height) × 24 feet (width) × 13 to 150 feet (length) theoretically (figure 30 and 31).

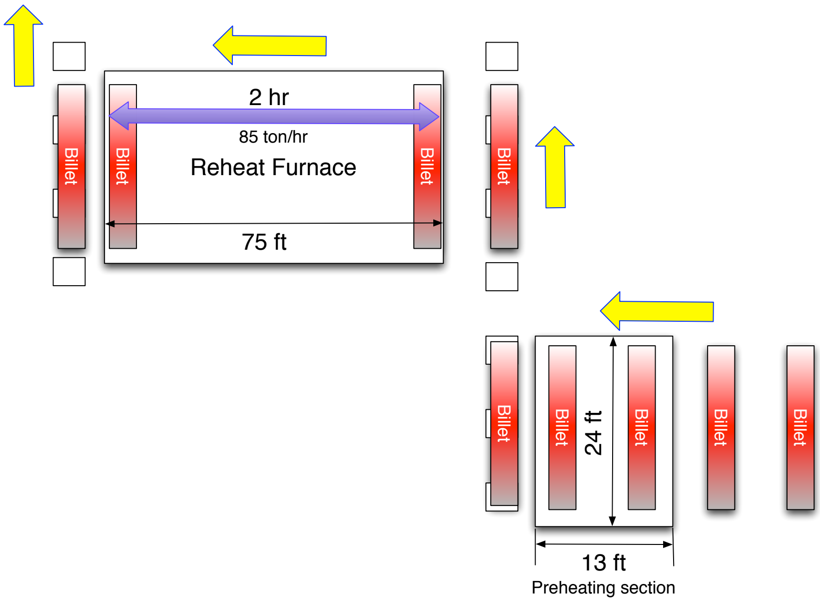


Figure 30: The dimension of the preheating box (13 feet long)

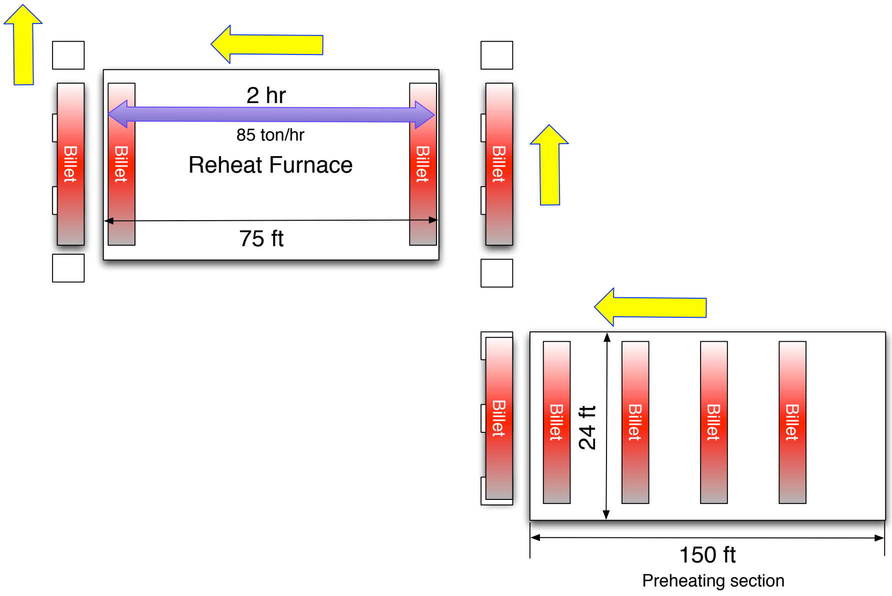


Figure 31: The dimension of the preheating box (150 feet long)

9.4 Conclusion

According to the mathematic model, preheating billets to 600 °F is theoretically feasible. The practical limit is the availability of space required for the preheating box. In order to reduce heat losses during the recovering process, the waste heat needs to be brought in to contact with the billets directly, preferably for the minimum preheating time and at the maximum the preheating temperature. The waste heat will be transferred to the load and preheat billets directly. What temperature can be reached through preheating depends on the size of the preheating box. The size of the preheating box is limited by the physical space and layout at Gerdau. A smaller preheating box of 13 feet may be a better fit for the space limitations and will have some energy savings if 1500 °F flue gas is used.

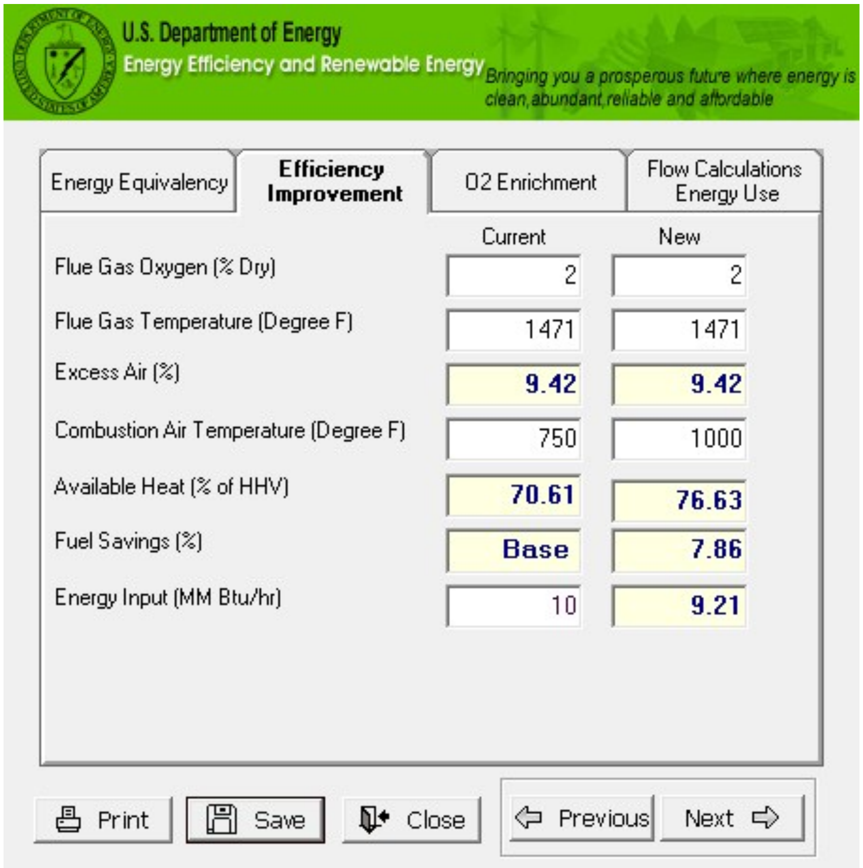
References

Natural Resources Canada (2009), RETScreen clean energy project analysis software, Retrieved from http://www.retscreen.net/ang/home.php

Chapter 10 Analysis of billet types and combustion air temperature

10.1 Background

Increasing combustion air temperature can improve energy efficiency significantly. Gerdau has a recuperator for the reheat furnace at site in order to increase combustion air temperature. The design temperature of the recuperator for combustion air is 900 °F to 1000 °F. However, in the daily production, the combustion air temperature is variable from 700 °F to 850 °F. Increasing combustion air temperature from 750 °F to 1000 °F will generate 7.9% natural gas savings calculated by PHAST (figure 32).



	Current	New
Flue Gas Oxygen (% Dry)	2	2
Flue Gas Temperature (Degree F)	1471	1471
Excess Air (%)	9.42	9.42
Combustion Air Temperature (Degree F)	750	1000
Available Heat (% of HHV)	70.61	76.63
Fuel Savings (%)	Base	7.86
Energy Input (MM Btu/hr)	10	9.21

Figure 32: Combustion air temperature analysis by PHAST

Ideally, Gerdau should keep combustion air temperature as high as possible. This chapter analyzes whether the combustion air temperature varies according to billet types and production periods.

10.2 Method

The steps in analyzing the statistical association between combustion air temperature and billet types and production periods are:

Step 1: Collected combustion air temperatures on production dates of April 9 2010, August 5 2006, August 20 2006, Sept 10 2006 and Sept 27 2006 for billet types of 6 ¾”, 7 ⅝”, 8”, 10” and 10 × 16 slab at production rate of 85 tons/hr (table 18).

Step 2: Applied analysis of variance (ANOVA) for statistical analysis. ANOVA is a procedure for assigning sample variance to different sources and deciding whether the variation arises within or among different groups. ANOVA can determine the possible combined effects of the independent variables. It also assesses the ways in which these variables interact with one another to influence scores on the dependent variable.

Step 3: Applied two-way analysis of variance (ANOVA) in this study. It is designed with two independent variables. Significant rate is considered to be 5%.

Step 4: Loaded temperature data into statistical software, SAS, for the calculation. SAS software is designed for both specialized and enterprise analytical needs for statistics. The data inputs are in the Appendix III.

Table 18: Production data used for statistics

Billet Type	Cycle	Observation	Production Date	Production Rate
7 ⅝”	7:00-19:00	145	April 9 2010	85 ton/hr
6 ¾”	19:00-7:00	145	Aug 5 2006	85 ton/hr
10”	7:00-19:00	145	Aug 20 2006	85 ton/hr
8”	19:00 -7:00	145	Sept 10 2006	85 ton/hr
10 X 16	19:00 -7:00	145	Sept 27 2006	85 ton/hr

10.3 Results

In the analysis, billet types have statistically significant effect on the combustion air temperature, (*F*(4,724) = 74.00 p < .001) (Appendix III).

Table 19: Statistical analysis between billet type and combustion air temperature

Significance	Mean of combustion air temperature	Number of observations	Type of billets
A	829.7	145	10”
B	802.3	145	10 × 16
B	796.6	145	8”
C	781.6	145	6 ¾”
D	745.2	145	7 ⅝”

Air temperatures vary considerably by size with the highest temperature being 10” and the lowest being 7 ⅝” in the following order from high combustion air temperature to lowest: 10” billet > 10 × 16 slab = 8” billet > 6 ¾” billet > 7 ⅝” billet (table 19). The result is not strictly that the larger the billet the greater the mean combustion air temperature as 10 x 16 slab is larger than 10” and 6 ¾” is larger than 7 ⅝”. Meanwhile, the production period does not have significant effect on the combustion air temperature (*F*(144,724) = 0.95 p = .6301) (Appendix III).

10.4 Conclusion

Higher combustion air temperature in the reheat furnace will decrease the flue gas losses and improve the energy efficiency. The results showed that the combustion air temperatures have statistical difference among different billet types. The production sequence needs to be considered by the production planners in order to keep combustion air temperature at a stable level in certain production periods as high flue gas temperature results in less flue gas losses according to PHAST calculation.

Chapter 11 "Tap to tap" time control

Gerdau is a mini-mill producer. In the melt ship, scrap metals are melted into liquid steel in EBT furnace with a 55-ton capacity at Gerdau. The transformer capacity is 48/55 MVA. The cycle starts from the charging of the furnace with steel scraps. After the furnace is charged, three electrodes are lowered into the scrap from the top. Current is initiated and electrodes bore through the scrap to form liquid steel (figure 33). During the process, oxygen is injected to oxidize the carbon in the liquid steel. Then, the molten steel is tapped to the ladle for refining through a tap hole. The typical material flow during melting processes is shown in figure 34.

