CARBON FOOTPRINT OF FLAT AND LONG STEEL PRODUCTS

Mr. Niwat Tontakul

A Thesis Submitted in Partial Fulfillment of the Requirements
for the Degree of Master of Science Program in Environmental Management
(Interdisciplinary Program)
Graduate School
Chulalongkorn University
Academic Year 2011

รอยเท้าคาร์บอนของผลิตภัณฑ์เหล็กทรงแบนและเหล็กทรงยาว

นายนิวัฒน์ ตั้นตระกูล

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต
สาขาวิชาการจัดการสิ่งแวดล้อม (สหสาขาวิชา)
บัณฑิตวิทยาลัย จุฬาลงกรณ์มหาวิทยาลัย
ปีการศึกษา 2554

Thesis Title	CARBON FOOTPRINT OF FLAT AND LONG STEEL PRODUCTS
By	Mr. Niwat Tontakul
Field of Study	Environmental Management
Thesis Advisor	Assistant Professor Pichaya Rachdawong, Ph.D.

Accepted by the Graduate School, Chulalongkorn University in Partial Fulfillment of the Requirements for the Master's Degree

…………………………………… Dean of the Graduate School
(Associate Professor Amorn Petsom, Ph.D.)

THESIS COMMITTEE

…………………………………... Chairman
(Assistant Professor Manaskorn Rachakornkij, Ph.D.)

…………………………………… Thesis Advisor
(Assistant Professor Pichaya Rachdawong, Ph.D.)

……………………………………Examiner
(Boonrat Lohwongwatana, Ph.D.)

……………………………………Examiner
(Associate Professor Chantra Tongcumpou, Ph.D.)

…………………………………..…External Examiner
(Trakarn Prapaspongsa, Ph.D.)

5187540420 : MAJOR ENVIRONMENTAL MANAGEMENT
KEYWORDS: CARBON FOOTPRINT\STEEL PRODUCTS\BIOMASS\PDP2010

NIWAT TONTAKUL: CARBON FOOTPRINT OF FLAT AND LONG STEEL PRODUCTS. THESIS ADVISOR: ASSISTANT PROFESSOR PICHAYA RACHDAWONG, Ph.D., 132 pp.

This study determines CO_2 emissions of steel products in Thailand using flat product and long product as a case study using the bottom-up and gate-to-gate approach. The boundary of the study covers from imported slabs and billets to hot rolled coils and rebars. Majority of the emission was originated from fuel combustion for heat (65-68%) and also electricity (32-35%) in the production line. This study proposes alternative solutions for emission reductions. For short-term solution, energy efficiency, is able to marginally reduce CO_2 intensity by as much as 7% in three years but not enough to cope with the growth of flat steel production. Fuel switching to natural gas which has lower carbon content could help reduce the emission up to 19% but will result in greater dependence on dwindling supply of fossil fuels. Switching to zero-emission biomass, which is abundant in Thailand, is able to virtually eliminate fuel-related emission, resulting in 65-68% of reduction from total emission. Biomass, too, could be used as electricity-generating fuels which will eliminate the electricity-related emission. Moreover, using biomass is one of solution for energy security situation. For electricity aspect, using cleaner source of energy could help reduce CO_2 emissions. If Power Development Plan 2010 could be successfully implemented, CO_2 intensity from the study plant in year 2030 would be 11.5 % lower than the 2009 level. For this to be successfully implemented, raw material supply system should be established to ensure continuous stream of fuel. Last but not least, there should be appropriate technologies, financial incentives, and the will power to ensure its success.

Field of Study : Environmental Management Student's Signature ....
Academic Year : 2011 Advisor's Signature ....
Co-Advisor's Signature ....

นิวัฒน์ ตั้นตระกูล: รอยเท้าคาร์บอนของผลิตภัณฑ์เหล็กทรงแบนและเหล็กทรงยาว (CARBON FOOTPRINT OF FLAT AND LONG STEEL PRODUCTS) อาจารย์ที่ปรึกษาวิทยานิพนธ์หลัก: ผศ.ดร.พิชญ รัชฎาวงศ์, 132 หน้า.

งานวิจัยนี้ประเมินการปล่อยก๊าซเรือนกระจกของผลิตภัณฑ์เหล็กกล้าที่ผลิตในประเทศไทยจากผลิตภัณฑ์สองชนิด ได้แก่แผ่นเหล็กรีดร้อนและเหล็กลวด วิธีการคำนวณเป็นแบบจากล่างขึ้นบนโดยมีขอบเขตงานวิจัยเป็นแบบประตูสู่ประตู โดยเริ่มจากวัตถุดิบซึ่งได้แก่บิลเล็ทและสแลปที่นำเข้ามาจากต่างประเทศไปสิ้นสุดที่ผลิตภัณฑ์แผ่นเหล็กรีดร้อนและเหล็กลวด พบว่าก๊าซคาร์บอนไดออกไซด์ที่ปล่อยออกมาส่วนใหญ่มาจากการเผาไหม้น้ำมันเตาเพื่อให้ความร้อนแก่วัตถุดิบคิดเป็น 65-68 เปอร์เซ็นต์ และส่วนที่เหลือ 32-35 เปอร์เซ็นต์มาจากการใช้ไฟฟ้าในโรงงาน งานวิจัยนี้ยังได้เสนอวิธีการลดการปลดปล่อยก๊าซคาร์บอนไดออกไซด์ มาตรการระยะสั้นได้แก่การเพิ่มประสิทธิภาพการใช้พลังงานนั้นสามารถลดการปลดปล่อยก๊าซคาร์บอนไดออกไซด์ได้ประมาณร้อยละ 7ในช่วงปี 2550-2552 ซึ่งยังคงไม่เพียงพอต่ออัตราการผลิตเหล็กที่เพิ่มสูงขึ้น การเปลี่ยนเชื้อเพลิงที่ใช้จากน้ำมันเตาไปเป็นก๊าซธรรมชาติที่มีปริมาณคาร์บอนที่ต่ำกว่า สามารถลดปริมาณก๊าซคาร์บอนไดออกไซด์ลงได้ 19 เปอร์เซ็นต์และช่วยลดการพึ่งพาพลังงานจากเชื้อเพลิงฟอสซิล แต่ถ้าสามารถเปลี่ยนเชื้อเพลิงไปเป็นเชื้อเพลิงชีวมวลซึ่งมีค่าการปลดปล่อยก๊าซคาร์บอนไดออกไซด์เท่ากับศูนย์ได้แล้ว ก็จะสามารถลดการปล่อยก๊าซคาร์บอนไดออกไซด์ส่วนจากเชื้อเพลิงได้จนเกือบหมด นั่นคือ 65-68 เปอร์เซ็นต์ของปริมาณการปล่อยก๊าซทั้งหมด นอกจากนี้เชื้อเพลิงชีวมวลยังสามารถใช้ผลิตพลังงานไฟฟ้าได้อีกทางหนึ่งซึ่งเป็นการช่วยลดการปล่อยก๊าซคาร์บอนไดออกไซด์จากการใช้ไฟฟ้า อีกทั้งยังเป็นการใช้เชื้อเพลิงที่มีศักยภาพในเชิงปริมาณและลดการนำเข้าพลังงานจากต่างประเทศอีกด้วย สำหรับการใช้ไฟฟ้านั้น สามารถลดการปล่อยก๊าซคาร์บอนไดออกไซด์ได้จากการหาแหล่งพลังงานไฟฟ้าที่สะอาดมากขึ้น ซึ่งถ้าสามารถนำแผนพัฒนาพลังงานแห่งชาติ ปี 2563 ที่มีการเพิ่มสัดส่วนแหล่งพลังงานสะอาดมาใช้ได้สำเร็จแล้วคาร์บอนไดออกไซด์ที่เกิดจากผลิตภัณฑ์เหล็กจะลดลงไปได้ถึง 11.5 เปอร์เซ็นต์ ทั้งหมดนี้ จำเป็นต้องมีการพัฒนาเทคโนโลยี ระบบสนับสนุนต่าง ๆ อาทิเช่นการขนส่งเชื้อเพลิงและความร่วมมือจากทุกภาคส่วน ไม่ว่าจะเป็นการสนับสนุนแรงจูงใจด้านการเงินจากภาครัฐเพื่อให้ผลิตภัณฑ์เหล็กของประเทศไทยก่อผลกระทบต่อโลกน้อยลงอย่างยั่งยืน

สาขาวิชา การจัดการสิ่งแวดล้อม	ลายมือชื่อนิสิต
ปีการศึกษา 2554	ลายมือชื่อ อ.ที่ปรึกษาวิทยานิพนธ์หลัก

ACKNOWLEDGEMENTS

I would like to express gratitude to my thesis advisor Assistant Professor Dr. Pichaya Rachdawong for his supports, advices, and patience; Dr. Promtida Sodsai for her suggestions, comments, and encouragements.

I also thanks to coordinators from both steel plants and the staffs of ISIT, for data and knowledge provision throughout the study.

This work is based on financial supported by the National Center of Excellence for Environmental and Hazardous Waste Management (NCE-EHWM), Chulalongkorn University, Thailand. Moreover, special thanks are extended to officers at NCE-EHWM program for their encouragement and help.

I also thank to my thesis defense committees for their invaluable advices and comments.

Finally, I wish to gratefully thanks my parent for their love, understanding and cheerfulness, and my friends for their help and support and wonderful suggestions.

TABLE OF CONTENTS

Abstract (in English) ii

Abstract (in Thai) iii

Acknowledgements iv

Table of Contents v

List of Figures viii

List of Tables x

List of Abbreviations xii

CHAPTER I INTRODUCTION 1

1.1 General Statement 1

1.2 Objectives 2

1.3 Hypotheses 2

1.4 Scopes of the Study 3

CHAPTER II THEORETICAL BACKGROUND AND LITERATURE REVIEWS 4

2.1 Steel 4

2.1.1 Raw Materials 6

2.1.2 Steelmaking Processes 6

2.1.3 Steel Recycling 15

2.1.4 Thailand Steel Industries 16

2.2 Global Warming 17

2.2.1 Climate Change 17

2.2.2 Greenhouse Gases 18

2.2.3 Sources of Greenhouse Gases 25

2.3 Carbon Footprint 26

2.3.1 Calculating Carbon Footprint 27

2.4 Biomass 30

2.4.1 Overviews 30

2.4.2 Fundamentals 33

2.4.3 Biomass situation in Thailand 35

2.4.4 Biomass Technology 38

2.5 Greenhouse Gas Emission from Iron and Steel Industries 40

2.6 Thailand Power Development Plan 2010 (PDP2010) 41

2.7 Literature review 43

2.7.1 Researches related to steel industries and carbon emission 43

2.7.2 Researches/reviews regarding biomass energy policy in Thailand 46

2.8 Summary 47

CHAPTER III METHODOLOGY 49

3.1 Research Plan 49

3.2 Definition of organizational boundaries 50

3.3 Definition of operational boundaries 51

3.4 Collection of Emission Data 51

3.5 Calculating GHG emissions 51

3.5.1 Fuel Emission 54

3.5.2 Electricity Emission 55

CHAPTER IV RESULTS AND DISCUSSION 58

4.1 Plant Information 58

4.1.1 Production Data 64

4.1.2 Fuel Consumption 67

4.1.3 Electricity Use 68

4.1.4 Absolute energy consumption 70

4.2 Carbon dioxide Emission 76

4.2.1 Carbon dioxide intensity 77

4.2.2 Possible factors that influence the emission intensity 79

4.2.3 Absolute plant emission 82

4.3 Carbon dioxide emission reduction measures 83

4.3.1 Reduction through energy efficiency 83

4.3.2 Reduction through fuel switching 88

4.3.3 Reduction through electricity shifts 94

4.3.4 Summary 99

4.4 Calculation formula for the expected reduction 102

4.4.1 Derivation 102

4.4.2 Sample calculation 105

4.5 Data Quality Discussion 107

CHAPTER V CONCLUSIONS AND RECOMMENDATIONS 109

REFERENCES 111

BIOGRAPHY 118

LIST OF FIGURES

Figure 2-1 Human-related carbon dioxide emission in the USA 21

Figure 2-2 Post-distribution Human-related carbon dioxide emission in the USA 22

Figure 2-3 Human-related methane emission in the USA 23

Figure 2-4 Diagram of biomass utilization 34

Figure 2-5 Possible biomass conversion route to heat-generating fuels 39

Figure 3-1 Flow diagram of research methodology 50

Figure 4-1 Production process diagram of Flat product plant 59

Figure 4-2 Production process diagram of Long product plant – Line 1 62

Figure 4-3 Production process diagram of Long product plant – Line 2 63

Figure 4-4 Production volume of Flat product plant 64

Figure 4-5 Production volume of Long product plant (Flat steel product) 65

Figure 4-6 The portion of National steel production (2008) that the studied plants contribute 66