Figure 33: The EBT furnace at Gerdau

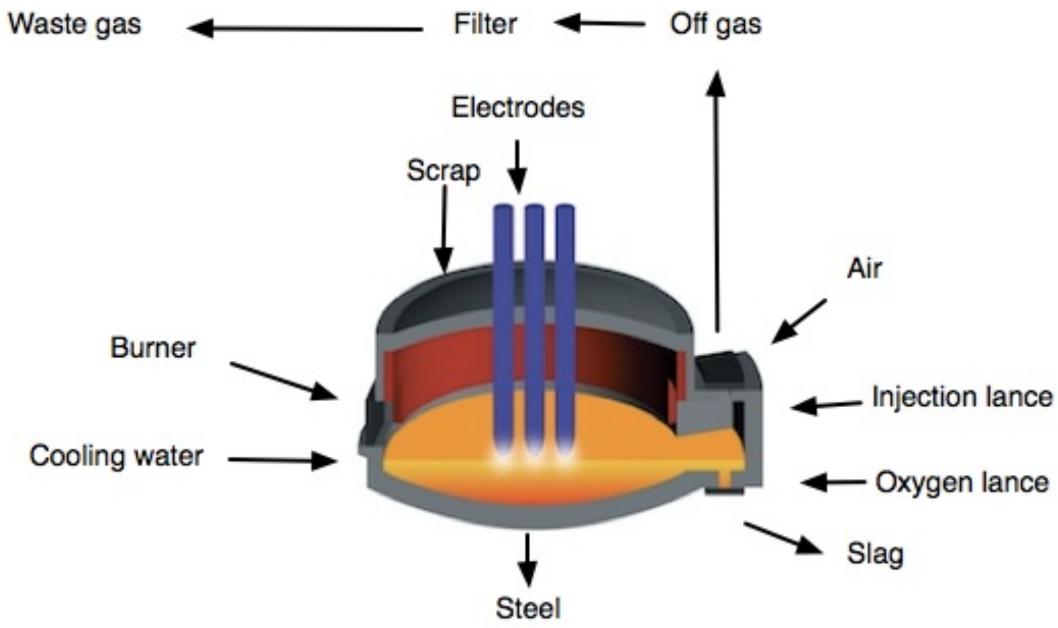


Figure 34: Material flow in the EBT furnace

Sources: Adapted from Sandberg, 2005; TATA Steel, 2011

The main source of energy is electricity in EBT. Gerdau also has some other chemical fuel inputs in the EBT furnace, including coal, coke, minerals, fines, and charcoal. The typical energy balance of EAF production process in steel manufacturing is shown in figure 35. About 65% of energy is electricity. The chemical energy is about 35% of total energy input. 53% of energy leaves the furnace with liquid steel; while the reminders are slag, waste gas, cooling and other losses.

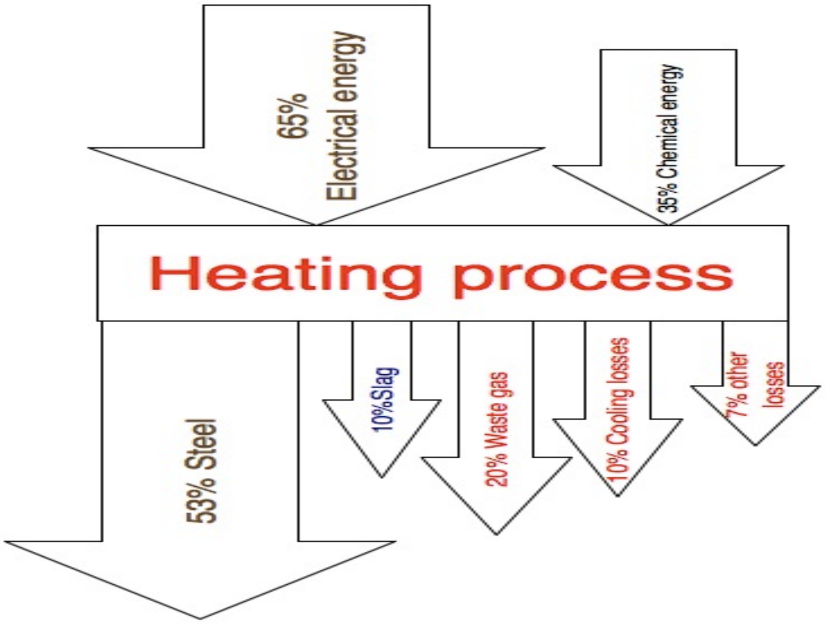


Figure 35: Energy flow in the EAF steel production process

Source: Adapted from Sandberg, 2005

One of the critical indicators of energy consumption is the "tap to tap'" time in the EBT furnace, which refers to the complete heating cycle in the furnace. "Tap to tap" time includes power-on time and power-off time. The time structure is shown in figure 36.

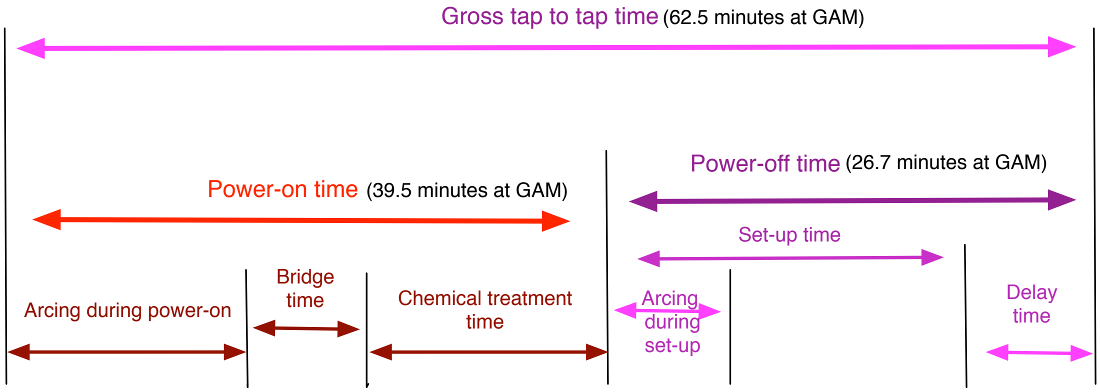


Figure 36: Time structure in a heat cycle applied to Gerdau

Source: Adapted from Riedinger et al., 2008

Power-on time is defined as the period from the beginning of charging to the end of chemical energy input. Power-off time includes set-up time, which includes activities like tapping and charging, and delay time, which refers to intervals from tapping to the start of scrap charge. The energy efficiency is improved primarily by minimizing “tap to tap” time. At Gerdau, the average heat time (gross tap to tap time) was 65.2 minutes in 2010, in which average power-on time was 39.5 minutes and power-off time was 26.7 minutes. Power-on time is close to Gerdau’s target time (39 minutes), but power-off time is 33.5% longer than its target time (20 minutes) (figure 37).

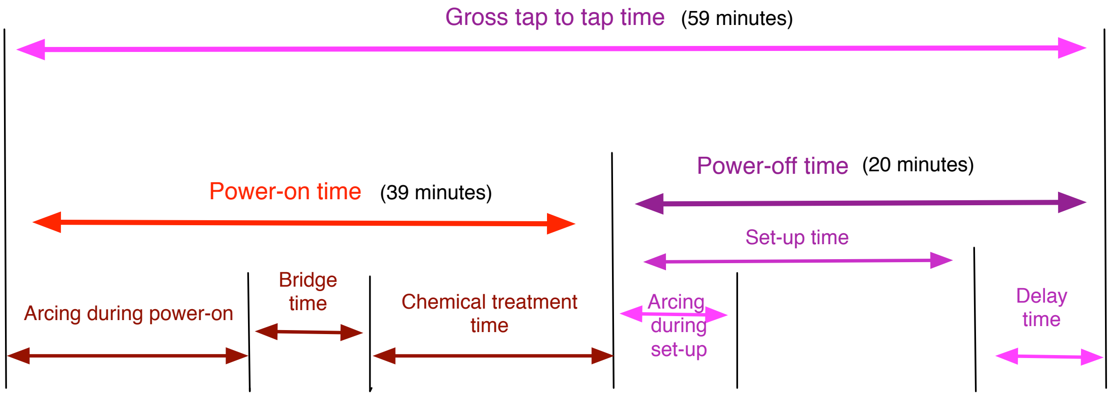


Figure 37: Targeted time structure in a heat cycle at Gerdau

From the EBT’s time record, the 2010 delay time at Gerdau was found to be 762.3 hr/yr. The unplanned downtime could influence on the delay time in the power-off time. Even though zero delay time is not achievable in real production, it is necessary to minimize the unplanned downtime. To achieve minimal maintenance related downtime, the following factors need to be considered (Riedinger, Hetzel, Fleischer, & Hagemann, 2008), namely having:

1) Qualified maintenance personnel, which requires continuous training is obligatory
2) Systematic coordination, planning, scheduling and execution of periodic downtimes

3) Close cooperation between maintenance and production
4) Regular cleaning activities during down times
5) Spare parts management providing parts in time and in condition
6) Objective and systematic record of delays and their reasons

As melting processes are the biggest electricity consumers at Gerdau with EBT furnace consumed 158, 224,437 kWh and 395, 725 kVa in 2010, a time analysis of the heat cycle is necessary in order to optimize and continuously improve the melting processes. Further research is needed to analyze the reason of delay in EBT furnace at Gerdau.

References

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Chapter 12 Other opportunities for energy saving

Other opportunities for energy saving at Gerdau, in addition to preheating billets, include: 1) upgrading charge end in the reheat furnace, 2) recovering waste heat in the ladle preheater, 3) replacing direct-fired natural gas heater with indirect-fired natural gas heaters, and 4) oxyfuel combustion.

12.1 Upgrading charge end

The charge end of the reheat furnace has a fixed opening area, which causes 1,164,517 Btu/hr energy losses that costs Gerdau $78,877.4 per year. The discharge end is a variable opening end that opens every 10 seconds for 120 seconds. The opening losses from the discharge end are 189,638 Btu/hr. Upgrading the charge end to a variable opening end is proposed.

12.1.1 Method

The steps to determine the energy savings of upgrading charge end are:

Step 1: Collected production data of the current opening losses and the proposed opening losses was applied to the calculation of energy savings (table 20).

Step 2: Calculated energy savings of the proposed opening losses by PHAST.

Step 3: Calculated energy savings by equation 5.

$$S_a = S_E \times R_F \quad (5)$$

Where

S_a = annual energy savings ($/yr)

S_E = annual energy savings (MM Btu/yr)

R_F = fuel rate ($/MM Btu).

The operating hours in the reheat furnace and fuel rate are considered to be 8016 hours/yr and \$8.2/MM Btu.

Step 4: Calculated the simple payback period of upgrading by equation 6. The project costs are estimated to be \$200,000, including materials, installation and upgrading control system.

$$Y_S = \frac{C_p}{S_a} \qquad (6)$$

Where

Y_s = simple payback period (yr)

C_p = project costs (\$)

S_a = annual energy savings (\$/yr)

Step 5: Calculated CO_2 emission reductions of upgrading by equation 7

$$E_R = S_E \times F_E \qquad (7)$$

Where

E_R = amount of CO_2 reductions per year (ton/yr)

S_E = annual energy savings (MM Btu/yr)

F_E = emission factor, natural gas's emission factor is 0.052 ton CO_2/MM Btu

Table 20: The data input of opening losses from the variable opening area

Item	Variable opening area	Fix opening area	Proposed opening area
Furnace wall thickness (inch)	13.5	13.5	13.5
Length of opening (inch)	288	288	288
Height of opening (inch)	18	18	18
Total opening area (ft^2)	36	20	28
Inside temp (°F)	2329	2329	2329
Outside of ambient temp (°F)	68	68	68
% of opening time (%)	7.6%	100%	100%

12.1.2 Results

Upgrading the charge end to a variable opening end reduces opening losses by 78.2% from 1,354,155 Btu/hr to 294,992 MM Btu/hr calculated by PHAST. The annual energy savings of upgrading are 8,490 MM Btu or $69,620 (table 21).