Figure 4-7 Fuel-based energy consumption in Flat product plant 67

Figure 4-8 Fuel-based energy consumption in Long product plant 68

Figure 4-9 Energy consumption in form of electricity in Flat product plant 69

Figure 4-10 Energy consumption in form of electricity in Long product plant 69

Figure 4-11 (a) Absolute energy consumption of Flat product plant (b) Production of Flat product plant (c) Absolute energy consumption of Long product plant (d) Production of Long product plant 71

Figure 4-12 Energy intensity from Flat product plant 73

Figure 4-13 Energy intensity from Long product plant 73

Figure 4-14 Energy use plotted against production in Flat product plant 75

Figure 4-15 Energy use plotted against production in Long product plant 75

Figure 4-16 Emission contribution from fuel and electricity in Flat product plant 78

Figure 4-17 Emission contribution from fuel and electricity in Long product plant 79

Figure 4-18 CO_2 reduction diagram of natural gas substitution 90

Figure 4-19 Energy potential of biomass and actual usage in Thailand 91

Figure 4-20 CO_2 reduction diagram of biomass fuel substitution 93

Figure 4-21 CO_2 reduction diagram of biomass electricity 96

Figure 4-22 CO_2 reduction diagram according to PDP2010 plan 98

Figure 4-23 Strategies to reduce CO_2 emission from steel product 101

LIST OF TABLES

Table 2-1 Source of Greenhouse Gases 19

Table 2-2 Sources of human-related carbon dioxide emission 20

Table 2-3 Sources of human-related methane emission 24

Table 2-4 Global warming potentials of some Greenhouse Gases 30

Table 2-5 Adder rate from the FT for electricity generated from biomass 35

Table 2-6 Electricity generation from renewable sources in Thailand 36

Table 2-7 Heating value of agricultural biomass in Thailand 36

Table 2-8 Notable researches regarding steel and emission 44

Table 3-1 Description of study scopes and associated boundaries 52

Table 3-2 Important data and the means to obtain 52

Table 3-3 Variables to calculate carbon footprint 53

Table 3-4 Variables to calculate carbon footprint from fuel 54

Table 3-5 Energy content values of fossil fuel (DEDE, 2010) 54

Table 3-6 Default carbon content values of fossil fuel 55

Table 3-7 Actual grid emission factor for 2007-2009 periods 56

Table 3-8 Projected Grid Emission factor according to PDP2007 and PDP2010 56

Table 4-1 Description of processes in Flat product plant 60

Table 4-2 Production of plants in the study 64

Table 4-3 Fuel Consumption of Flat product plant and Long product plant 67

Table 4-4 Electricity consumption of studied Plants 68

Table 4-5 Absolute energy consumption of Flat product plant 70

Table 4-6 Absolute energy consumption of Long product plant 70

Table 4-7 Energy intensity of Product 72

Table 4-8 Energy intensity of Product, percentage 72

Table 4-9 Slope and interception obtained using linear regression 74

Table 4-10 CO_2 intensity of flat product plant 77

Table 4-11 CO_2 intensity of Long product plant 78

Table 4-12 Explanation for Variables in Energy/emission function 80

Table 4-13 Operation Period of Long product plant 81

Table 4-14 Absolute CO_2 emission (Unit is in ton CO_2) 82

Table 4-15 Attempts to increase energy efficiency in Flat product plant in 2007 85

Table 4-16 Attempts to increase energy efficiency in Flat product plant in 2008 86

Table 4-17 Attempts to increase energy efficiency in Flat product plant in 2009 87

Table 4-18 CO_2 intensity at different substitution levels: flat product, natural gas 88

Table 4-19 CO_2 intensity at different substitution levels: long product, natural gas 89

Table 4-20 CO_2 intensity at different substitution levels: Flat product, biomass 92

Table 4-21 CO_2 intensity at different substitution levels: long product, biomass 92

Table 4-22 Amount of biomass required for full fuel substitution 93

Table 4-23 Amount of biomass required for complete electricity generation 95

Table 4-24 Emission expected from PDP2010, Flat product plant 97

Table 4-25 Emission expected from PDP2010, Long product plant 97

Table 4-26 Maximum possible reduction of Flat product plant 99

Table 4-27 Maximum possible reduction of Long product plant 99

Table 4-28 Biomass required to completely substitute energy of steel production 100

Table 4-29 Nomenclatures used in the derivation 102

Table 4-30 Formulae to calculate emission and reduction after fuel substitution 105

Table 4-31 Possible uncertainties in the calculation of greenhouse gas emission 107

LIST OF ABBREVIATIONS

CH_4	Methane
CO_2	Carbon dioxide
CRC	Cold rolled coil
EF	Emission Factor
EPA	Environmental Protection Agency
GHG	Greenhouse Gas
GWP	Global Warming Potential
HRC	Hot rolled coil
LCA	Life Cycle Analysis
N_2O	Nitrous Oxide
HFCs	Hydrofluorocarbons
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization of Standard
PFCs	Perfluorocarbons
SF_6	Sulphur Hexafluoride
TGO	Thailand Greenhouse Gas Management Organization
UNFCCC	United Nations Framework Convention on Climate Change
WRI	World Resource Institute

CHAPTER I

INTRODUCTION

1.1 General Statement

Iron, the most common metal, has been one of the important materials of human civilization. It serves as raw material for wide range of products including vehicle, building materials, furniture, as well as other commodities. This is proven by the fact that global production of iron and steel continually increased to satisfy the demand from emerging markets. According to a report from World Steel Association (2009), total production of crude steel in 2007 nearly doubled from 1998 level. Steel consumption in Thailand, too, was reported to be raised from 12.7 million ton in 2004 to 13.5 million ton in 2008 (ISIT, 2009). High recycling rate and low energy required by recycling also contribute to the popularity of this versatile material, since the production cost could be significantly reduced.

Iron and steel industries, however, is energy-intensive, and their reliance on fossil fuel causes it to be one of the major CO_2-emitting sources. Steel industries also include emission from an indirect source in the form of electricity as well as a non-combustive source like limestone used in smelting process. Iron and steel industry, according to various data sources, accounts for 4.1% of global CO_2 emissions, 6-7% of anthropogenic emission, and 15% of all manufacturing emissions. It is also estimated that 70% of emissions originated from direct fuel uses (Kevin, 2005.)

To be able to align with the current global warming trend, iron and steel industries are now faced with the challenges of GHG reduction. Works and researches focused on the issue were widely conducted. To assess the effectiveness of these, variety of tools and indicators were available. Carbon footprint, for example, is a widely popular tool that is applicable on a wide range of scope, activities, and regulatory framework.

This research was an attempt to quantify and identify the volume of CO_2 emission from iron and steel production in Thailand. Despite of some conventions used to avoid complexities, the result obtained could be used as the baseline and the reduction potential that would be useful to the industries.

1.2 Objectives

- To determine carbon footprint of long and flat shape steel products manufactured in Thailand
- To identify sources of carbon emissions of steel products in selected steel factories
- To propose possible options for decreasing CO_2 emission of steel products in selected steel factories

1.3 Hypotheses

Flat shape steel products have different sizes of carbon footprint than long shape steel products.

Switching and appropriate selecting the types of a fuel source could reduce the carbon footprint of steel product manufactured in Thailand.

1.4 Scopes of the Study

This research is aimed to determine carbon footprint of the steel product manufactured in Thailand in the steel industry and to develop the feasible options for minimization of the carbon footprint. The two steel plants manufacturing flat and long products are used as case studies. These two steel plants are different in terms of characteristics and types of products and input materials. Scopes of this study are as follows:

1. This study will use the standard procedures following the guideline of
    a. PAS 2050 : 2008 Specification for the assessment of the life cycle greenhouse gas emission of goods and services (CARBON TRUST)
    b. PAS 2050 : How to assess the carbon footprint of goods and services (CARBON TRUST)
    c. Product Life Cycle Accounting and Reporting Standard, The GHG Protocol Initiative, World Resources Institute & World Business Council for Sustainable Development, 2009
2. The primary and secondary data will be obtained from the steel factories in Thailand.
    a. One factory for flat shape product.
    b. One factory for long shape product.
3. Calculations are based on gate-to-gate boundary using bottom-up approach.

CHAPTER II

THEORETICAL BACKGROUND AND LITERATURE REVIEWS

Background knowledge of steel production, status of global steel sector, and effect of steel industries on climate change is vital to all effective managements. Moreover, implementing CO_2 reduction measure requires that basic concepts related to decision making are understood. Therefore, steel production process, status of Thai steel production, CO_2 emission related to steelmaking process, methodological trends, and important concepts were reviewed in this chapter. The related researches were also reviewed.

2.1 Steel

(Adapted from Asia-Pacific Partnership on Clean Development and Climate, 2010)

Steel is used in many aspects in such diverse applications as buildings, bridges, automobiles and trucks, food containers, and medical devices. Countless additional jobs and economic benefits are created in steel industry supply and support activities, including mining, capital equipment supply, utilities and many community businesses.

The process in steel manufacturing is energy-intensive and requires a large amount of natural resources. Energy costs a major portion of the total cost of steel production. Thus, increasing energy efficiency is the most cost-effective way to improve the environmental performance of this industry.

To address these issues, there has been significant investment in new products, plants, technologies and operating practices. The result has been a dramatic improvement in the performance of steel products, and a related reduction in the consumption of energy and raw materials in their manufacture. Recent developments have enable the steel industry's customers to improve their products through better corrosion resistance, reduced weight and improved energy performance. This improvement is seen through a wide range of products, including passenger cars, packaging and construction materials.

The steel industry is critical to the worldwide economy, providing the backbone for construction, transportation and manufacturing. In addition, steel has become the material of choice for a variety of consumer products, and markets for steel are expanding. Steel, already widely regarded as a high performance contemporary engineering material, is continuously being improved to meet new market demands.

Traditionally valued for its strength, steel has also become one of the most recycled materials. At the end of their useful life, products containing steel can be converted back in to "new" steel, ready for other applications. Furthermore, the steel production process can utilize wastes and by-products as alternative reductants and raw materials, which reduces overall CO_2 emissions per ton of steel produced.

2.1.1 Raw Materials

2.1.1.1 Iron Ores

The principal ores used in the production are magnetite (Fe_3O_4), siderite ($FeCO_3$), and limonite (Fe_2O_3-xH_2O, where x is typically around 1.5). Most ores contain 50% to 70% iron by weight.

Moreover, scarp metals were also widely used as raw material, especially when the demand outgrew the supply of iron ore.

2.1.1.2 Coke

Coke is a high carbon fuel produced by pyrolysis of bituminous coal in oxygen-starved condition followed by quenching. Coke serves two functions in the process, to supply heat as a fuel and supply carbon monoxide as the reducer.

2.1.1.3 Limestone

Limestone is a mineral containing calcium carbonate ($CaCO_3$). It is used as flux to remove impurities in the molten iron, resulting in solid slag.

2.1.2 Steelmaking Processes

2.1.2.1 Agglomeration

Agglomeration is a group of processes that prepares the raw ores for further processing. Although the raw lump ore could be directly used, agglomeration could significantly improve iron content and adjust physical properties of the ore.