Table 21: Energy saving by upgrading charge end

Item	Value
Current opening losses (Btu/hr)	1,354,155
Proposed opening losses (Btu/hr)	294,992
Energy saving (Btu/hr)	1,059,163
Operating hour (hours)	8,016
Fuel rate ($/MM Btu)	$8.2
Annual saving ($/yr)	$69,620
Simple payback period (yr)	2.9
CO_2 reductions (ton)	441

12.2 Waste recovery in the ladle preheater

12.2.1 Introduction

At Gerdau, the ladle preheater uses ambient air as combustion air. The flue gas temperature is up to 1600 °F. It is possible to recovery part of the waste heat to preheat combustion air (figure 38 and 39). However, the heater at Gerdau does not have an information system in it and so no metrics are known. The firing capacity of burners is unknown. Based on the average level in steel industries, installing a recuperator to preheat combustion air for the ladle preheater is proposed.

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Figure 38: Recuperator to recover hot flue gases from ladle

Source: U.S. Department of Energy, 2006

Figure 39: The ladle at Gerdau

12.2.2 Method

To determine the feasibility of waste heat recovery in the ladle preheater, we carried out the following steps:

Step 1: Applied 15 MM Btu/hr as firing capacity in the ladle preheater at Gerdau. It is the average specification in steel industries to heat a 55 to 70 ton ladle (U.S. Department of Environmental Quality, 2008; Whiting, 2011).

Step 2: Estimated flue gas temperature to be 1600 °F as well as 2% oxygen in flue gas in a dry condition.

Step 3: Considered ambient temperature to be 68 °F, as the ladle heater is located in the melt shop.

Step 4: Loaded all data into the calculator in PHAST to estimate the fuel saving with the use of preheated combustion air.

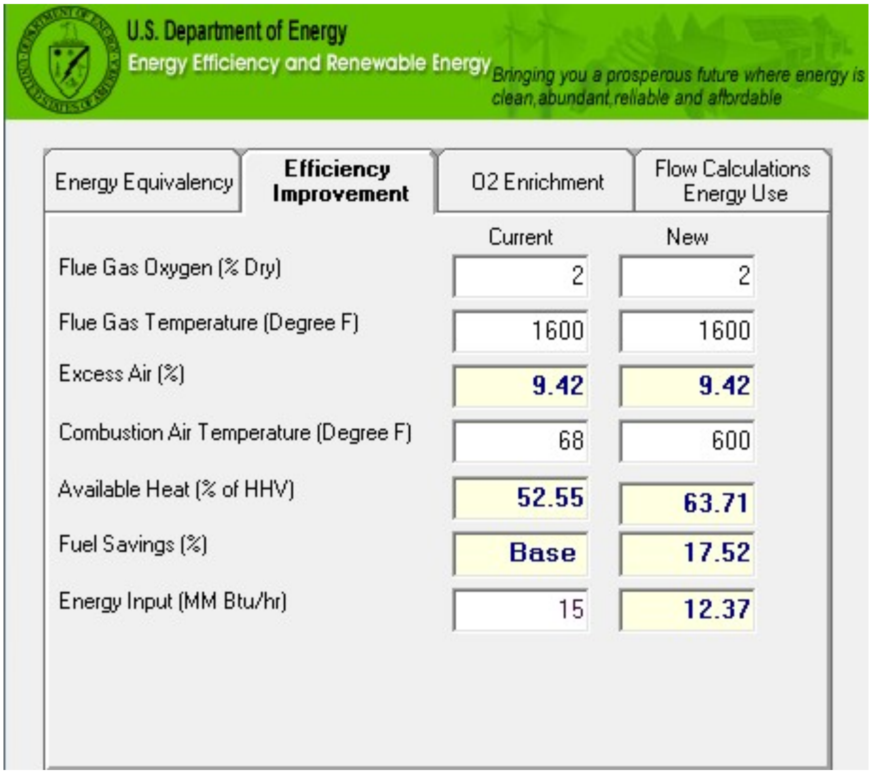
Step 5: Calculated the annual energy saving by equation 5

Step 6: Calculated the simple payback by equation 6. Based on the similar installations from other steel manufacturers, the installation cost was estimated to US $30,000 to $40,000 and the recuperator cost was US $40,000 in 2001 (U.S. Department of Energy, 2001). The total project cost was expected to be approximately US $70,000-$80,000. The quotation of the total project cost was obtained from Exothermic, Inc. (U.S. Department of Energy, 2001), which is a major supplier of recuperators used for combustion air preheating. Allowing the higher project cost, the present value is $144,017.

Step 7: Calculated CO_2 reductions by equation 6.

12.2.3 Results

Figure 36 shows that preheating for the ladle is estimated to have 2.6 MM Btu/hr energy savings or $170,560 annual every savings by PHAST (figure 40, table 22). The payback period is estimated to be 0.8 year or 10.1 months. From both technical and economic perspectives, waste heat recovery in the ladle preheater seems to be feasible.



	Current	New
Flue Gas Oxygen (% Dry)	2	2
Flue Gas Temperature (Degree F)	1600	1600
Excess Air (%)	9.42	9.42
Combustion Air Temperature (Degree F)	68	600
Available Heat (% of HHV)	52.55	63.71
Fuel Savings (%)	Base	17.52
Energy Input (MM Btu/hr)	15	12.37

Figure 40: The calculation of heat recovery in the ladle preheater

Table 22: The calculation of annual energy saving by heat recovery in the ladle preheater

Indicators	Data
Fuel saving (MM Btu/hr)	2.6
Operating hours (hr)	8,000
Annual fuel saving (MM Btu)	20,800
Fuel rate ($/MM Btu)	$8.2
Annual saving ($)	$170,560
Cost ($)	$144,017
Simple payback (yr)	0.8
CO_2 reduction (ton)	1,081

It should be noted that a limitation of this research is the lack of metering for all temperatures and for the firing capacity in the ladle preheater to determine the actual energy input in the ladle.

12.3 Replacing direct-fired natural gas heaters

Gerdau still operates three direct-fired natural gas heaters (figure 41). Those heaters operated through the winter season for space heating. The heaters are used as a permanent heating system. However, according to the natural gas installation regulation, direct-fired heaters are not certified for permanent use. Gerdau has replaced 14 heaters in 2008 - 2010 and intends to replace remaining heaters to increase safety and conform to the Natural Gas Installation Code (CSA/CGA B149.1) in 2011. The three remaining heaters are in the open hearth building. Gerdau plans to replace them in 2011.

Figure 41: Direct-fired natural gas heater

The heaters provide space heating in the open hearth building. Gerdau is required to replace the three remaining mobile, direct-fired, natural gas heaters with four natural gas –fired indirect heaters. Each heater's firing capacity needs to be 275,400 Btu/hr to supply 3400 cfm. The operation hours are expected to vary from years to years based on annual temperature changes (table 23). The fuel savings are estimated to be 1.9 MM Btu/hr theoretically. However, the actual fuel savings depend on the operating hours and the operating capacity. With many variables, fuel savings may not occur after replacing.

Table 23: Energy saving by replacing direct-fired heater

Item	Value
Firing capacity of direct-fire heater	1
No. of direct heaters	3
Firing capacity of indirect-fire	275,400
No. of indirect heater	4
Energy saving (MMBtu/hr)	1.9
Operation hours (hr/yr)	2,880
Fuel rate ($/MMBtu/hr)	$ 8.2
Annual energy saving ($/yr)	$ 44,870.4
Costs ($)	$ 200,000
Simple payback period (yr)	4.5
CO_2 reductions (ton/yr)	284

12.4 Oxyfuel combustion

12.4.1 Introduction

To start and maintain combustion in the furnace, three factors need to be considered, oxygen, fuel and energy for ignition. Energy consumption in furnaces for processing heat can be represented by the following chemical reaction that produces pollution including greenhouse gases (figure 42). 79% ballast, almost all nitrogen, in air has to be heated in the heating process, which wastes energy.

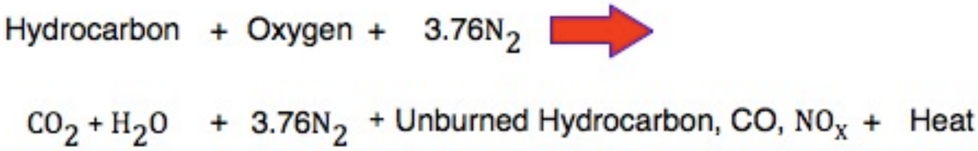


Figure 42: Hydrocarbon combustion reaction

Due to the rising price of fossil fuel in the 1970s, some industrial furnaces use enriched air from liquid oxygen or vacuum pressure swing adsorption units to remove N_2. Furnace efficiency through oxygen enrichment relies on the flue gas temperature, combustion air temperature, etc. Figure 43 shows the relationship between flue gas temperature and furnace efficiency by oxygen enrichment. Numerical studies have indicated that replacing air with oxygen for combustion significantly reduces the energy loss in exhaust gases and increase heating system efficiency in the heating process. Qiu & Hayden (2009) reported that a 22% natural gas saving was generated by increasing oxygen concentration to 28% in the combustion air of the reheat furnace. Huang, Chang, & Wu (2008) pointed out that the payback period of enriching oxygen to 30% in the combustion air was 5.75 years.

However, partial oxygen enrichment may result in a large increase of NO_X unless the furnace has a perfectly sealed chamber and a very high furnace pressure. In other words, without having a much hotter flame in the furnace and controlling the infiltrating air, the NO_X will increase. A completely sealed furnace is not feasible at Gerdau because the reheat process is continuous, with billets entering and leaving the furnace. Thus, partial oxygen enrichment is not an option for Gerdau.

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Figure 43: Energy saving by oxygen combustion

Source: U.S. Department of Energy, 2005

Steel industries began to use pure oxygen (industrial grade) to replace air for combustion fossil fuel since 1990s, called oxyfuel combustion. Today, oxygen combustion is widely applied to EAF for scrap melting, ladle preheating, and reheating. The first reheat furnace using oxyfuel combustion in the world was converted by Linde in 1990 at Timken in the United States (Schéele, 2010). Meanwhile, a new technique of oxyfuel combustion, flameless oxyfuel combustion, has been established and implemented widely in parallel with conventional oxyfuel combustion. Flameless combustion means the flame is no longer seen or detected by the human eye. There are two ways to obtain flameless oxyfuel combustion. One is to dilute the flame by recirculating part of its flue gas to the burners. The other is to use separated injection of fuel and oxygen at high velocities (Schéele et al., 2009) (Figure 44).