Sintering

Sintering uses iron dust from other processes as raw materials. The dust was blended with powdered coke and then burned. The metal dust would be fused together into metal lump that could be used in blast furnace.

Pelletizing

Pelletizing crush and ground iron ore so that some impurities could be removed first. Mineral-rich ore would be mixed with binding agent and then burned to create marble-sized pellets for further uses.

Briquetting

Similar to sintering, crushed and fine ores are heated and compressed to produce a brick-like lump of ore.

2.1.2.2 Cokemaking

Coke, produced from metallurgical-grade coal, is a vital component in steelmaking since it produces carbon monoxide to reduce the ore and supply heat to melt metals. Cokemaking contributes to 50% of steelmaking total energy use. In the process, coal is heated in oxygen-starved condition to get rid of hydrocarbon content in the coal leaving only elemental carbon structure. Hydrocarbon-rich off-gas could be collected and used as fuel.

2.1.2.3 Ironmaking

An ironmaking process reduces iron ore into iron by removing oxygen. This step is also energy-intensive and the greatest source of CO_2 emission. The most common method is blast furnace which includes adding coke and limestone flux. Iron ingot produced from this process is called “pig iron”. There is also another technique that directly use reducing gas, the iron produced is called “direct reduced iron” (DRI) that could be made into briquette.

Blast Furnace

A blast furnace was usually built as tall cylindrical shafts lined with refractory materials. Ore feed, coke, and flux are provided (charged) at the top, while the reducing gases are produced at the bottom by burning coke with 1,000-1200˚C preheated air. The materials pass through the furnace in opposite direction with reducing gases which, using heat from coke burning, remove oxygen content of iron ore feed material. A flux agent will react with ore’s impurities, effectively removing them from molten iron stream, and then deposit as solid residual called slag. Molten iron and slag are tapped periodically from the bottom of the vessel. The iron produced from the blast furnace contains approximately 4% carbon and considered too brittle for most engineering applications and therefore should be further refined into steel.

Direct Reduction

Direct reduction processes require a reducing gas to remove the oxygen from the iron in solid state, opposing to blast furnace where the iron reduction occurs in liquid state. Reducing gases are mostly CO and H_2. Despite classified as a different method, direct reduction occurs in shaft furnaces where the reducing gases are produced from natural gas. This shaft-based version operates on a counter current basis like blast furnaces. Ore feed is preferred to be pellets. Similar to blast furnaces, ore, coke, and flux passes down through the furnace while reducing gases flow up, progressively removing oxygen content of the iron ore feed material. Reducing gases are produced, pre-heated, and introduced into the middle of the vessel. The pre-reduced solid iron is cooled and removed from the bottom of the shaft. An example of one shaft based process is shown below. Direct reduction processes that are based on natural gas have lower emissions (including CO_2) than integrated plants that use coke ovens and blast furnaces.

DRI is favored by electric arc furnace (EAF) steelmakers, who blend it as a feedstock with lower quality scrap to improve the steel quality. Direct reduction processes tend to be located near readily available natural gas supplies, but often have higher fuel costs compared to coal/coke based processes. The amount of DRI that can be charged into an EAF is limited by remaining residue oxygen, which increases steelmaking energy requirements. For good quality DRI the iron ore used must have low levels of impurities. Ores with iron content below 65% are usually considered unsuitable.

Direct Ironmaking

Concerns over limited long term supply of coking coals and environmental impact of both coking and sinter plants help drives the development of alternative ironmaking processes that use non-coking coals to reduce iron ores directly. These emerging direct ironmaking processes can be categorized by those producing molten iron (similar in quality to the blast furnace), and those producing a solid direct reduced iron.

2.1.2.4 Steelmaking

Steelmaking is the process to produce molten iron with carbon content between 0.02% and 2% by weight. This is accomplished using either Basic Oxygen Furnace or Electric Arc Furnace. Both processes produce batches of steel known as “heats”.

Basic Oxygen Furnace (BOF) Steelmaking

The basic oxygen furnace (BOF) is charged with molten iron and scrap. The term “basic” refers to the magnesia (MgO) refractory lining of the furnace. Oxygen is injected into the furnace through a water-cooled lance, causing oxidation of carbon in the molten iron. As a result, tremendous release of heat occurs. No other fuels are needed apart from carbon content in molten iron and oxygen. However, to maintain such autothermal process, the amount of scrap that can be charged is limited to about 30%. Steelmaking is considered completed when the carbon content of the iron charge is reduced from 4% to less than 2% (usually <1%). After the molten steel is produced in the BOF and tapped into ladles, it may undergo further refining in a secondary refining process or be sent directly to the cast, where it solidifies into semi-finished shapes: blooms, billets or slabs.

Electric Arc Furnace (EAF) Steelmaking

Electric arc furnace (EAF) steelmaking uses heat supplied from electric arc from graphite electrodes to the metal bath to melt the solid iron feed materials. Although electricity provides most of the energy for EAF steelmaking, supplemental heating from oxy-fuel and oxygen injection is used. The major advantage of EAF steelmaking is that it does not require molten iron supply, thus eliminating the need for blast furnaces and associated plant processes like coke oven. EAF technology has facilitated the proliferation of mini-mills, which can operate economically at a smaller scale than larger integrated steelmaking. EAF steelmaking can use a wide range of scrap types, as well as direct reduced iron (DRI) and molten iron. Uses of recycled materials saves virgin raw materials and the energy required for converting them. The EAF operates as a batch process, producing heats of molten steel with 60-minutes cycle times for most modern furnaces.

Current ongoing EAF steelmaking research includes reducing electricity requirement per ton of steel, modifying equipment and practices to minimize consumption of the graphite electrodes, and improving the quality and range of steel produced from low quality scrap.

2.1.2.5 Ladle Refining and Casting

After the molten steel is produced in the BOF or EAF, it will be tapped into ladle, and it may undergo further refining or be sent directly to the continuous caster where it is solidified into semi-finished shapes: blooms, billets or slabs. These casting shapes helps save energy during further downstream processing. Refining prior to casting can improve the efficiency of both the downstream casting and the upstream steelmaking steps. Continuous casting is most efficient when multiple ladles of a consistent steel grade can be fed through the caster to reduce the overall tap-to-tap times of the BOF or EAF and maximizes the efficiency.

Ladle Refining for BOF and EAF

After steel is created in either BOF or EAF, it may be refined before being cast into solid forms. This process is called "ladle refining", "secondary refining" or "secondary metallurgy", and is performed in a separate ladle/furnace after being poured from the BOF or EAF. Steel refining helps steelmakers meet steel specifications required by customers. Refining includes: chemical sampling; composition adjustment; vacuum degassing to remove dissolved gases; heating/cooling to specific temperatures; and inert gas injection to "stir" the molten steel.

Casting

Casting is the process to produce solid steel from molten steel by pouring refined steel from a ladle into a tundish, which is a small basin at the top of the caster. The falling steel passes through a mould and begins to take on its final shape. The strand of steel passes through the primary cooling zone, where it forms a solidified outer shell sufficiently strong enough to maintain the strand shape. The strand continues to be shaped and cooled as it curves into a horizontal orientation. After additional cooling, the strand is cut into long sections with a cutting torch or mechanical shears, opposing to classic, primitive way which pours steel into mould in a batch process that produced large steel ingots that must be preheated prior to additional processing. Continuous casting has replaced ingot casting at most steelmaking facilities because it could mass produces semi-finished steel closer to their final shape. Moreover, resulting steel often proceed directly to rolling or forming while retaining significant heat, which reduces downstream reheat costs. There are overall improvements in continuous casting which reducing reheating and hot rolling costs. There is also an emerging technology, strip casting for example, which uses two rotating casting rolls to directly produce strip smaller than 2mm. This can reduce or eliminate further downstream processing requirements.

2.1.2.6 Rolling and Finishing

Rolling and finishing transform semi-finished shapes into finished steel products, which could be shipped as is to downstream customers directly or to make further finishing. The processes could be adjusted for important product characteristics including: final shape, surface finish, strength, hardness, flexibility, and corrosion resistance. Current finishing technology research focuses on improving product quality, reducing production costs, and reducing pollution.

Rolling and Forming

Rolling and forming mechanically shape steel as desired. Operations can include hot rolling, cold rolling, forming or forging. In hot rolling, for example, steel slabs are heated to over 1,000˚C and passed between multiple sets of rollers. The pressure reduces the thickness of the steel slab while increasing its width and length. After hot rolling, the steel may be cold-rolled at ambient temperatures to further reduce thickness, increase strength (through cold working), and improve surface finish. In forming, bars, rods, tubes, beams and rails are produced by passing heated steel through specially shaped rollers to produce the desired final shape. In forging, cast steel is compressed with hammers or die-presses to the desired shape, with an increase in strength and toughness.

Finishing

Steel finishing is performed to meet specific physical and visual specifications. Operations include pickling, coating, quenching and heat treatment. **Pickling** is a chemical treatment, in which rolled steel is cleaned in an acid bath to remove impurities, stains or scales prior to coating. In **coating**, cold-rolled sheet steel is coated to provide protection against corrosion and to produce decorative surfaces. Strip coating lines are generally operated continuously, so that in the entry section an endless strip is produced which is divided into coils at the exit section. Coatings may be applied in a hot bath (often zinc-based), in an electro galvanizing bath, or in a bath containing liquid tin. **Quenching**, the rapid cooling of steel, is often achieved using water or other liquids. Quenching can increase the hardness and is often combined with tempering to reduce brittleness. The controlled heating and subsequent cooling of steel in heat treatment can impart a range of qualities upon the steel by altering its crystalline structure. **Heat treatment** is often performed after rolling to reduce the strain that occurs in rolling processes. Annealing, tempering and spheroidizing are three examples of heat treatment, which may be performed in a large batch furnace or in a continuous furnace under a controlled atmosphere (i.e., hydrogen).

Recycling and waste reduction Technologies

Steel production used large quantities of raw materials, energy and water, while millions of tons products reach the end of their useful lives each year.

The steel industry is a recognized leader in developing recycling efforts that minimize the environmental footprint of steel production while reducing costs. Below are some examples in steel recycling, energy efficiency and generation, dust and solids reduction and reuse, and water and gas recycling.

2.1.3 Steel recycling

Steel is the world's most recycled material. In many counties, more than half of all old cars, can and appliances are recycled. EAF steelmaking is based primarily on the use of scrap steel.

2.1.3.1 Energy

The use of scrap dramatically reduces energy intensity per tons of steel produced. The use of combined heat and power (CHP) technology to burn off-gased from steelmaking produced on-site steam and electricity, reducing inefficiencies in generation off-site and distribution across long distances.

2.1.3.2 Dust and solids

Coke dust (breeze), iron ore dust and other solids are processed and recycled in steel mills. Slag from ironmaking and steel making is sued for road construction.

2.1.3.3 Water and gases

Steelmakers recycle and reuse much of their water. Coke oven gas is recovered and refined for internal use (fuel) and external sales (tars, oils and ammonia). Blast furnace gas is recovered and used to provide heat to the ironmaking process.

2.1.4 Thailand Steel Industries

Steel production in Thailand is growing rapidly with 20 percent-per-year rate during 1988-2005 (ISIT, 2005). In Thailand, there is only scrap-based steel production, thus, Thailand steel production could be classified into two types from products: crude steel production and finished steel production. Crude steel includes slab, billet and bloom. On the other hand, finished steel products are grouped by shape as long and flat.

In 2008, 49 percent of Thailand steel product employed Electric Arc Furnace (EAF) process which manufactures crude steel from scraps, which is then processed through hot rolling machine. The other 51 percent were imported crude steel and other finished steel product, such as slab, hot-rolled coil (HRC), and cold-rolled coil (CRC). The industries consuming steel utilized around 9.3 million tons of steel as their raw material in 2007 (NESDB, 2009). Construction sector consumed most steel product, followed by automotive, appliance, and food industries. Flat steel accounted for 60 percent of total domestic production in 2008 (ISIT, 2009). This is because flat steel product is the major raw material for automotive and appliance industries which are one of the most important industry in Thailand. Moreover, the amount of steel consumption is estimated that the demand will triple within 2038.

2.2 Global Warming

2.2.1 Climate change

Climate change refers to any significant change in climate (such as temperature, precipitation or wind) lasting for an extended period. Since the late 18th century, activities associated with the industrial revolution have changed the atmosphere and significantly influenced the Earth's climate; for example, temperature, precipitation, storms and sea level (IPCC, 2007). However, such features could naturally vary, making it a great challenge of scientific communities to identify the actual impact of human activities on the global climate.

In fact, one of the things scientists agree upon is, human actions alone have increase the level of greenhouse gases in the earth atmosphere by burning fossil fuel, deforestation, and many industrial activities. These gases, in turn, have been credibly believed to cause the average global temperature to rise by absorb, retain, and emit heat imposed by the sunlight. (IPCC, 2007)

Temperature records from various locations indicate that the global mean surface temperature rise by 0.9°F since 1880. The records also show that the temperature does not rise until after 1910, where the industrial revolution is in full effect (NRC, 2006). It is also estimated in the National Oceanic and Atmospheric Administration's (NOAA) *2008 State of the Climate Report and the National Aeronautics and Space Administration's (NASA) 2008 Surface Temperature Analysis* that the eight warmest years on record (since 1880) have all occurred since 2001, with the warmest year being 2005, and the Earth’s surface is currently warming at a rate of about 0.29ºF/decade or 2.9°F/century. Furthermore, The Intergovernmental Panel on Climate Change (IPCC) concluded in 2007 report that warming is now “unequivocal,” based on observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level (IPCC, 2007).

In addition, climate change is widely described as one of the biggest threats to humankind. In response to this threat governments and industries around the globe are setting targets to bring about reductions in greenhouse gas (GHGs) levels.

To set and achieve the target, the value of baseline emission, natural background emission, and the emission offset achieved should be known, but this also raise the question of data reliability. Multitudes of standard tools such as LCA, ISO14000 series, carbon footprint, etc., are then established in order to quantitatively or qualitatively aid the assessment process. Carbon footprint, for instance, are a few tools to quantify the contribution of a product or service to the problem of global warming.

2.2.2 Greenhouse Gases

Greenhouse gases (GHGs) are gases that, in the Earth’s atmosphere, absorb and emit thermal infrared radiation, creating the well-known greenhouse effect. The major greenhouse gases are water vapor, carbon dioxide, methane, nitrous oxide, and ozone.

Historically, level of GHGs as well as the Earth’s temperature was controlled by natural processes like volcanic activity, wildfire, continent drifts, etc. Some gases, especially carbon dioxide and methane, occur and emitted to the atmosphere naturally.

Other greenhouse gases, however, are created and emitted only through human activities.

Table 2-1 summarized the important greenhouse gases that are either human or nature-based. Further part of this section also explains the sources, characteristics, and importance aspects of each one of the gases.

Table 2-1 Source of Greenhouse Gases

Species	Source of GHGs
Carbon dioxide	Fuels for Energy, Transport, and Manufacturing Processes
Methane	Waste (Landfills, natural activity)
Nitrous oxide	Chemical manufacturing and agriculture
Hydrofluorocarbons	Refrigerants, chemical manufacturing, foams and aerosols
Sulphur hexafluoride	Magnesium smelting, high voltage switchgear, electronics manufacturing
Perfluorocarbons	Aluminum manufacturing, electronics manufacturing

Sources: Carbon Trust, 2007

2.2.2.1 Carbon Dioxide (CO_2)

Carbon dioxide is the primary greenhouse gas created by human activities. It is estimated that carbon dioxide accounts for 84% of total greenhouse gases emission in the U.S. (EPA, 2009), and 77% of global greenhouse gases emission (IPCC, 2007).

Carbon dioxide naturally exists in the atmosphere which helps maintain the global temperature at life-supporting range. The carbon cycle that involves respiration, photosynthesis, and sequestration help balance the carbon level in the atmosphere, ocean, soil, plants, and animals.

However, since the industrial revolution human actions have altered the balance either directly by adding more CO_2 into the atmosphere and indirectly by affecting the nature's ability to absorb CO_2; Fuel burning, for instance, is considered direct while deforestation is considered indirect.

Table 2-2 Sources of human-related carbon dioxide emission

Source	**Description**
Electricity	Electricity generation is considered to be the greatest source of emission in the U.S. Amount of CO_2 emission depends on the type of fossil fuel used and the plant efficiency. Old coal-fired power plants, for example, emit more carbon dioxide per unit energy produced than plants using natural gases or fuel oil. Electricity use, in turns, could be distributed into different sectors, which will associate the emission with them. The post-distribute emission is shown in Figure 2-2.
Transportation	Vehicles using gasoline and diesel fuel contribute greatly to CO_2 emission, totaling 31% of total GHGs in the US.
Industry	Various industrial activities produce CO_2 by direct burning of fuels, but many more produce by chemical reaction. Carbonated mineral processing and steel smelting are a few examples.

According to US EPA, primary activity that emits the largest share of CO_2 is fuel burning for energy and transportation. Non-combustive chemical reactions activities are also responsible for the emission; cement manufacturing, for example, emits carbon dioxide during heat conversion of limestone into cement. Figure 2-1 shows the sources of CO_2 in the US and Table 2-2 describe each of them

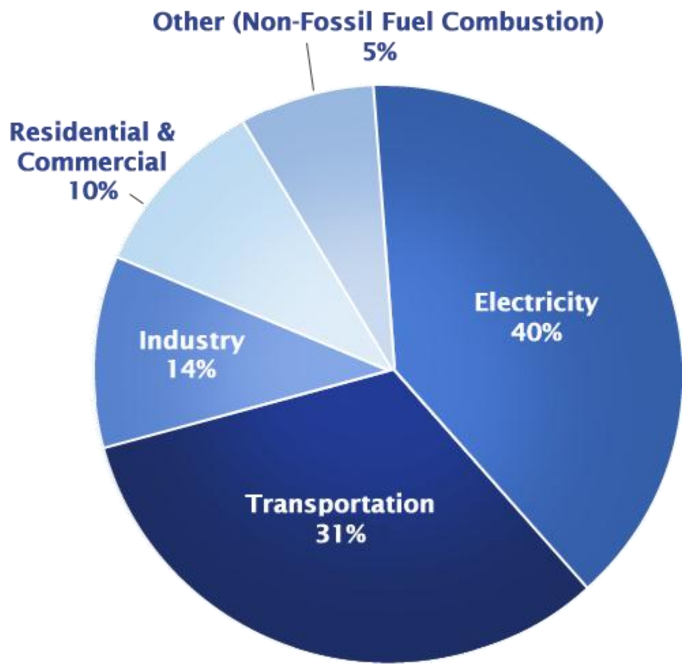


Figure 2-1 Human-related carbon dioxide emission in the USA

Source: Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2010.

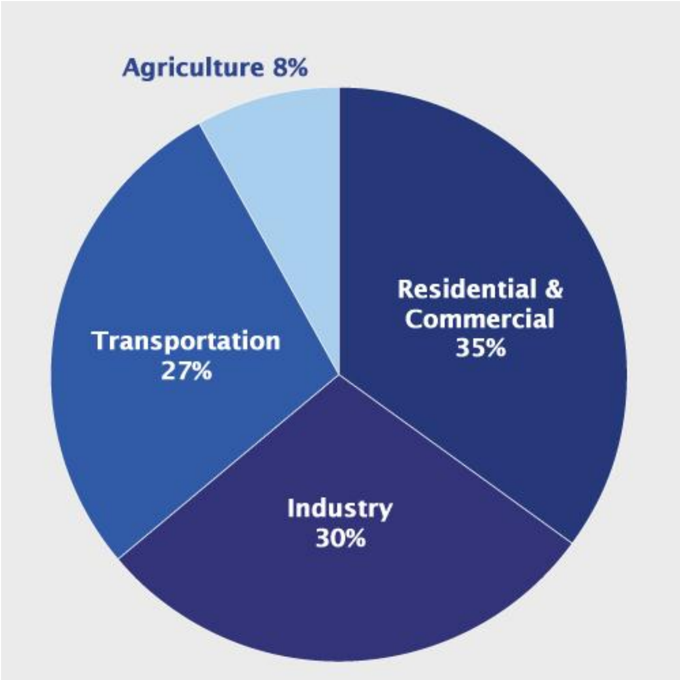


Figure 2-2 Post-distribution Human-related carbon dioxide emission in the USA

Source: Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2010.

2.2.3.2 Methane

Methane (CH_4) is the second most emitted GHGs, accounting to 14% of global emission and 10% of emission in the United State. Although it is highly associated with natural processes, majority (estimated to be 60%) of the current emission are caused by human activities.

Methane is normally produced by anaerobic degradation of organic matters. It could occur naturally, especially in wet swampy regions, or as consequences of human action, like in agricultural and livestock activities. Collection and disposal of organic waste, too, could result in methane generation.

Apart from these, methane too could be emitted as a byproduct from industrial processes. Coal, for example, contains a small amount of hydrocarbons which could be emitted as methane during coal processing and transportation. Chemical and petroleum industries also emit methane as a by-product or due to leakages.

Methane has comparatively short life in the atmosphere due to the fact that it could be destruct by photoreactions caused by sunlight. However, methane could capture greater heat energy than carbon dioxide. Methane could contribute 20 times greater impact in 100-year period.

Figure 2-3 shows the sources of CH_4 in the USA and Table 2-2 describe each of them.

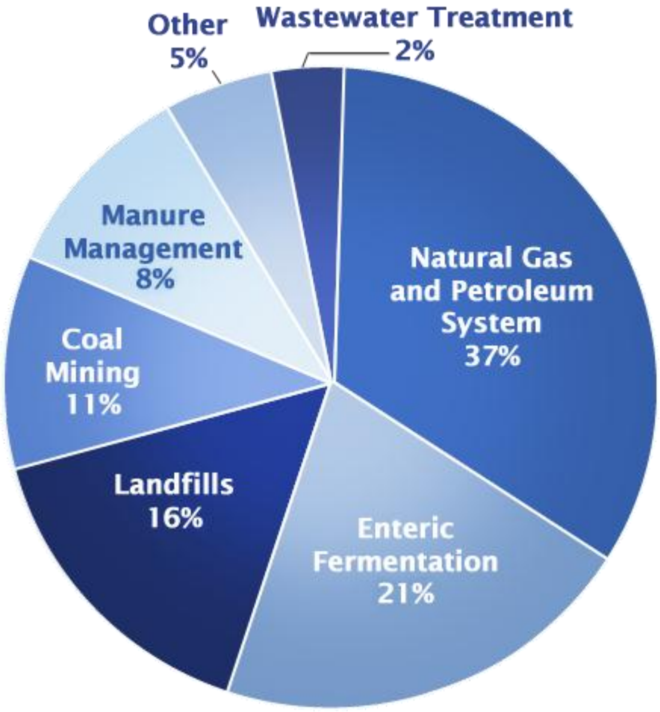


Figure 2-3 Human-related methane emission in the USA

Source: Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2010.

Table 2-3 Sources of human-related methane emission

Source	**Description**
Industry	Most industrial CH_4 emission in the United State is caused by Petroleum and Natural gas industries, since methane is the primary composition of natural gases. The gas could be emitted as off-gas, in accidents, or due to leaks in the system.
Agriculture	Domestic ruminal livestock produces methane in their digestive processes. Animal manure and carcass, too, usually undergo anaerobic degradation which results in methane. Moreover, agricultural practices in some countries, e.g. rice paddies, create man-made wetland which in turn emits methane.
Waste	Domestic and agricultural waste contains high organic percentage which could produce methane in anaerobic condition in landfills. Anaerobic wastewater treatment also leads to methane generation.