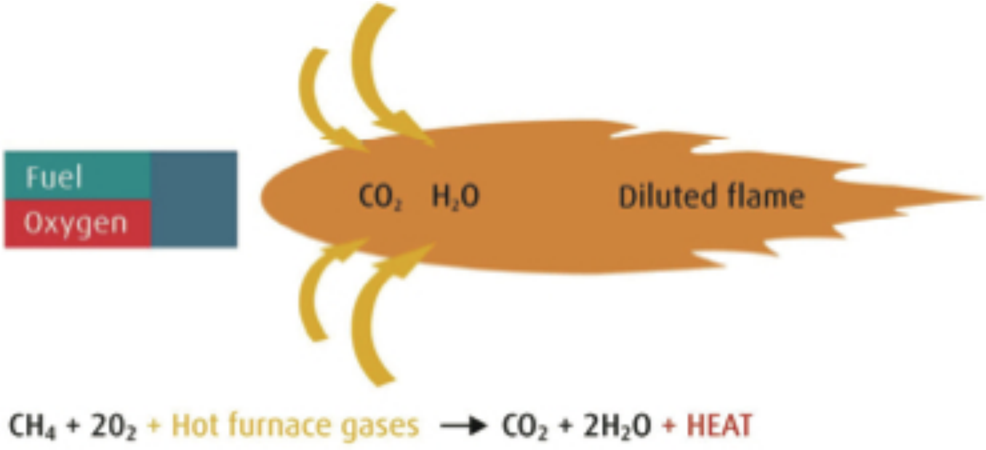

Figure 44: The principle of flameless oxyfuel combustion

Source: Schéele, 2010. Used with permission by Joachim Von Schéele. The permission was obtained on March 1 2011.

Flameless combustion significantly reduced heat time and brings more uniform heating by diluting flame through hot furnace gas (figure 45). Dispersing combustion gases ensures more effective and uniform heating because the dispersed flame can spread over a greater volume. Diluting flame also controls flame temperature under 2552 °F to avoid NO_X formation(Schéele et al., 2008). By using flameless oxyfuel in furnaces, the thermal efficiency may reach 80% without a recuperator and the specific energy used could be less than 426 Btu/lb (table 24).

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Figure 45: Heating time at Ovako's Hofors Works using different combustion technologies

Source: Fredriksson, Vesterberg, Claesson, Moroz, & Schéele, 2008

Table 24: Energy comparison between air-fuel and oxyfuel combustion

	Unit	Air-fuel	Air fuel with recuperator	Flameless oxyfuel without recuperator
Enthalpy in steel	kwh/t	200	200	200
Transmission losses	kwh/t	10	10	10
Flue gas enthalpy	kwh/t	290	155	50
Flue gas temperature	°F	2,192	1,562	2,192
Air preheating	°F	68	450	68
Thermal efficiency	%	42%	60%	80%
Specific energy use	Btu/lb	768.1	554.7	384

Source: Schéele, et al., 2008. Used with permission by Joachim Von Schéele. The permission was obtained on March 1 2011.

The first flameless oxyfuel combustion furnace was installed in 2003. Today, more than 115 reheat furnaces and annealing lines have been equipped with flameless oxyfuel (Schéele, Ritzén, & Zilka, 2009), including ArcelorMittal, Ascométal (SeverStal), Böhler-Uddeholm (Voestalpine), Cosipa, Dongbei Special Steel, Outokumpu, Ovako, Scana Steel and SSAB (Schéele et al., 2009). Fredriksson et al. (2008) stated that flameless oxyfuel combustion reduced heating time by 66% at Ovako, Hofor Works, Sweden. For example, Outokumpu stainless steel rebuilt a walking beam furnace in Degerfors plant, Sweden. The air-fuel system was replaced by flameless oxyfuel in the furnace by the Linde group. The flameless oxyfuel increased heating capacity by 40%-50% and reduced fuel consumption by 25% (Ljungars, Gartz, & Schéele, 2004).

As oxyfuel significantly reduces heating time and increase productivity, the productivity benefits have been measured by:

- Productivity increased by 50% (Fredriksson, et al., 2008), the annual production is estimated to be 352,372 ton, which is average production over ten years
- Billet price: $550 (London Metal Exchange, 2011)
- Net profit margin: 8% (Latibex, 2011)

12.4.2 Method

The following steps are applied to determined the feasibility of oxyfuel combustion:

Step 1: Calculated the fuel saving for oxyfuel combustion by PHAST based on the production figures of:

- O_2 in combustion air: 21%
- Flue gas temperature: 1471 °F
- O_2 in flue gases: 2%

Step 2: Calculated the annual energy savings of oxyfuel combustion by equation 5 based on 8016 hr operation and \$8.2/MM Btu.

Step 3: Determined the amount of oxygen required by the *stoichiometric* combustion, which means one volume of natural gas needs two volumes of oxygen to completely burn. The cost of oxygen is \$4.5/MCF that is the price Gerdau purchases from its supplier.

Step 4: Calculated CO_2 reduction of oxyfuel combustion by equation 7.

Step 5: Calculated productivity benefits of flames oxyfuel combustion by equation 8

$$B_p = P_i \times P_b \times P_p \quad (8)$$

Where

B_p = productivity benefits by production improvement (\$/yr)

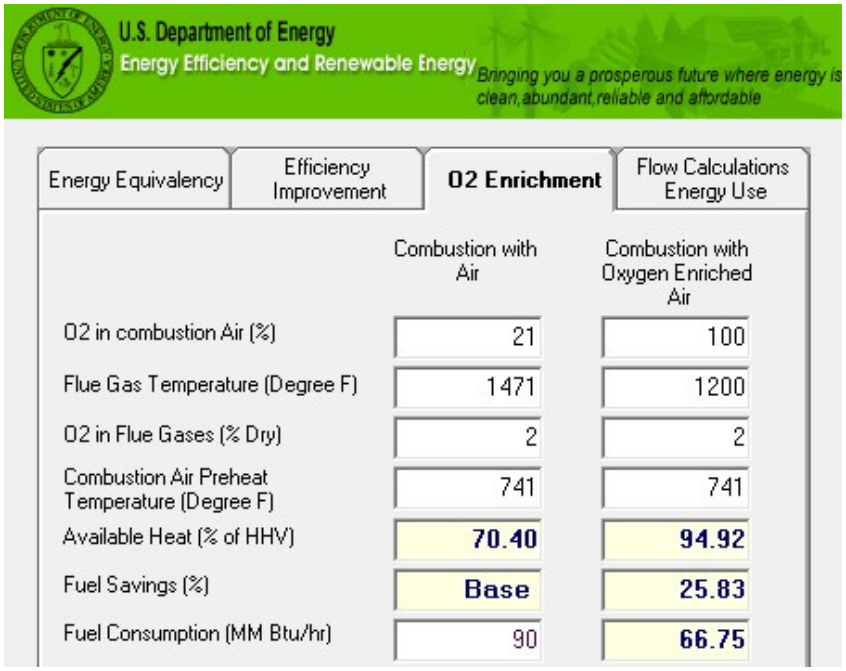
P_i = production improvement (ton/yr)

P_b = billet's price (\$/ton)

P_p = net profit margin (%)

12.4.3 Results

Oxyfuel combustion was estimated by PHAST to offer 25.8% energy saving (figure 46), The energy saving is 186,131.5 MM Btu/yr or \$1,526,278/yr (table 25). The annual oxygen needed is 1,042,470.3 MCF or \$4,691,116.2 (table 25). Considering productivity increases by 50%, the productivity benefits are \$7,752,191/yr by flameless oxyfuel combustion (table 26).



	Combustion with Air	Combustion with Oxygen Enriched Air
O2 in combustion Air (%)	21	100
Flue Gas Temperature (Degree F)	1471	1200
O2 in Flue Gases (% Dry)	2	2
Combustion Air Preheat Temperature (Degree F)	741	741
Available Heat (% of HHV)	**70.40**	**94.92**
Fuel Savings (%)	**Base**	**25.83**
Fuel Consumption (MM Btu/hr)	90	**66.75**

Figure 46: Energy saving calculation by oxyfuel in PHAST

Table 25: Energy saving and oxygen cost for oxyfuel combustion

Item	Value
Fuel consumption (MM Btu/hr)	90
Fuel saving (%)	25.8%
Fuel saving by oxyfuel (MM Btu/hr)	23.2
Fuel input by oxyfuel (MM Btu/hr)	66.8
Annual operation hours (hr/yr)	8,016
Fuel saving (MM Btu/yr)	185,971.2
Fuel rate ($/MM Btu)	$ 8.2
Annual gas saving ($/yr)	$ 1,524,963.8
Annual fuel consumed by oxyfuel (MM Btu/yr))	535,468.8
Annual gas by oxyfuel (MCF/yr)	521,391.3
Annual Oxygen needs (MCF/yr)	1,042,782.6
Oxygen rate ($/MCF)	$ 4.5
Annual oxygen cost ($/yr)	$ 4,691,521.7
Saving / (cost)	$ (3,167,557.9)
CO_2 reduction (ton)	9,670

Table 26: Benefits of productivity improvement by flameless oxyfuel combustion

Item	Value
Annual Production (ton)	352,372
Annual production improvement (ton)	176,186
Billets price ($/ton)	550
Net profit margin (%)	8%
Productivity benefits ($/yr)	$7,752,191

12.4.4 Discussion

Oxyfuel combustion replaces air with pure oxygen when burning fuel. It has several features:

- Low volume of flue gas by removing nitrogen during combustion, approximately 75% less flue gas than air fuel combustion.
- Less flue gas losses by reducing the volume of flue gas
- Low NO_X emissions. Theoretically, there are no NO_X emissions produced in oxyfuel combustion. In real production, it is very hard to prevent invasion air from furnace because typical furnaces have opening areas. By diluting flame, flame temperature could be controlled under 2552 °F to avoid NO_X formation.
- Shorter heating time by flameless oxyfuel.

The fuel savings by flameless oxyfuel combustion depends on many factors, including the rate of flue gas being circulated, oxygen in the flue gas, the flame temperature in the reheat furnace, oxygen injection rate and so on. Further research is needed to analyze the feasibility of oxyfuel or flameless oxyfuel at Gerdau to determine the fuel saving, quantity of oxygen needed as well as the need and benefit of improved productivity.

12.4.5 Conclusion

Oxyfuel is considered to be the best available technology in production processes that need a high temperature, such as coal-fired power plants, glass industries and steel industries. Flameless oxyfuel combustion has been in the commercial stage for over seven years. Flameless oxyfuel could reduce fuel consumption in the reheating process, significantly reduce the heating time and increase productivity. Even though the technology of flameless oxyfuel is mature, the high cost of oxygen is the bottleneck for wide implementation in industry. In this study, oxyfuel combustion is not feasible without considering productivity benefits as the oxygen cost is much higher than the fuel saving.

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Chapter 13 Incentive programs

13.1 Global incentive programs

Faced with energy insecurity, energy's environmental impacts and other energy issues, several incentives are available from governments to bridge the energy efficiency gap in the world. For instance, the Cohesion Policy Program in Europe resulted in the allocation of over €4.2 billion for energy efficiency improvements in the period 2007-2013 (European Commission, 2008). The United States has many incentive programs for energy efficiency projects as well, such as establishing voluntary programs, guarantee program for innovative energy technologies (109th U.S. Congress, 2005). The U.S. Department of Energy supports energy efficiency projects for energy - intensive industries by research, development, technology transfer, etc. (110th U.S. Congress, 2007).

13.2 Incentive programs in Canada

In Canada, the energy sector plays an important role in Canada's economy, the primary energy production and consumption increased by 64% and 26% respectively in the period of 1990 to 2007 (Environment Canada, 2007a). Canada does not have the same energy security problem as the United States due to its large domestic supply. However, Canada signed onto the Kyoto Protocol and does have a Kyoto target it is required to meet. By 2007, Canada's emissions were already 26% above 1990 levels and 33.8% above its Kyoto target (Environment Canada, 2007b). In Canada's iron and steel sector, emissions from stationary source (energy consumption) in 2007 were 2.5% above the 1990 level of total GHG emissions as figure 47 (Environment Canada, 2007c). The iron and steel industry includes four groups, iron and steel integrated producers, steel integrated companies, steel processors, and foundries and fabricators. Gerdau accounted for 5.1% of stationary emissions in the Canada's iron and steel sector.

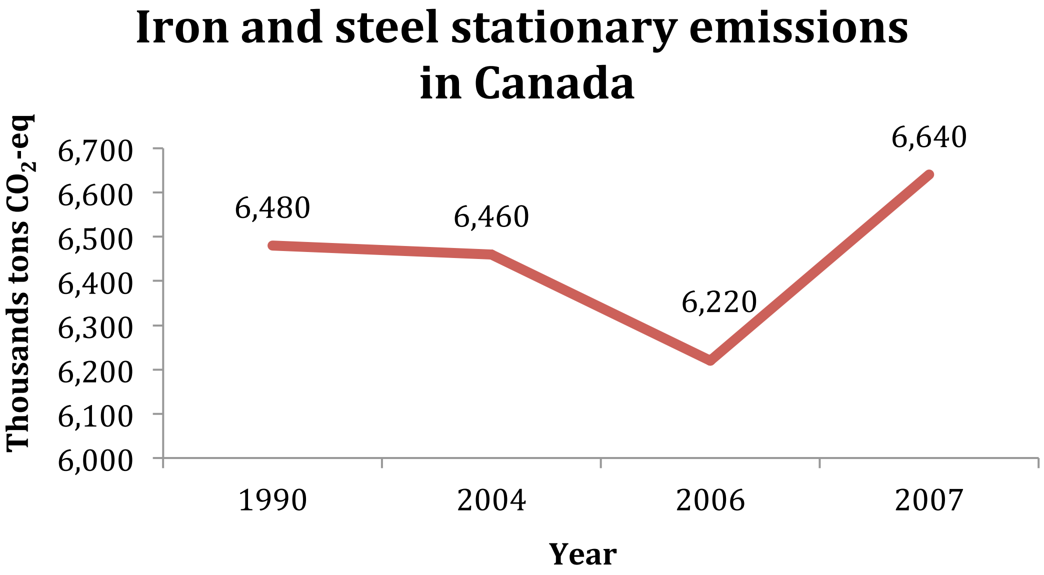

Figure 47: Iron and steel stationary emissions in Canada

In order to deal with climate change and environmental issues, the government of Canada has released some policies and measures, such as investing $10 billion in green infrastructure, energy efficiency, clean technologies, etc since 2006; providing new investments of $190 million to support cleaner and more sustainable environment in 2010 (Government of Canada, 2010). Some federal incentive programs for industries in Canada include:

13.2.1 Federal incentive programs

1) Accerated capital cost allowance

The accelerated capital cost allowance (CCA) allows investors an accelerated write-off of certain equipments used to produce energy in a more efficient way or to produce energy from alternative renewable sources (Huang, et al., 2008). This is a tax incentive.

A 50% accelerated CCA is provided for eligible equipment that generated either: (1) heat for use in an industrial process; or (2) electricity by using a renewable energy, waste fuel or making efficient use of fossil fuels.

In Canada’s 2010 Budget, accelerated CCA extended further eligibility, including (a) heat recovery equipment used in a broader range of applications; and (b) distribution equipment used in district energy systems that rely primarily on ground source heat pumps, active solar systems or heat recovery equipment.

2) Advantage energy technologies for high temperature processes

This measure is to improve the energy efficiency of the iron making process and other high temperature processes. Computer modelling capabilities for blast furance industrial gas turbine is also included (IEA, 2010).

3) Industrial buildings incentive program

This measure is to increase the energy efficiency of newly constructed buildings for manufacuturing and other industrial activities (IEA, 2010).

13.2.1 Manitoba Hydro’s incentove programs

In addition to some incentive programs from governments, Manitoba Hydro also provides its customers with technical support and financial incentives to identify, investigate, and implement energy efficiency improvements. For example, Manitoba Hydro’s natural gas optimization program and power smart performance optimatizaiton programs.

1) Natural gas optimization program (Manitoba Hydro, no date)

The optimization program provides access to technical and financial resources, including projects' idenfication, a feasibility study, and implementation. Projects need to qualify following criteria for implementation:

- 50% of total project cost, or
- the amount required to reach a one year payback on incremental cost; or
- $100,000.

2) Power smart performance optimization program (Manitoba Hydro, no date)

The program is to optimizate of three phase electrical power end-use systems, including compressed air, pumps and fans, industrial refrigeration, process heating, electro-chemical processes and plant-wide energy management systems. The projects for implementation need to be

- 50 per cent of total project cost; or
- the amount required to achieve a one year payback on incremental cost; or
- $250,000.

13.3 Conclusion

A number of incentive programs are available from federal government and Manitoba Hydro. These basically provide certain amount of capital for energy efficiency projects. Most incentive programs from federal government are available in the form of reduced taxation. Barriers to accessing these programs, such as Gerdau's corporate tax policies, should be considered, which are reported to have prevented accessing the accelerated

CCA program. Most of incentive programs from federal governments are in the form of taxation. As Manitoba Hydro's power smart programs are not in the form of tax, Gerdau should not have any barriers to taking advantage of these programs.

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Chapter 14 Discussion

14.1 Drivers of energy efficiency improvement

High energy costs have been the main driver of energy efficiency improvement in the steel sector over past decades. For example, in Japan, steel manufacturers established technologies of scrap preheating in the EAF steel production process due to high electricity price. In Europe and the United States, high natural gas prices forced steel producers to pursue oxyfuel combustion in reheating processes. Since 2000, environmental regulations and carbon trading requirements are new drivers to improve energy efficiency in the steel industry. Steel producers in Europe can sell emission credits through efficiency improvement, which makes energy efficiency projects more attractive to manufacturers and triggered the technologies' development, such as such as hot charging rolling and flameless oxyfuel combustion.

In Manitoba, however, electricity and natural gas price are relatively lower and there is no emission trading market. The low energy pricing changes the drivers, so that energy cost at Gerdau hardly becomes a main driver to improve efficiency. Even though a GHG cap and trade program has not been implemented in Canada, Canada has strict environmental regulations, which may become the main driver.

In Manitoba, 98% electricity is generated from hydro dam (Province of Manitoba, 2010), which has low emissions. Natural gas is the only source of stationary emissions at Gerdau. Therefore, reducing natural gas consumption is the key step to reduce GHG emissions and sustainability at Gerdau.

14.2 SWOT analysis of energy efficiency projects

Even if energy efficiency is looked at as the most cost-effective way to reduce energy consumption and greenhouse gas emissions (European Commission, 2008) and has economic benefits for industries, such as increased competiveness and higher productivity (Worrell et al, 2003), industries still need to commit to implement energy efficient projects. The strengths, weaknesses, opportunities, and threats (SWOT) of each energy efficiency implementation at Gerdau follow:

14.2.1 Strengths

- Energy efficiency saves money. Typically, energy costs are the second highest cost area in EAF steel production(Bisio, Rubatto, & Martini, 2000). For example, preheating billets to 600 °F will have annual fuel savings of $468,838 and upgrading the charge end will have annual energy savings of $69,620.
- Emissions reductions. As natural gas is the only stationary emissions at Gerdau, reducing natural gas consumption will significantly reduce the total emissions at Gerdau. For example, preheating billets will reduces 2,999 ton CO_2-eq per year.
- Productivity benefits. Waste heat recovery and oxyfuel combustion can increase heating capacity in the reheat, which reduces heating time and increase productivity. For example, flameless oxyfuel combustion can reduce heating time by 50%.

14.2.2 Weaknesses

- Production interruption. Energy efficiency projects have the risks of production interruption. Gerdau operations run 8,016 hours that does not count the annual maintenance period. For example, maintenance for flameless oxyfuel operation requires changing burners, upgrading control systems handling systems and so on. At Gerdau, only 744 hours down time could shut down every year. Therefore, energy efficiency projects needs to be well planned to ensure no interruption of production.

- Access to capital. Access to capital and production interruption are the main barriers to energy efficiency (Rohdin, 2007; Thollander & Ottosson, 2008). Although incentive programs, like Manitoba Hydro's performance optimization program, help fund capital project, these do not provide all the funding needed to carry out the project and are not always used. For example, the ceramic fiber project in 2009 is in the scope of Manitoba Hydro's performance optimization program (Hydro meeting, 2010), but Gerdau did not apply for funding from Manitoba Hydro.
- Lack of operating data that provides the first step to assess energy efficiency and efficiency project. For example, in this study, the ladle furnace at Gerdau has the potential to recovery the part of waste heat to preheat combustion air. However, due to lack of an information management system in the ladle, the energy savings could not be calculated precisely.

14.2.3 Opportunities

- Environmental regulation trends. It is projected that environmental regulations will become more and stricter. The company that takes further steps in energy efficiency will have advantages in the future competition in markets.
- Market demand. Steel is a critical material for a nation's development being a major raw material for infrastructure, such as transport, buildings, energy and

water supply. With the economy growth, steel demand must be surged in the long-term trends.

- Incentive programs. Federal, provincial and local governments provide many incentive programs for energy efficiency projects as well as local utilities. Those funds can help Gerdau access to the capital gap.
- Cap and trade program. Manitoba is a member of Western Climate Initiative (WCI) partner jurisdictions. The objective WCI is to reduce 15% emissions below 2005 level by 2020 through cap and trade program. The program will cover 90% of emissions in WCI provinces and states (WCI, 2010a), including iron and steel manufacturing. Four provinces in Canada and seven states in U.S. will participate the program (WCI, 2010b). With higher efficiency and lower emissions, Gerdau will have carbon benefits once cap and trade program implements.

14.2.4 Threats

- Economic recession. During the present economic recession, companies are struggling to cut their costs, including production costs. For example, Gerdau reduced its production in 2008 and 2009 as market demand was decreased. Energy efficiency projects are more difficult to implement during recession.
- Energy price. Natural gas price has been dropping by 50% since 2008 (Index Mundi, 2011)(figure 48). In this project, the natural gas price of $8.2/MM Btu is used for analysis at Gerdau and it is the average price over 6 years (2005 -2010). The energy price now is much lower than $8.2/MM Btu. The low energy price results in longer payback periods for natural gas energy efficiency projects.