2.2.3.3 Nitrous Oxide (N_2O)

Nitrous oxide is similar to carbon dioxide and methane by the fact that it naturally exists in atmosphere. A part of nitrogen cycle, nitrous oxide has a variety of natural sources, but it too could be produced by human activities. Data from US EPA suggests that 40% of Nitrous oxide emission is caused by human.

Nitrous oxide could be emitted from agricultural activities where excessive nitrogen fertilizer was used. Nitrification process that came along with organic degradation too can result in nitrous oxide. It is also byproduct of nitrogen-based chemicals. Combustion at high temperature (especially in vehicles), too, would lead to oxidation of nitrogen content in air into nitrous oxide.

Nitrous oxide has long lifetime in the Earth's atmosphere. One molecule could exist for 120 years before absorbed or transform. Considering this fact, it is estimated that Nitrous oxide has 300 times impacts compared to carbon dioxide in the same amount.

2.2.3.4 Fluorinated Gases

Fluorinated gases such as CFCs, HFCs, and SF_6 are different from other GHGs that they have no natural source. They were used in almost every types of industry as coolant, solvent, flame retardant, refrigerant, and propellant.

Fluorinated gases are so inert that the lifetime in atmosphere could be as long as 50,000 years. Such a long time make the global warming potential 140 – 24,000 times higher than carbon dioxide.

2.2.3 Sources of Greenhouse Gases

According to IPCC's report, activity that contributes to the largest portion of GHGs emission is energy generation, which is estimated to be as much as 26% of the global value. Electricity generation in the United State, however, was estimated to be higher at 34%.

IPCC also suggested that industries-related (energy, industries, and transportation) in developed countries have larger contribution to the national emission compared to the developing ones. However, developing countries contributes larger emission from agricultural-related activities than the counterparts.

2.3 Carbon Footprint

Carbon footprint is one of the tools to represent the effect human activities have on the global warming in terms of total amount of greenhouse gases emissions caused directly and indirectly by an individual, organization, event or product. Carbon footprint takes the quantity of all GHGs emission using the concept called "cradle to grave". The concept is that the product and its associated impacts should be accounted for from the extraction of raw materials, transportation and parts for assembly all the way to waste management for end of product life. For simplicity, it is often expressed in units of metric ton (or kg) of carbon dioxide equivalent.

The concept of carbon footprints helps businesses, public, and governments understand the impact of a particular product of service to the environment in simpler terms. However, it does not account for the damages that are not related to the global warming such as acid deposition, hazardous waste, water contamination, etc. For those proposes, different tools such as ecological footprints are considered more appropriate.

2.3.1 Calculating Carbon Footprint

(Adapted from Carbon Trust, 2008)

There are five steps to calculate the value of carbon footprint:

- Building process map
- Creating boundaries and prioritization
- Collecting data
- Calculating the footprint
- Checking uncertainty

2.3.1.1 Building process map

This step objective is to identify all materials, activities, and process associated with the life cycle of the product. Process map should be first built as high-level and then refined further by thorough researches and surveys.

In most products, process map should be separated for each components of the product; however, rough calculations and reviews should be done to identify and prioritize the component and eliminate the need to use work resources immaterial (<1% of total contribution) ones.

Process map could be categorized into B2C and B2B, that are, business-to-consumer and business-to-business, respectively. The former are applied to products that produced to the direct user, where the use and disposal should be incorporated into the calculation. The latter is the products which are raw material for other businesses such as steel, aluminum, and plastic pellets.

2.3.1.2 Checking boundaries and prioritization

After the process map is developed, relevant boundaries for the analysis should be determined. ISO 14025 have defined Product Category Rules (PCR) that is the collection of rules, requirements, and guidelines for developing environmental declarations for specific set of products.

This process involves a major decision, that is, what to and not to include in the analysis. Entries that could be excluded are

- Immaterial sources that contribute to less than 1% of emission
- Human inputs
- Consumption by retail outlet
- Animal transport

To decide what sources are immaterial, high level calculation should be conducted using estimation and accessible data. Estimation will help identify the sources to focus. Data could be then replaced by more comprehensive data.

2.3.1.3 Data collection

After the initial calculation, specific data could then be collected using the mean and quality that complies with the standard required by the regulating bodies. There are two groups of data required: activity data and emission factor.

The activity data refers to all material and energy inputs involves in the life cycle. The emission factor, in turns, are the values that link the activity data with the emission in terms of greenhouse gases emitted per unit value of the activity, e.g. kg GHGs per kg input or per kWh of energy used.

The activity data could come from either primary or secondary sources. Primary data refers to direct measurement made in the supply chain and secondary data that are not direct but calculated or estimated using external data such as industry report or data from trade association.

2.3.1.4 Footprint calculation

Total footprint from a product is the sum of the activity data multiplied with appropriate emission factors for each component of the products. That is,

$$Carbon\ footprint\ of\ a\ product = \sum (Carbon\ footprint\ of\ activity)$$

$$Carbon\ footprint\ of\ an\ activity =$$

$$Activity\ Data\ (mass, volume, distance, energy\ unit) \times$$

$$Emission\ factor\ (CO_2\ equivalent\ per\ unit)$$

Values expressed as carbon dioxide equivalents (CO_2eq) are calculated based on their global warming potential (GWP). GWP is the ratio of the warming that would result from the emission of one kilogram of a greenhouse gas to that from the emission of one kilogram of carbon dioxide over a fixed period of time such as 100 years.

GWP values allow for a comparison of the impacts of emissions and reductions of different gases. According to the IPCC, GWPs typically have an uncertainty of ±35 percent. The parties to the UNFCCC have also agreed to use GWPs based upon a 100-year time horizon although other time horizon values are available.

2.3.1.5 Uncertainty checks

The objective of this step is to determine the precision of the calculation in order to know the reliability of the result as well as in order to improve confidence in the estimate.

Table 2-4 Global warming potentials of some Greenhouse Gases

Gas	**Formula**	**Relative GWP / CO_2 (100 years)**
Carbon dioxide	CO_2	1
Methane	CH_4	25
Nitrous oxide	N_2O	298
Perfluorocarbons	C_nF_{2n+2}	7400 to 12200
Hydrofluorocarbons	$C_nH_mF_p$	120 to 14800
Sulfur hexafluoride	SF_6	22800

Source: IPCC, 2007

Uncertainties in the result could be reduced using a number of techniques. Replacing secondary data with primary data or switch to the same secondary data with more specific value are the ones that potentially reduce uncertainties in collected data. Moreover, calculation model could also be adjusted.

2.4 Biomass

2.4.1 Overviews

Rapid expansion of world economic has put pressure on the global supply of agricultural, industrial, and energy sectors, and it is clear that non-renewable resources especially fossil fuels and minerals are not sustainable in the long term.

Recently, there are initiatives from both public and private sectors to promote the use of bio-based fuels and resources. World steel association, as the most relevant, has stated that biomass such as charcoal or syngas could be used to produce the reduction agent. Charcoal could be used as is in blast furnace and coke oven, yet it also serves as fuel in furnaces. Syngas, on the other hand, could only serve as an agent in direct reduction processes.

Biomass could be originated either directly in facilities or indirectly as residue from human activities that includes food production, forestry, marine crop, municipal waste, manure, and animal products. However, such diversity also poses an issue of heterogeneity and another issue on the logistic due to the fact that biomass could be generated in a wide area.

Another issue regarding the use of biomass is the readiness of industrial sector to incorporate these bio resources into the production process. The majority of industrial processes were initially designed based on non-renewable resources and minerals, and new technological and fundamental adjustment should be devised. Nevertheless, shifts to renewable sources would benefits the industry in the long run, since it adds the sustainability to the process in addition to minimizing environmental impacts.

UNIDO has stated in 2007 that benefits of biomass include:

- New areas of economic growth and development for the many regions that have plentiful biomass resources;
- Creation of new innovative business sectors and entrepreneurial skills;

- Improved energy security, by reducing dependence on non-renewable resources;
- Enhance economic and environmental linkages between the agricultural sector and a more prosperous and sustainable industrial sector;
- Reduction of greenhouse gas emissions;
- Improved health by reducing exposure to harmful substances through substitution of natural bio-based materials for chemical and synthetic materials;
- Job creation and rural development.

However, there are also issues to be addressed as follow:

- How to manage competition of land used as raw material for industry with other land uses, especially in relation to food and animal feed;
- Bioethical issues, where genetically modified crops are used or proposed;
- Potential loss of biodiversity through large-scale and/or contract farming;
- Equitable treatment of farmers in their interaction with bio-based companies;
- Expanded research and development efforts, including potential integration of fossil fuel and bio-based approaches;
- Improving transportation and delivery systems, e.g. supply of raw materials, delivery to/from processing facilities, and final product distribution and use.

Apart from this, UNFCCC has claimed that, with processing and transportation excluded, burning biomass results in zero emission since the carbon released are actually taken up from the atmosphere during its growth. It also prevents the methane that could be generated in landfill when disposal. Note that this basis only applies when the forest carbon sink is not affected by the production of biomass.

2.4.2 Fundamentals

Growth of virgin biomass consists of a few key steps where chlorophyll captures carbon dioxide via photosynthesis and then forms into complex organic compounds (mainly carbohydrates). The process could be depicted using the following equation:

$$CO_2 + H_2O + hv + chlorophyll \rightarrow (CH_2O) + O_2$$

The CH_2O block represents the basic building block of any carbohydrates, while hv represents the photon energy of light. Each mole of carbon dioxide that is absorbed needs approximately 470 kJ (112 kcal) of energy. Chlorophyll, in turns, could capture only 8-15% of sunlight radiation at maximum and 2% in general conditions (Klass, 2004).

The largest source of standing terrestrial biomass carbon is forest biomass, which contains about 80 to 90% of the total biomass carbon. Marine biomass carbon is then the second largest reservoir of biomass but the availability is rather limited due to high turnover rates in oceanic environment. The main aspects of how biomass is used as energy and fuels are schematically illustrated in Figure 2-4.

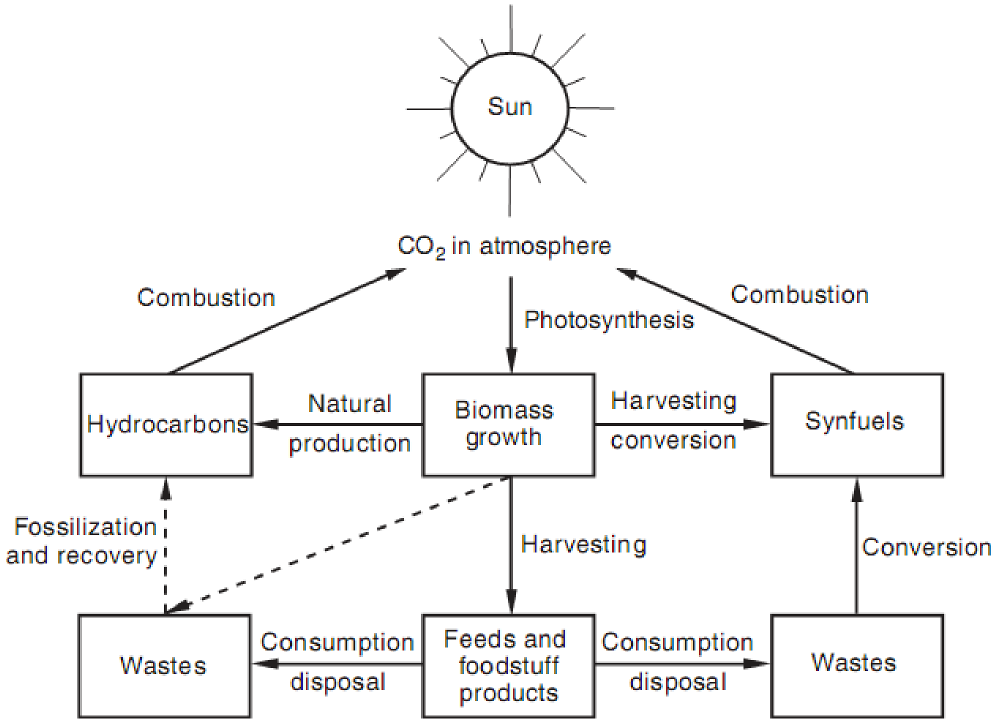


Figure 2-1 Diagram of biomass utilization

(Source: Klass, 2004)

Biomass is normally harvested for feed, food, fiber, and construction materials or is left in the areas to be naturally decomposed. Decomposing biomass in or on land could be recovered into the energy cycle as fossil fuels; the processes involved are indicated by the dashed lines in the figure.