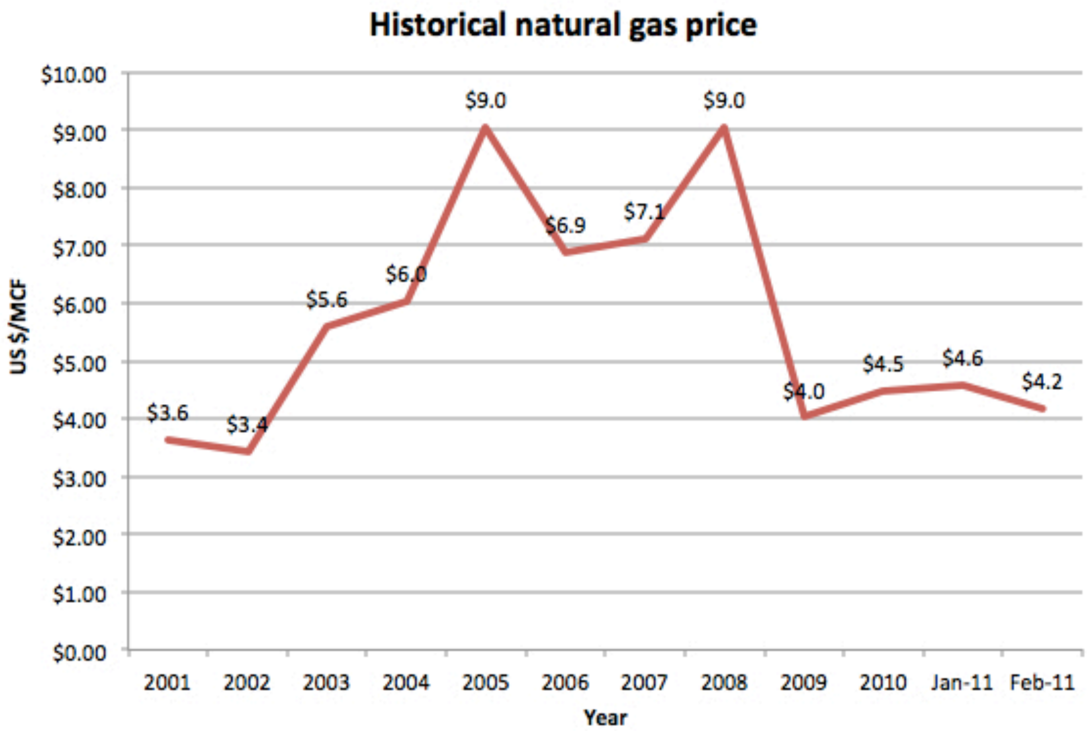

Figure 48: Historical natural gas price in US $

- Outsourcing to developing countries. Cost cutting is one of the most influential drivers of outsourcing manufacturing to developing countries. Typically, labor costs are the highest cost in large industries in developed countries, unlike developing countries. More stringent environmental regulations required in developed countries also add extra costs to manufacturers, like Gerdau. If a company has a plan to outsource their manufacturing in developed countries to developing countries as a mid term strategy, there will be no need or benefits for energy efficiency projects which generally have a three to five years payback.

14.3 Conclusion

Energy efficiency projects need a high degree of commitment at all levels. Green production and corporate responsibility are expected to become more and more important in future market competition. Gerdau should pursue these energy saving opportunities.

Energy price, increased regulation and the global economic situation can influence companies' green initiatives and Gerdau are expected to do more with increasing energy prices and growing regulation of GHG.

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Chapter 15 Conclusions

Many energy efficiency and waste heat recovery projects were analyzed for their feasibility at Gerdau in this research, including: 1) preheating billets for the reheat furnace, 2) upgrading the charge end in the reheat furnace, 3) recovering waste heat to preheat combustion air in the ladle preheater, 4) replacing direct-fired natural gas heaters with indirect-fired natural gas heaters, 5) Oxyfuel combustion, and 6) “tap to tap time” control. In addition, this research analyzed end-user distribution, assessed energy efficiency in the reheat furnace and reviewed inventive programs.

15.1 Energy efficiency potential

Several energy efficiency potential at Gerdau are identified as feasible through this project: 1) preheating billets 2) upgrading charge end, 3) recovering waste heat to preheat combustion air in the ladle preheater and 4) replacing direct-fired natural gas heaters with indirect-fired natural gas heaters. These four energy efficiency projects have many benefits including: 1) being good for the environment, 2) reducing fuel use and 3) providing a good payback period and annual savings. Table 27 shows emissions reductions, costs, energy savings and payback for energy efficiency.

Table 27: Summary of project identified at Gerdau in the research

	Environment		Economic			
Project name	CO_2 reduction (ton/yr)	Fuel saving (MM Btu/yr)	Annual saving /cost ($/yr)	Initial Cost ($)	Payback period (yr)	Feasibility (Y/N)
Preheating billets to 600 °F*	2,999	57,175	$ 468,838	$ 1,250,000	3.0	Y
Upgrading charge end	441	8490	$ 69,620	$ 200,000	2.9	Y
Recovering waste heat in the ladle preheater	1,081	20,800	$ 170,560	$ 144,017	0.8	Y
Replacing direct-fired natural gas heaters**	284	5,472	$ 44,870	$ 200,000	4.5	Y
Oxyfuel	9,670	535,468.8	$ (3,167,557.9)	----	----	N

* Initial cost is estimated based on preheating section is 150 feet long. Preheating billets to 600 °F, 400 °F and 200 °F is estimated to result in annual energy saving of 22.4%, 14.4% and 4.8%, respectively.

** Replacing direct-fired natural gas is to comply with Canada's natural gas installation code, the energy saving depends on operating capacity.

15.2 End-user distribution

The melt shop is the biggest consumer of electricity consumption (kWh) and electric demand (kVa), which accounted for 68.7% and 73.6 % respectively. From the EBT's time record, it was found that the delay time at Gerdau was 762.3 hr/yr in 2010. This delay time significantly influences the power-off time in the "tap to tap" time and this unplanned downtime wastes energy. However, the EBT furnace in the melt shop could not be further analyzed in this energy efficiency study because of difficulties accessing the records of the causes of delay time.

The reheat furnace is the biggest natural gas consumer at Gerdau with 437,563 MCF in 2010.

15.3 Energy efficiency in the reheat furnace

Flue gas losses are the biggest energy losses in the gross heat distribution with 26,874,657 Btu/hr. Energy losses from hearth and roof by heat transmission are the biggest energy losses in the net heat distribution during operation, which accounted for 8.9%. Hearth and roof losses are the biggest energy losses during idling with 5,687,690 Btu/hr. The thermal efficiency is 56.4% when 7 ⅝" is reheating. The average thermal efficiency of the reheat furnace is 58.9%. The flue gas losses significantly impact on thermal efficiency. The average thermal efficiency in the reheat furnace at Gerdau is 58.9% ± 3.6%. Compared to peak capacity, idle and partial operations of the reheat furnace are less efficient.

15.4 Incentive programs

There are many federal and Manitoba Hydro incentive programs that apply to Gerdau. The barriers, such as parent company's tax policy, should be reviewed and may be worth reconsidering.

Chapter 16 Recommendations for energy efficiency at Gerdau

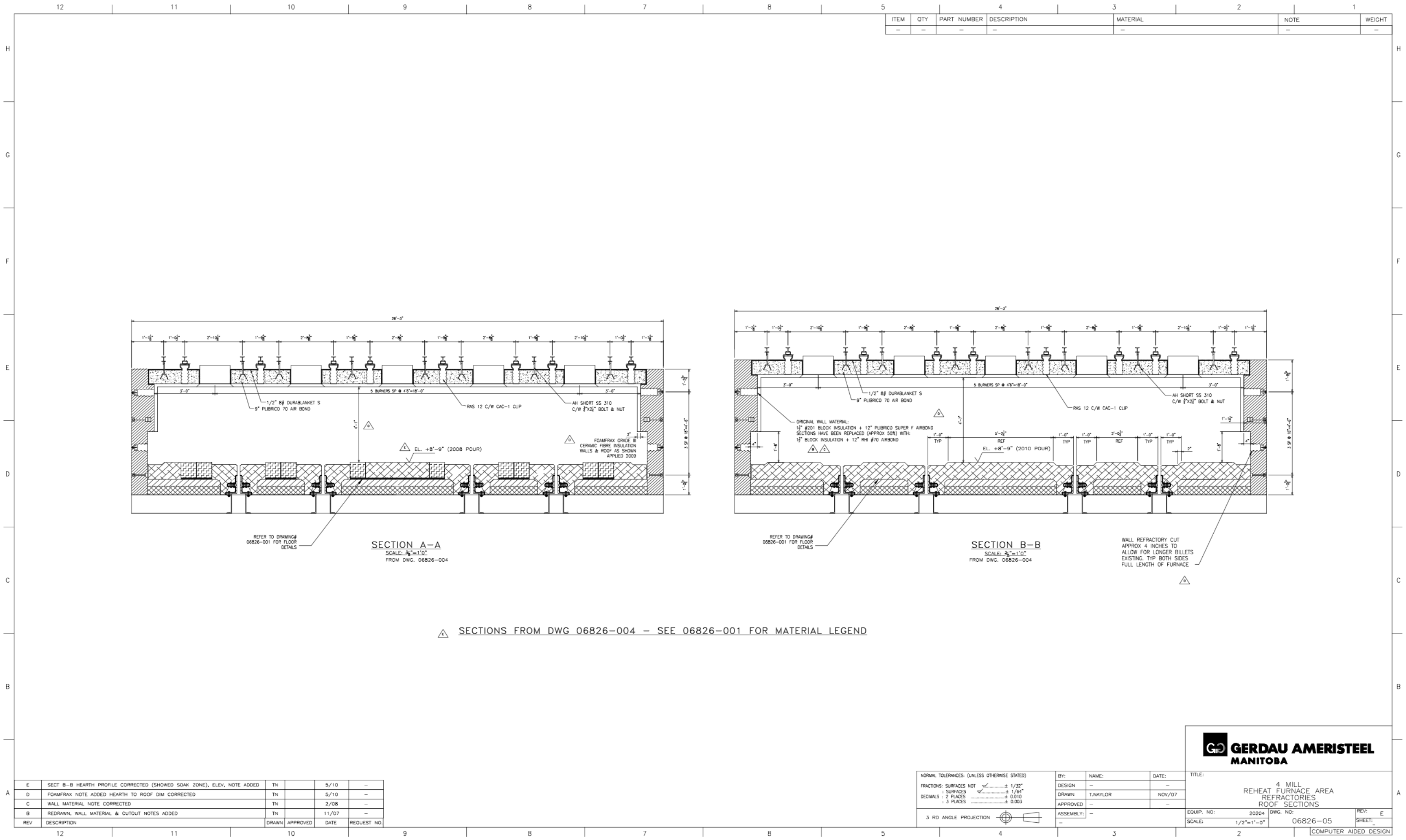
Several energy efficiency potential are recommended based on this analysis, including

1) Recovering waste heat to preheat billets. Preheating billets from ambient temperature to 600 °F results in fuel savings of 57,175 MM Btu annually with $468,838 per year. The simple payback period is 3.0 years. Preheating billets to 600 °F, 400 °F and 200 °F will have annual energy saving of 22.4%, 14.4% and 4.8%, respectively.
2) Upgrading the charge end in the reheat furnace. Upgrading the opening area in the charge end has 8,490 MM Btu/yr fuel saving with $ 69,620 annually
3) Recovering waste heat to preheat combustion air in the ladle preheater. The preheating will have 17.5% fuel saving per year with 20,800 MM Btu. The annual energy savings are $179,560.
4) Replacing direct-fired natural gas heaters with indirect-fired natural gas heaters. The project is to comply with natural gas installation code rather than to save energy
5) Analyzing the reason for the delay in EBT to determine whether it can be eliminated or has potential to reduce delay time, which will result in energy savings. Further research is needed to identify the reason of delay in the EBT furnace, because it is critical to know exactly where, when and why process times are lost in order to minimize the power off time.
6) Maximizing furnace operation capacity. Production planners should attempt to keep furnace operations to its peak capacity to maximize energy used per unit of production. This recommendation does not require any capital projects but could results in large energy savings. In addition, production planners need to consider production sequence to keep combustion air temperature at a stable level.