Alternatively, biomass and any wastes that result from its processing or consumption could be converted directly into synthetic organic fuels. Another route to energy products is to grow certain species with high-energy hydrocarbons such as the rubber tree (*Hevea braziliensis*) or the Chinese tallow tree (*Sapium sebiferum*). In these cases, biomass serves as a carbon-fixing apparatus and a continuous source of high-energy organic products where the plant is not consumed in the process.

Apart from atmospheric, CO_2 in other form could also be captured into biomass; the dissolved carbons in the oceans and the earth's large carbonate mineral deposits could serve as renewable carbon resources.

2.4.3 Biomass situation in Thailand

Biomass-based energy in Thailand, like in other part of the world, depends on political, technological, agricultural, environmental, and societal factors.

On the political aspect, the national energy policy in Thailand has promoted renewable energy on the aspect of energy security, that is, it aims to reduce the energy imports along with greenhouse gas emissions. In 2009, Thailand has imported 62,006 ktoe of energy, which equals to 2,596 PJ. This is nearly 93% of total energy consumption of the country, which is 66,698 ktoe (DEDE, 2009). Such independence on foreign oil has posed pressure on the matter of energy security.

Energy Conservation Promotion Fund is one of the economic measures that implement purchases and subsidies for generators of renewable energy by providing "Adder" to the price of energy purchase as well as soft loans for Renewable Energy projects. Adder rate for biomass-based energy varies by the capacity of a project, but fixed for the first 7-years supporting period. The rates are shown in Table 2-4.

Table 2-5 Adder rate from the FT for electricity generated from biomass

Project type	**Adder**
Capacity < 1 MW	0.5 THB/kWh
Capacity > 1 MW	0.3 THB/kWh
Situated in Pattani, Yala, Narathiwat	1.0 THB/kWh added to the existing rate

Source: Ministry of Energy, 2009

Thailand is situated in tropical area which has a high potential of biomass generation. In 2009, biomass contributes to 94% of renewable energy produce in Thailand (refer to Table 2-5).

Table 2-6 Electricity generation from renewable sources in Thailand

Sources	**Production (MW)**	**%**
Wind	5.13	0.3
Solar	37.6	2.0
Hydro	67	3.6
Biomass	1729.2	94
Solid	(1644)	
Biogas	(79.6)	
MSW	(5.6)	

Source: DEDE (2009)

Moreover, Thailand has a wide range of agricultural products with associated biomass residue. Southern part of the country focuses mainly on palm and coconut, while eastern part focuses on cassava and sugar cane. The remaining part of the country focuses on rice. Table 2-6 lists the heating values of each agricultural biomass in Thailand.

Table 2-7 Heating value of agricultural biomass in Thailand

Types	**Unit**	**Energy Content**		
		kcal/unit	**toe/10^6 unit**	**MJ/unit**
Sugarcane				
Bagasse	kg	1800	178.34	7.53
Top/ Trashier	kg	3858.55	382.3	16.15
Rice				

Types	Unit	Energy Content		
		kcal/unit	toe/10^6 unit	MJ/unit
Straw	kg	3297.08	326.67	13.8
Stalk	kg	3029.14	300.12	12.68
Paddy Husk	kg	3440	340.83	14.4
Maize				
Stalk	kg	3825.15	378.99	16.01
Skin	kg	3029.14	300.12	12.68
Cob	kg	4009.14	397.22	16.78
Cassava				
Top/ Trashier	kg	3029.14	300.12	12.68
Stalk	kg	3724.82	369.05	15.59
Root	kg	3849.07	381.36	16.11
Oil palm				
Empty Bunches	kg	3899.23	386.33	16.32
Fiber	kg	4121.37	408.34	17.25
Shell	kg	4427.19	438.64	18.53
Frond	kg	3829.89	379.46	16.03
Male Bunches	kg	3901.1	386.51	16.33
Coconuts				
Husk	kg	3920.73	388.46	16.41
Shell	kg	4362.7	432.25	18.26
Empty Bunches	kg	3686.57	365.26	15.43
Frond	kg	3822.26	378.7	16
Groundnuts Shell	kg	3024.37	299.65	12.66
Cotton Stalk	kg	3461.54	342.96	14.49
Soybeans				
Stalk, Leaves, Shell	kg	3877.63	384.19	16.23

Types	**Unit**	**Energy Content**		
		kcal/unit	**toe/10^6 unit**	**MJ/unit**
Sorghum Leaves, Stem	kg	4593.88	455.15	19.23
Pineapple	kg	3765.39	373.07	15.76
Para rubber				
Frond	kg	3030	300.21	12.68
Leaves	kg	3030	300.21	12.68
Husk	kg	3030	300.21	12.68
Seed	kg	3030	300.21	12.68
Fuel Wood	kg	3820	378.47	15.99
Charcoal	kg	6900	683.64	28.88

Source: DEDE (2010)

2.4.4 Biomass technology

There are a variety of methods to convert biomass to bio-energy and industrial products. Methods could be biological, chemical, or thermal processes. Figure 2-5 shows the possible routes to use biomass as energy sources. Apart from the ones shown in the Figure, there are also technologies, products, and services that are under development and do not reached commercial levels yet.

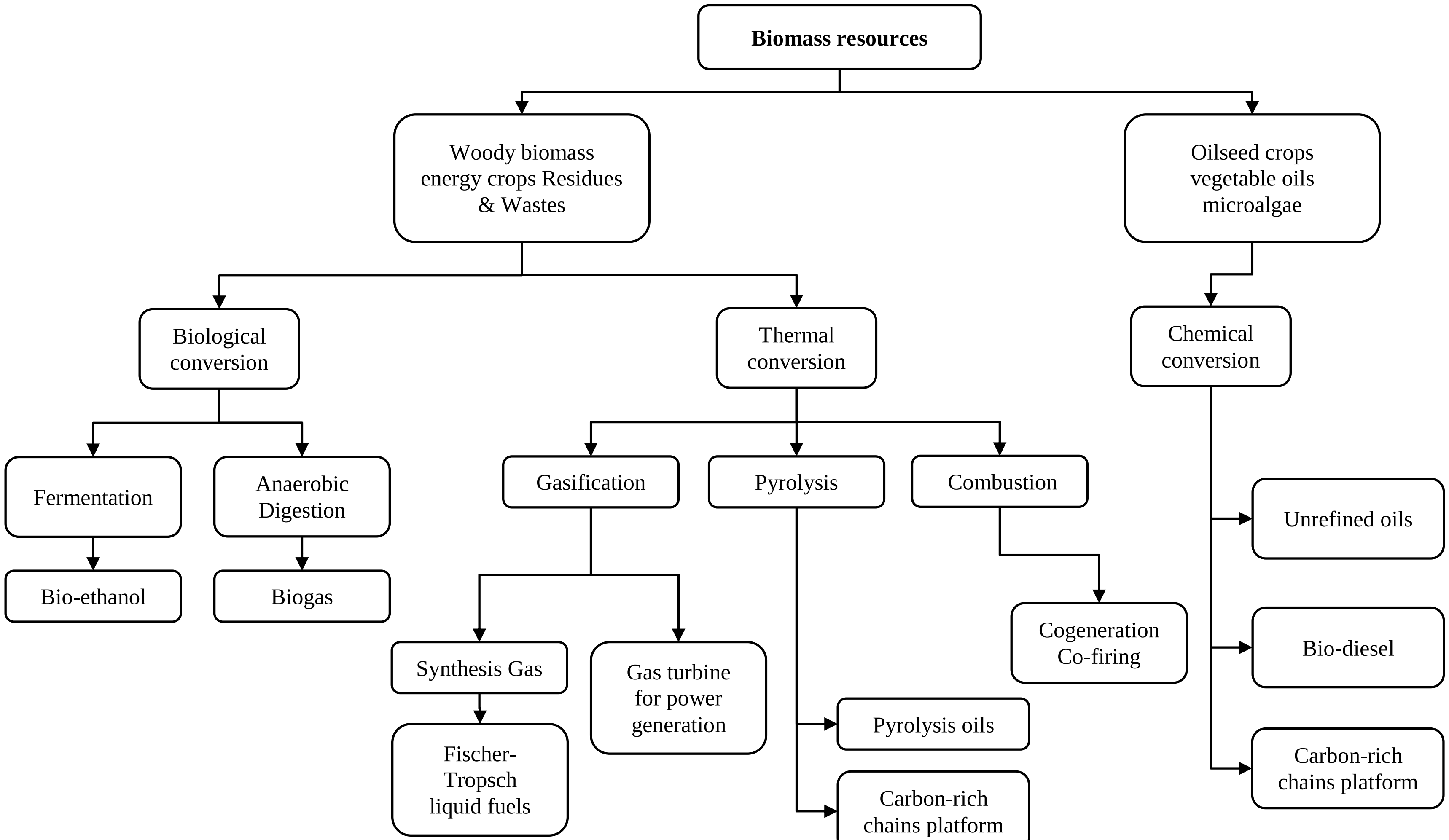


Figure 2-2 Possible biomass conversion route to heat-generating fuels (source: UNIDO, 2007)

2.5 Greenhouse Gas Emission from Iron and Steel Industries

In 2004, industrial sector emitted 9.7 billion tons of CO_2, which accounted for 36 percent of global CO_2 emission (IEA, 2007). In this portion, steel sector exhibited approximately 27 percent which was the largest share for manufacturing sector during the same year. The majority source of direct CO_2 emission from steel sector is reduction process of iron ore in blast furnaces (Tomi, 2009). Over 80% of total CO_2 emissions of the industry generate from blast furnace unit, the remaining direct emission released from fossil fuel combustion for heat in BOF. Iron smelting via EAF is the most electricity-intensive. Casting and rolling also require reheating of raw material which needs fossil fuel feed.

For the past twenty years, almost 60 percent of steel are produced from pig iron via blast furnace pathway (IEA, 2007). However, the proportion of steel product from direct reduced iron has increased steadily. The types of input materials consumed are important since they could affect directly energy use and CO_2 emission. EAF base consumed less energy and emits less CO_2 emission compare to other processes. In 2005, iron ore-based steel production emitted CO_2 in a range of 1-3.5 tons CO_2 per ton of crude steel (IISI, 2007; Trevor et al., 2008). On the contrary, the EAF emitted around 1.5 tons. Significant variation in CO_2 depends on the production technologies, product mix, energy efficiency, fuel mix and electricity carbon intensity for each location (IPCC, 2007). Data regarding long product, however, are difficult to obtain.

2.6 Thailand Power Development Plan 2010 (PDP2010)

(Excerpted from EGAT, 2010)

Since the global economic downturn in 2008, electricity demand in Thailand has decreased significantly. This turns of event have forced Ministry of Energy to revise the plan from its 2008 revision to be more appropriate to the situation. The new plan was designed to be "greener" that focuses on reducing GHGs emission and promoting energy efficiency and reliability.

Electricity Generation from Renewable Energy

At present, the proposed power generation from renewable energy projects are indefinite in aspects of duplicated locations and no robust guarantee of implementation, while their influences on system reliability and the readiness of transmission network are also needed to be studied. Therefore, PDP 2010 contains power generation from renewable energy regarding the 15 Years AEDP to the year 2022 and not less than 5% of energy production referring to the VSPP purchase projected by distribution authorities afterward. The table below shows the cumulative generating capacity from all renewable energy resources.

Since renewable technologies are in their early stage and recently commercially introduced, there is insufficient evidence to assure their dependable generating capacity. Most of available data are average values on daily and monthly basis, which cannot reflect the power generation at a certain point of time, particularly that of wind and solar power. Consequently, concerning risk aversion, PDP 2010 recommends deeming their dependable capacity at confident level and later adjusting it when the actual information is available.

Greenhouse Gas Emission Reduction

In 2009, the power generation sector released 0.546 kg of carbon dioxide for every kWh of electricity production. To respond to clean energy policy and the Green PDP, the concrete plan to cut down greenhouse gas emission in generation system was incorporated into PDP 2010. The goal is to have a lower emission rate than that of PDP 2007 Revision 2 in the year 2020 and then to retain it at not a higher rate, which can be done by apportioning assorted types of low emission power plant.

Renewable Energy and Cogeneration System

Power generation from renewable energy and cogeneration SPPs was the first priority in future planting up. Their capacity and operating schedule of the renewable energy in 2010-2022 was in line with the 15 Years AEDP. Thereafter, their energy generation was set to not less than 5% of total energy requirement as predicted by distribution power utilities. Meanwhile, cogeneration SPPs utilizes energy resources and infrastructures more efficiently. Their capacity and commissioning schedule was according to the purchasing progress in 2010-2014, the NEPC's resolution on 24 August 2009 in 2015-2021 (2,000 MW) and the agreed capacity in 2022-2030 (360 MW annually).

Nuclear Power Plant

Nuclear power plants were selected by the optimization because of their low production cost. In addition, they can serve base load for a long duration and thus secure the power system. They can also help trimming down the number of fossil fuel fired power plants since they do not release greenhouse gases. However, due to public acceptance, PDP 2010 allowed only 5 units of them with a maximum energy generation share of 10% to the total generation requirement. Besides, they had to come in intervals to ease the investment burdens.

Clean Coal Power Plant

As well as nuclear power plants, coal-fired power plants were picked up by the optimization due to their low production cost. However, there are difficulties with location, greenhouse gas emission and public acceptance, despite Supercritical or Ultra-supercritical technologies with bituminous fuel and FGD equipment. Educating people about facts, knowledge and understanding is therefore very essential. To avoid greenhouse gas emission, clean coal power plants were the last precedence of new planting up in PDP 2010.

2.7 Literature review

2.7.1 Researches related to steel industries and carbon emission

Recent trends to reduce environmental impacts from industries has result in researches that aimed to assess, identify, find means to minimize or mitigate environmental impacts from steel. Table 2-7 lists some of these notable researches.

Table 2-8 Notable researches regarding steel and emission

Researches	**Results**
Tongpool et al. (2010)	Environmental impacts from galvanized steel are higher than those from flat steel in all aspects; this is due to the use of zinc in the process. Impacts from steel production could be minimized by substituting the raw material from virgin iron to iron scarp. Impacts from galvanized production could be alleviated by more process/environmental controls.
Sodsai and Rachdawong (2012)	Flat steel production in Thailand emitted approximately 1.26 million tons of CO_2 in 2008 alone. Implements of PDP2010 power generation plan could reduce as much as 23% of CO_2 intensity by the year 2030 while fuel switching to natural gas or biomass could reduce it for 4% further or totally eliminate the fuel-related emission in case of biomass.
Oda et al. (2007)	Fuel efficiency model that is applies projected that as much as 15% of greenhouse gases emission from global steel sector could be reduced in 2030 if the new energy efficiency standard and advanced technologies are in place. However, to reach 550ppmv target, reduction should reach as much as 25-30%.

Researches	Results
Ozawa et al. (2002)	Mexico's growth in steel production has caused the energy consumption to be driven up by 211% in 25-year-period. However, process efficiency and structural changes help reduce the energy consumption by 51% and 12%, respectively. Some of the efficiency techniques are: substituting OHF by BOF, increase continuous casting, implementation of new technologies for DRI production, and increase use of coke oven and blast furnace gases for on-site electricity generation. Structural changes include: increase of scrap input, use of hot rolled instead of cold rolled products, substitution of coke by natural gas. Nevertheless, Mexico still has the potential to further reduce the emission for 34 percent.
Wang et al. (2007)	CO_2 emissions from steel industries in China are calculated for 2030 in three different scenarios: reference, Recent Policy and the New Policy. The result shows that two latter policies could reduce the emission compare to the reference policy by 51 and 107 million tons.
Gielen and Moriguchi (2002)	Model result indicated that carbon taxation could cause CO_2 to decline from 185 Mt to 150 Mt in 2030. Further increase of carbon tax would result in 90 Mt.

The projected emission from various models is too based on an assumption that all technology could readily be applied into use while, in reality, there should be some economic considerations.

2.7.2 Researches/reviews regarding biomass energy policy in Thailand

Recently, there are pushes in Thailand to shift the energy dependence of the country toward renewable sources. The one with dominance is biomass, which is used in rural Thailand since the pre-industrial time.

Papong, Yuvaniyama, Lohsomboon, and Malakul have reviewed in 2004 that biomass amount to second largest energy source in Thailand, especially in rural area. Biomass could either be charcoal produced from wood residue, or agricultural byproducts. By latter, the ones with potential vary by the regions, palm-based product, for instance, tends to focus in Southern Thailand. This is in accord with those found by Prasertsana and Sajjakulnukit (2005); they also found that agricultural residue in Thailand could amount as much as 61 million tons, in which a major portion of 41 million ton left unused and discarded. This ‘waste’ portion is equal to 426 petajoule of energy.

To promote biomass utilization in Thailand, however, there should be some groundwork for the continuous supply, economic incentives, and technological readiness. For the technological aspects, Prasertsana and Sajjakulnukit proposed that technologies used in Thailand are “quite old with low efficiency”. Nevertheless, Barz and Delivand (2011) have suggested techniques to optimize biomass utilization in Thailand.

Economic aspect is now considered by Thai government in form of back-to-the-grid electric purchasing with additional ‘adder’. There are, however, considered not as high enough to be the incentive, as Sawangphol and Pharino (2010) have discussed.

Regarding funding, Thai government has set up a fund for renewable projects including biomass or biogas power generation. However, Carlos and Khang (2008) analyzed 165 biomass projects and found that most biomass plants are situated in agricultural-related mills or agro-industries where biomass residues are concentrated in one place. These concentrated biomass bulks, however, constituted a lesser portion (one-third) of all potential biomass in Thailand. Thus, there should be a systematic mean to collect and control the biomass supply that is sparsely spread throughout the country.

Sawangphol and Pharino also proposed that government plan to rely on the biomass in the future are actually vulnerable. They discussed that by making the food and energy security relies solely on agricultural production, the nation has put itself on the position that is prone to the impact of climate change (drought/flood). Instead, the government should too emphasize on other form of renewable energy: hydro, solar, and wind. This should include funding as well as research focuses.

2.8 Summary

It could be seen that various researches have attempted to characterize, quantify, measure, as well as reduce steel-related greenhouse gas emission. These researches were conducted in both local and regional scale. Most studies related to

Thailand, however, were not scoped in plant-by-plant basis. Sodsai and Rachdawong, for example, based their research on national scale. Development of reduction measures would face several shortcomings, since variation in production process across steel plants will result in different outcomes of the same measure.

To bridge this gap, a study should be conducted as an attempt to characterize the nature of steel production plants in Thailand, to determine the energy consumption, to identify the emission sources, to find common pattern across different types of product. As the result, localized measures and techniques to reduce the emission could then be developed based on the technological knowledge and potential of the country.

CHAPTER III

METHODOLOGY

This study has selected the carbon footprint as the tool to directly quantify the impact of steel industry to the climate changes. Values obtained could serve as a baseline standard for the benchmarking against others as well as to state the reduction goals. Also, PAS2050 was selected as the main guideline for the calculation due to the fact that it was the first standard for product's carbon footprints that was developed from ISO14000 by the helps of 20 leading companies that include thousands of experts. As the result, PAS is now regarded to be one of the standard tools to quantify carbon footprint, especially in Europe which is the major importer for Thai steel industries.

3.1 Research Plan

The first objective of this study is to calculate the carbon footprint of steel products from two steel factories in Thailand whose products are flat steel and long steel, respectively. Then, feasible solution for reducing the carbon footprint of both products would be developed. This chapter describes the methodology to achieve these objectives. This study can be divided into seven parts as follows:

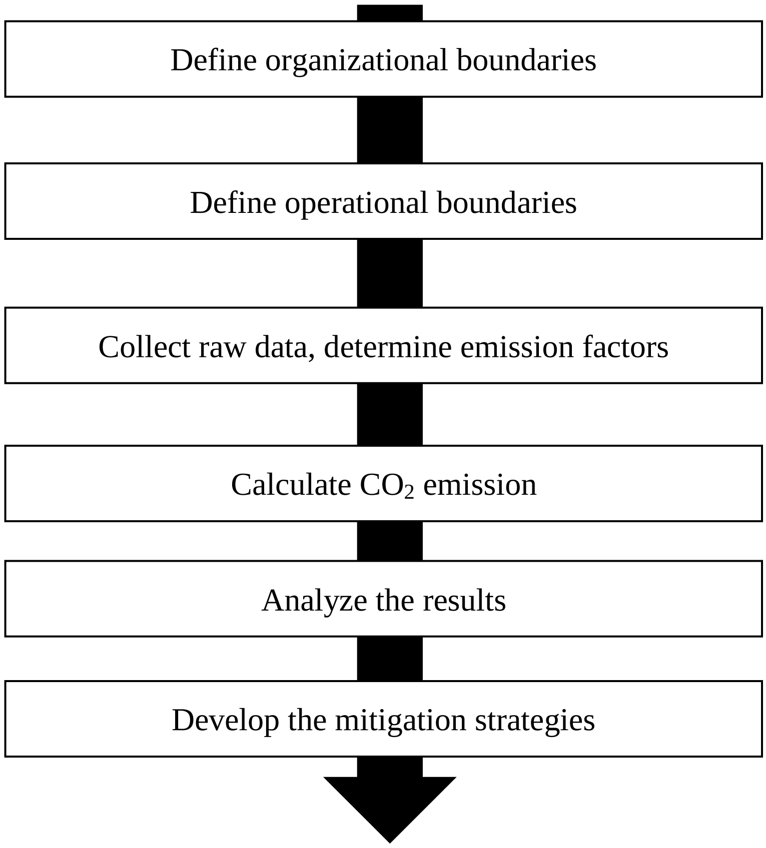


Figure 3-1 Flow diagram of research methodology

3.2 Definition of organizational boundaries

Calculations in this study were based on gate-to-gate basis; meaning that only the activities in the factories were taken in to accounts. Other activities apart from this were excluded.

Considering the calculation basis and the characteristic of the plant, footprint caused by all processes up to the primary and secondary steel production would be excluded. This is due to the fact that both plants do not produce raw steel but process steel from other plants. Greenhouse gases emission caused by transportation, too, would be omitted due to this basis.

3.3 Definition of operational boundaries

This step identifies the activities in the organization boundary to be calculated. Area to be determined in this study was classified into 3 sub-areas as defined in Table 3-1. The classification was adapted from the Greenhouse gases protocol (IPCC, 2006) and the guidelines issued by the Thailand Greenhouse Gas Management Organization (2011).

Note that emissions that was related to office and utilities as defined in Scope 3 would be omitted due to the fact that (1) the interviewees did not stated this amount in the returned questionnaire and (2) the interviewees stated that electricity consumption in the office was considered minimal compared to the amount consumed in the production process, so it may be legible to claim that it is “immaterial” and could be excluded.

3.4 Collection of Emission Data

Data needed to calculate the emission from all sub-areas were collected during one-timed visit and follow-up by e-mail contact with coordinator of each plant. Data from year 2007-2009 are available for the study.

3.5 Calculating CO_2 emissions

The methodology of this study used to quantify the CO_2 emissions from the visited steel factories was calculated by Microsoft Excel.

Table 3-1 Description of study scopes and associated boundaries

Scope description	Standard Boundaries
Scope 1: Direct emissions that are owned and controlled by the organization in this study is referred to emission for heat.	▪ Consumption of fuels for heat
Scope 2: Energy indirect emissions that are from the purchase of power	▪ Purchased electricity
Scope 3: Any other emissions that are a result of activities related to the organization, but are not emitted from manufacturing process	▪ Use of electricity for air condition, light and other electrical appliances.