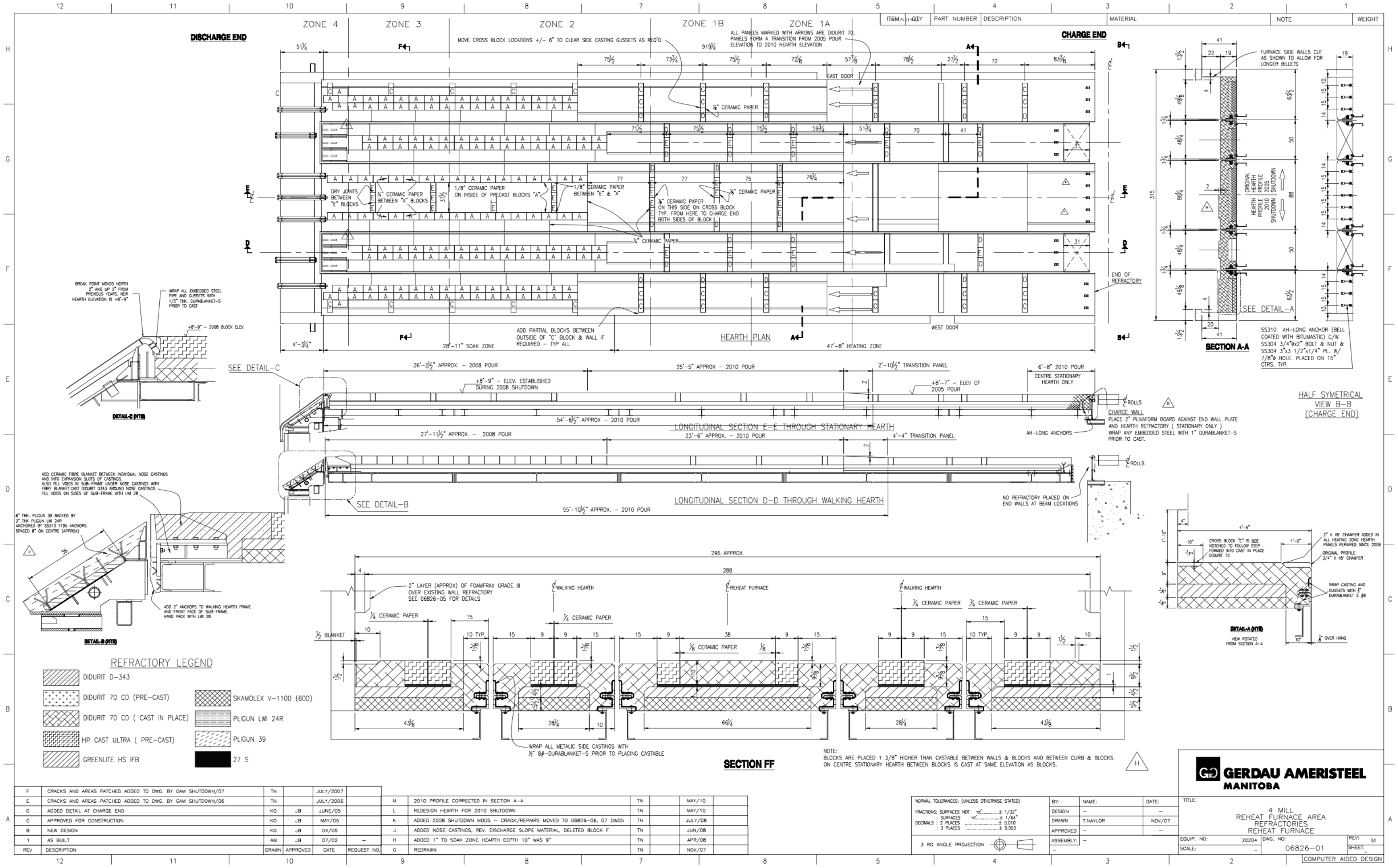
7) Manitoba Hydro’s natural gas optimization program is recommended to Gerdau for capital costs associated with natural gas optimization.

Oxyfuel combustion is not recommended as it is not considered feasible without taking productivity benefits into account because the natural gas saving is less than oxygen cost. However, as long as Gerdau has plans to increase its production or oxygen rate goes down, oxyfuel could be the first optional for Gerdau as oxyfuel combustion significantly reduces GHG emissions and fuel combustion.

Appendix I: Reheat furnace structure



Appendix I (Continuous)



Appendix II: PHAST data input

Load/Charge Material

	85 ton/hr	Idling	65 ton/hr
Type of material	Carbon Steel	Carbon Steel	Carbon Steel
Charge (wet)-Feed Rate (lb/hr)	170,000	0	130,000
Water content as Charged (%)	0%	0%	0%
Water content as Discharged (%)	0%	0%	0%
Initial temperature (°F)	37	0	37
Water discharge temperature (°F)	68	68	68
Discharge Temp (°F)	2050	0	2050
Charge Melted (% of charge)	0%	0%	0%
Charge Reacted (% of Dry)	0%	0%	0%
Heat of Reaction	0%	0%	0%
Additional heat required	0	0	0

Fixtures, Tray, Basket Losses

	85 ton/hr	Idling	65 ton/hr
Type of fixture material	No fixtures, tray or basket	No fixtures, tray or basket	No fixtures, tray or basket
Fixture weight	0	0	0
Initial Temp (°F)	0	0	0
Final Temp (°F)	0	0	0
Correction Factor	1	1	1

Atmosphere Losses

	85 ton/hr	Idling	65 ton/hr
Type of Air	Air	Air	Air
Initial Temp (°F)	746	746	754
Final Temp (°F)	917	917	940
Flow Rate (scfh)	1,365,335	1,365,335	1,365,335
Correction Factor	1	1	1

Appendix II (Continuous)

Water Cooling Losses

	85 ton/hr	Idling	65 ton/hr
Water Flow (gal/min)	13	13	13
In Temp (°F)	74	74	90
Out Temp (°F)	90	90	90
Correct factor	1	1	1

Wall Losses

	85 ton/hr	Idling	65 ton/hr
Surface area (ft^2)	744	744	744
Average surface temp (°F)	451	286	451
Ambient temp (°F)	68	68	68
Correct factor	1	1	1

Opening Losses

Charge End (Fixing opening)

	85 ton/hr	Idling	65 ton/hr
Furnace wall thickness (inch)	13.5	13.5	13.5
Length of Opening (inch)	288	288	288
Height of Opening (inch)	10	10	10
Total Opening area (ft^2)	20	20	20
Inside Temp (°F)	2329	2329	2329
Outside of Ambient Temp (°F)	68	68	68
% of opening time	100%	100%	100%

Appendix II (Continuous)

Discharge End (Variable Opening)

	85 ton/hr	Idling	65 ton/hr
Furnace wall thickness (inch)	13.5	13.5	13.5
Length of Opening (inch)	288	288	288
Height of Opening (inch)	18	18	18
Total Opening area (ft^2)	36	36	36
Inside Temp (°F)	2329	2329	2329
Outside of Ambient Temp (°F)	68	68	68
% of opening time	7.6%	7.6%	7.6%

Other Losses (hearth and Roof)

	85 ton/hr	Idling	65 ton/hr
Approx. area (ft^2)	3600	3600	3600
Average Temp (°F)	473	366	473
Ambient Temp (°F)	68	68	68

Heat Storage

Furnace Shape

	85 ton/hr	Idling	65 ton/hr
Width (ft)	24	24	24
Length (ft)	75	75	75
Height (ft)	4.08	4.08	4.08
Furnace temp (°F)	2329	2329	2329
Ambient temp (°F)	68	68	68
Starting wall temp (°F)	141	141	141
Furnace layer information			
Opening	NO	NO	NO
NO of Layers	1	1	1
Layer material	Ceramic fibre block	Ceramic fibre block	Ceramic fibre block
Layer thickness (inch)	2	2	2
NO of Layers	2	2	2

Layer material	Hi temp Insulating firebrick	Hi temp Insulating firebrick	Hi temp Insulating firebrick
Layer thickness (inch)	9	9	9
Sides			
Opening	NO	NO	NO
NO of Layers	1	1	1
Layer material	Ceramic fibre block	Ceramic fibre block	Ceramic fibre block
Layer thickness (inch)	2	2	2
NO of Layers	2	2	2
Layer material	Hi temp Insulating firebrick	Hi temp Insulating firebrick	Hi temp Insulating firebrick
Layer thickness (inch)	13.5	13.5	13.5
Discharge End			
Opening Area (ft^2)	36	36	36
NO of Layers	1	1	1
Layer material	Ceramic fibre block	Ceramic fibre block	Ceramic fibre block

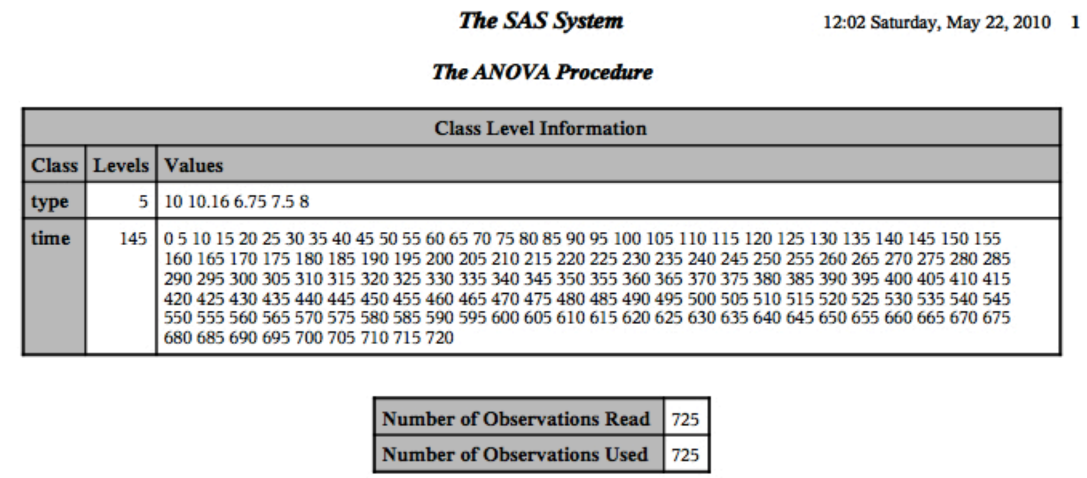
Layer thickness (inch)	12	12	12
Charge End			
Opening Area (ft^2)	20	20	20
NO of Layers	1	1	1
Layer material	Ceramic fibre block	Ceramic fibre block	Ceramic fibre block
Layer thickness (inch)	2	2	2
NO of Layers	2	2	2
Layer material	Hi temp Insulating firebrick	Hi temp Insulating firebrick	Hi temp Insulating firebrick
Layer thickness (inch)	13.5	13.5	13.5
Bottom			
Opening	NO	NO	NO
NO of Layers	1	1	1
Layer material	Hi-density castable	Hi-density castable	Hi-density castable
Layer thickness (inch)	9	9	9
NO of Layers	2	2	2

Layer material	Insulating firebrick	Insulating firebrick	Insulating firebrick
Layer thickness (inch)	4.5	4.5	4.5
NO of Layers	3	3	3
Layer material	Insulating firebrick	Insulating firebrick	Insulating firebrick
Layer thickness (inch)	5.5	5.5	5.5

Appendix II (Continuous)

NO of Layers	3	3	3
Layer material	Insulating firebrick	Insulating firebrick	Insulating firebrick
Layer thickness (cm)	13.97	13.97	13.97

Appendix III: SAS results of comparison among billets types and combustion air temperature



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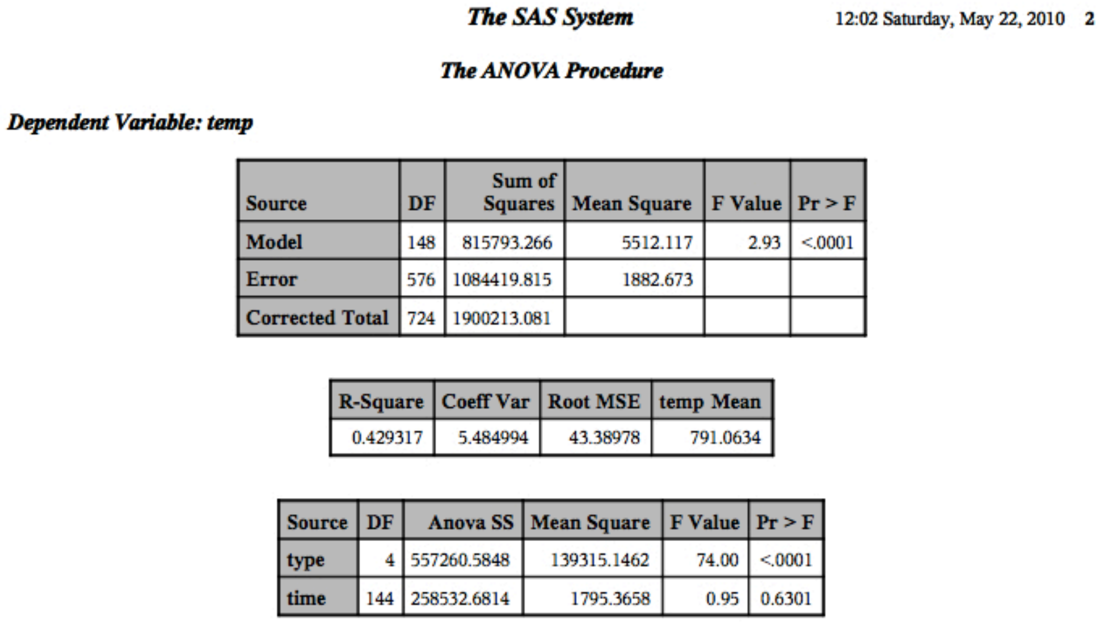
The ANOVA Procedure

Class Level Information		
Class	**Levels**	**Values**
type	5	10 10.16 6.75 7.5 8
time	145	0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100 105 110 115 120 125 130 135 140 145 150 155 160 165 170 175 180 185 190 195 200 205 210 215 220 225 230 235 240 245 250 255 260 265 270 275 280 285 290 295 300 305 310 315 320 325 330 335 340 345 350 355 360 365 370 375 380 385 390 395 400 405 410 415 420 425 430 435 440 445 450 455 460 465 470 475 480 485 490 495 500 505 510 515 520 525 530 535 540 545 550 555 560 565 570 575 580 585 590 595 600 605 610 615 620 625 630 635 640 645 650 655 660 665 670 675 680 685 690 695 700 705 710 715 720

Number of Observations Read	725
Number of Observations Used	725



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The ANOVA Procedure

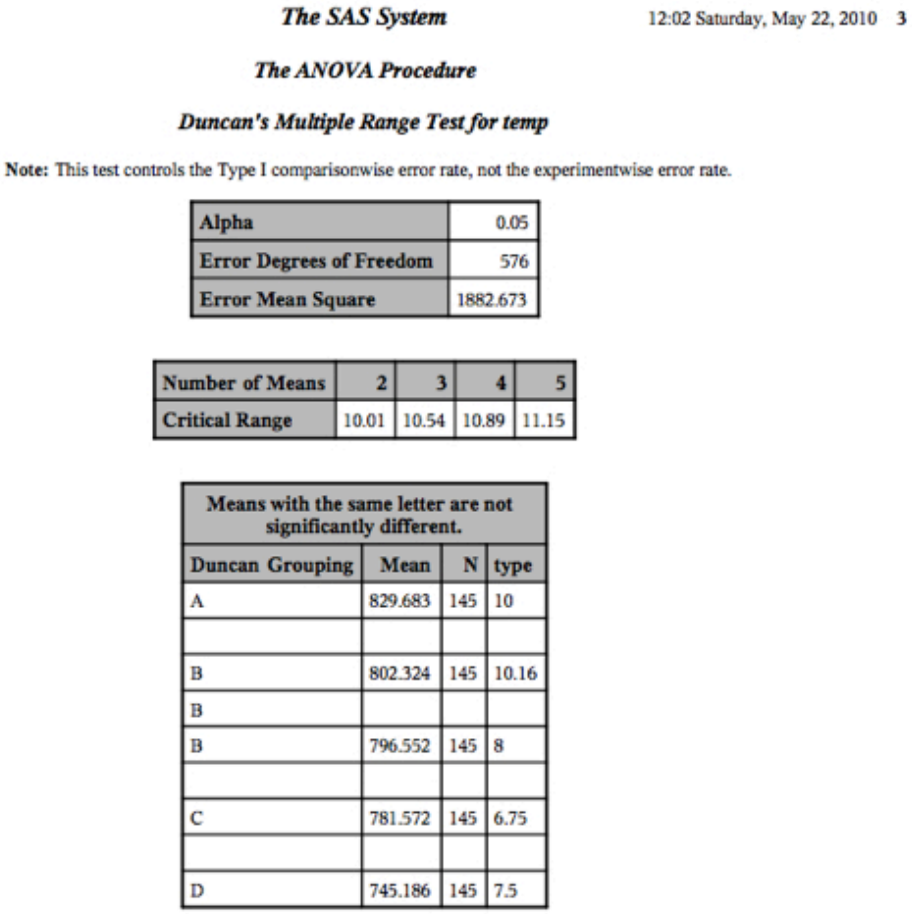
Dependent Variable: temp

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	148	815793.266	5512.117	2.93	<.0001
Error	576	1084419.815	1882.673		
Corrected Total	724	1900213.081			

R-Square	Coeff Var	Root MSE	temp Mean
0.429317	5.484994	43.38978	791.0634

Source	DF	Anova SS	Mean Square	F Value	Pr > F
type	4	557260.5848	139315.1462	74.00	<.0001
time	144	258532.6814	1795.3658	0.95	0.6301

Appendix III (Continuous)



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The ANOVA Procedure

Duncan's Multiple Range Test for temp

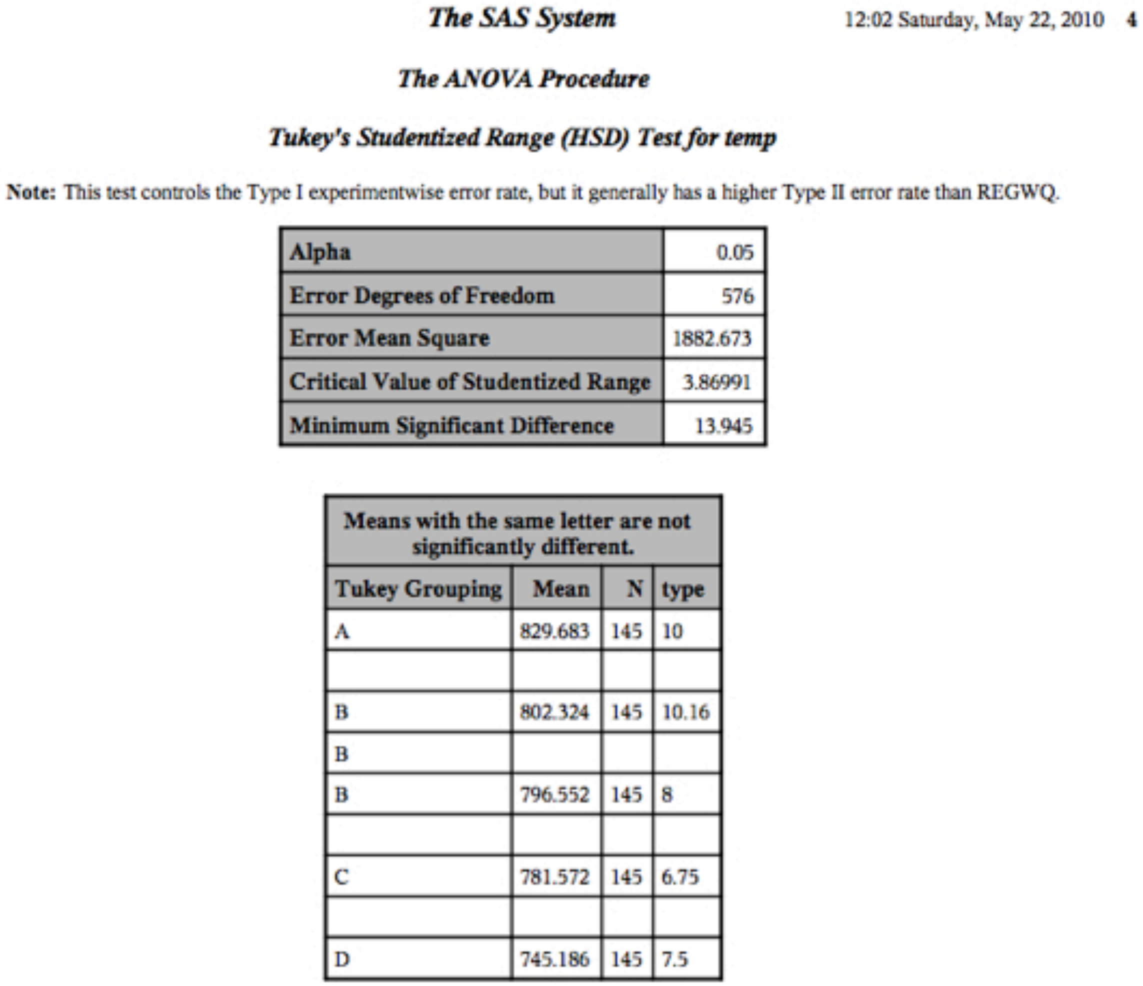
Note: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	576
Error Mean Square	1882.673

Number of Means	**2**	**3**	**4**	**5**
Critical Range	10.01	10.54	10.89	11.15

Means with the same letter are not significantly different.			
Duncan Grouping	**Mean**	**N**	**type**
A	829.683	145	10
B	802.324	145	10.16
B			
B	796.552	145	8
C	781.572	145	6.75
D	745.186	145	7.5

Appendix III (Continuous)



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The ANOVA Procedure

Tukey's Studentized Range (HSD) Test for temp

Note: This test controls the Type I experimentwise error rate, but it generally has a higher Type II error rate than REGWQ.

Alpha	0.05
Error Degrees of Freedom	576
Error Mean Square	1882.673
Critical Value of Studentized Range	3.86991
Minimum Significant Difference	13.945

Means with the same letter are not significantly different.

Tukey Grouping	Mean	N	type
A	829.683	145	10
B	802.324	145	10.16
B			
B	796.552	145	8
C	781.572	145	6.75
D	745.186	145	7.5