(Adapted from IPCC guideline, 2006)

Table 3-2 Important data and the means to obtain

Emission Source	**Activity data**	**Proprietary Data**	**Obtain Data by**
Processes that use fuels	Fuel consumption	Carbon content of each fuel	Visiting questionnaire
Purchased Electricity	Electricity consumption	Grid emission factor according to EGAT	Electricity bills
Offices Uses*	N/A	N/A	N/A

*stated in the interview to be insignificant compared to others source, so it is omitted.

A GHG inventory for the plants was generated to identify what data was needed to use GHG-originating activities and emission factor. The two kinds of data to calculate the plants' GHG emissions include "activity data" and "emission factor"

The equation for calculating greenhouse gas emissions (IPCC, 2006) from activities in the factory is:

$$Carbon\ footprint\ of\ an\ activity = Activity\ Data\ \times Emission\ factor$$

Each variable of the equation are described in Table 3-3.

Table 3-3 Variables to calculate carbon footprint

Variable	**Description**	**Units**
Carbon footprint of a given activity	Sum of all energy use, transportation material use, and waste across all activities multiplied by their emission factors	kg CO_2
Activity data	all material and energy amount throughout all activities	kWh (electricity) GJ (fuel) ton (raw material)
Emission factor	the amount of greenhouse gases emitted per unit of activity data	kg CO_2/kWh kg CO_2/GJ kg CO_2/ton

3.5.1 Fuel Emission

For fuel-based emission factors, this study has summarized important values in Table 3-5 and Table 3-6. Footprint is then calculated using the following equation:

$$Footprint_{fuel} = Consumption \times Energy\ content \times Carbon\ Content \times \frac{44}{12}$$

Since the values used are in elemental carbon unit, the 44/12 factor is then added to convert mass of carbon (molecular weight = 12) into mass of carbon dioxide that would be produced upon combustion (molecular weight = 44).

Table 3-4 Variables to calculate carbon footprint from fuel

Variable	**Description**	**Units**
$Footprint_{fuel}$	Emission that is related to fuel	kg CO_2
Consumption	Amount of fuel consumed	Liter, m^3
Energy content	Energy obtained from a unit of fuel	GJ/liter, GJ/m^3
Carbon content	Amount of carbon contained in fuel	kg C/GJ

Table 3-5 Energy content values of fossil fuel (DEDE, 2010)

Fuel types:	**Unit**	**Energy content**
		MJ/unit
Natural gas	cubic foot	1.04
Liquid Petroleum Gas (LPG)	Liter	26.62
Kerosene	Liter	34.53
Diesel oil	Liter	36.42
Fuel oil	Liter	39.77

Source: DEDE (2010)

Table 3-6 Default carbon content values of fossil fuel

Fuel types	**Carbon content**
	kg carbon/GJ
Natural gas	15.3
Liquid Petroleum Gas (LPG)	17.2
Kerosene	19.6
Diesel oil	20.2
Fuel oil	21.1

Source: IPCC (2006)

3.5.2 Electricity Emission

Emission that is related to electricity use is in fact cannot be directly calculated due to variety of power generation. Solar and hydro power plant, for example, emits virtually no carbon dioxide while coal power plant do the opposite.

Grid emission factor is a factor that includes all the electricity generation entities into consideration. It is formulated by summing all possible emission from every plant and then averaged over the total amount of electrical energy produced. The resulting factor will be in $kgCO_2/kWh$ unit.

This study obtained the values of grid emission factors from two main sources. The first is annual report issued by the EGAT that provide the actual emission factors in the year. The second is the predicted grid emission factor provided in the PDP2010 report. The values are listed in Table 3-7 and Table 3-8.

Table 3-7 Actual grid emission factor for 2007-2009 periods

Year	Emission Factors $kgCO_2/kWh$
2007	0.579
2008	0.572
2009	0.58

Source: EGAT, (2008,2009,2010)

Table 3-8 Projected Grid Emission factor according to PDP2007 and PDP2010

Years		Gird emission intensity in kg CO_2 per kWh	
A.D.	**B.C.**	**PDP 2007**	**Draft PDP 2010**
2008	2551	0.580	0.580
2010	2553	0.464	0.482
2011	2554	0.459	0.471
2012	2555	0.459	0.470
2013	2556	0.456	0.462
2014	2557	0.447	0.468
2015	2558	0.440	0.448
2016	2559	0.452	0.423
2017	2560	0.465	0.408
2018	2561	0.456	0.398
2019	2562	0.445	0.401
2020	2563	0.425	0.387
2021	2564		0.374
2022	2565		0.373
2023	2566		0.381
2024	2567		0.361
2025	2568		0.341
2026	2569		0.357

Years		Gird emission intensity in kg CO_2 per kWh	
A.D.	**B.C.**	**PDP 2007**	**Draft PDP 2010**
2027	2570		0.354
2028	2571		0.363
2029	2572		0.367
2030	2573		0.368

Source: EGAT

CHAPTER IV

RESULTS AND DISCUSSION

This chapter first describes the studied plants and their production processes, their fuel and electricity consumption, and then the calculated total energy consumption. Total energy consumptions are then normalized in order to obtain the energy required per a ton of product. After that, emission values are calculated from the energy-based emission factors into functional unit of $kgCO_2$ / ton product. Finally, CO_2 abatement techniques including fuel switching, electricity generation strategies, and power efficiency, are discussed. This chapter also discusses the possibility of using biomass, which is a potential low-emission fuel, as energy source.

4.1 Plant Information

For Flat product plant that was studied, the process flow was shown in Figure 4-1 and the descriptions of each process are provided in Table 4-1. Information from Long product plant which produces long steel product, however, is very limited, and only the process flows from both production lines are shown in Figure 4-2 and Figure 4-3.

Nevertheless, both plants have a few common aspects; both do not use any raw steel furnace; they use imported steel intermediate products (as billet for Long product plant and slab for Flat product plant); they use reheat-then-finish process train. This would surely impact the result of energy use and CO_2 emission patterns. That is because raw steel furnace, regardless of fuel- or electrical-based, consumes greater amount of energy than reheating furnace.

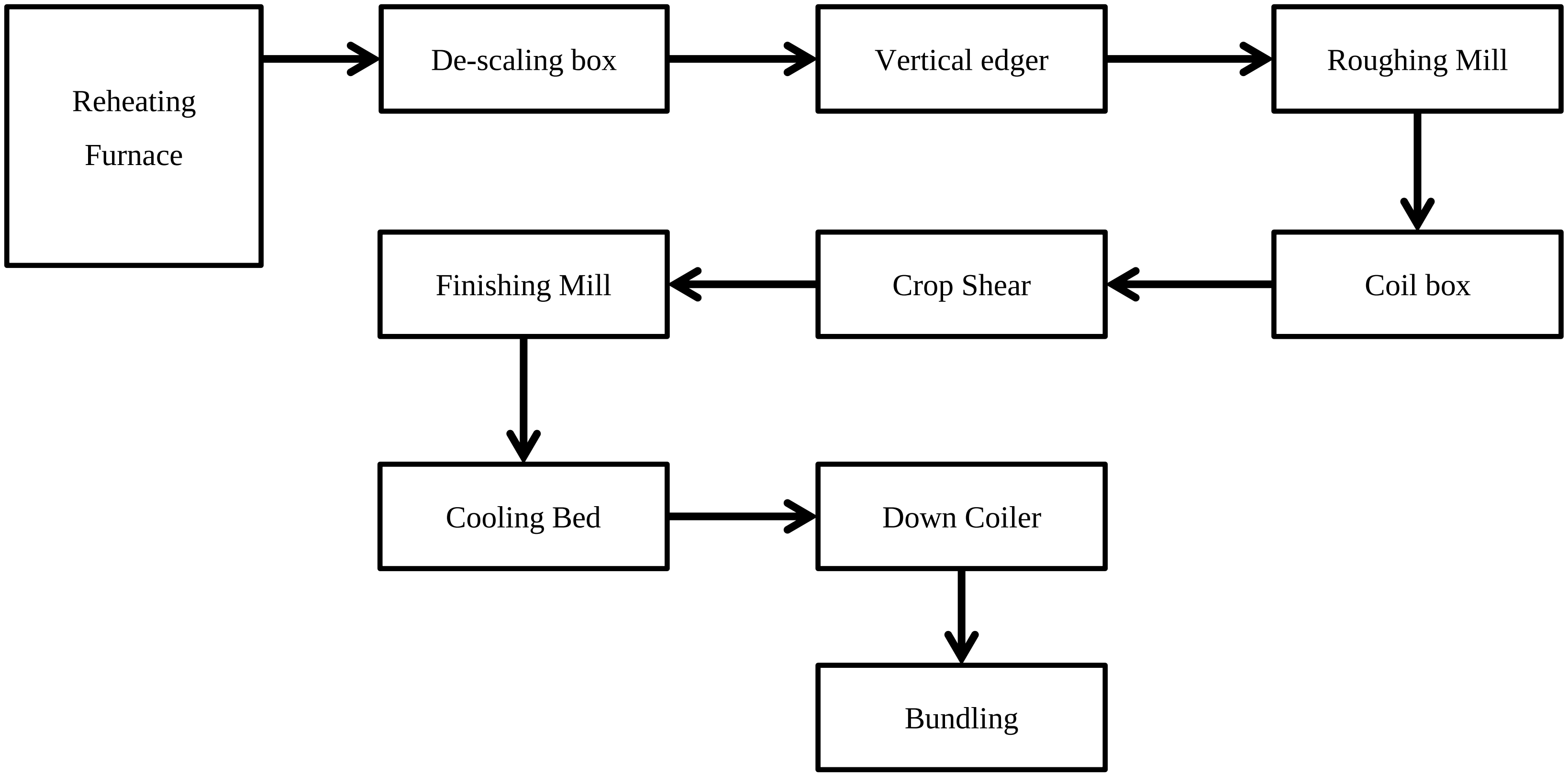


Figure 4-1 Production process diagram of Flat product plant

Table 4-1 Description of processes in Flat product plant

Process name	Process description
Walking Beam Reheating Furnace	The furnace that continuously reheats steel slabs to the temperature of 1,250-1,300˚C, which is the appropriate temperature for rolling. Reheating capacity enable 275 ton of steel to be reheated every hour.
High pressure De-scaling Box	De-scaling box cleans reheated slab with pressurized water (at 160-180 bar) that separates oxide scales from the steel surface. These scales are caused by oxygen contact in high temperature. De-scaling helps prevent the scale to be embedded into the material.
Vertical Edger and Reversing Roughing Mill	Vertical edger reduces the width of heated slab while reversing roughing mill reduces the thickness. Both machine operate simultaneously, with the slab rolled back and forth for 5-7 times until desired thickness and width are achieved. Processed slabs are then called “steel bar”.
Coil box	Since smaller steel bars have a larger surface area than the slabs of the same mass, they are more susceptible to heat loss. Coil box prevent this by coiling the steel bars into thick rough coil. Coiling also serve another propose, that is coiled steel could conduct temperature within its bulk more easily.

Process name	Process description
Crop shear	When heated coiled steel bars are released from coil, two ends of the bar are susceptible to heat loss, so they are quickly solidified. To make the bar suitable for the finishing, these two ends are cut off by this crop shear.
Finishing Mill	Finishing mill adjusts the thickness of steel bar as specified by the order.
Cooling Bed	Cooling bed uses water to conduct heat from the heated strip, decreasing its temperature from 850-900˚C to 650˚C. The cooling process is controlled so that the steel retains its original metallurgy and physical characteristics.
Down Coiler	After the cooling, strips are coiled at down-coiler.
Bundling	Steel strips coils are bounded together by strapping band. They are then weighted and registered. A minuscule portion might be cut as a sample for quality check. The product will then be moved to the storage until it cools to the room temperature.

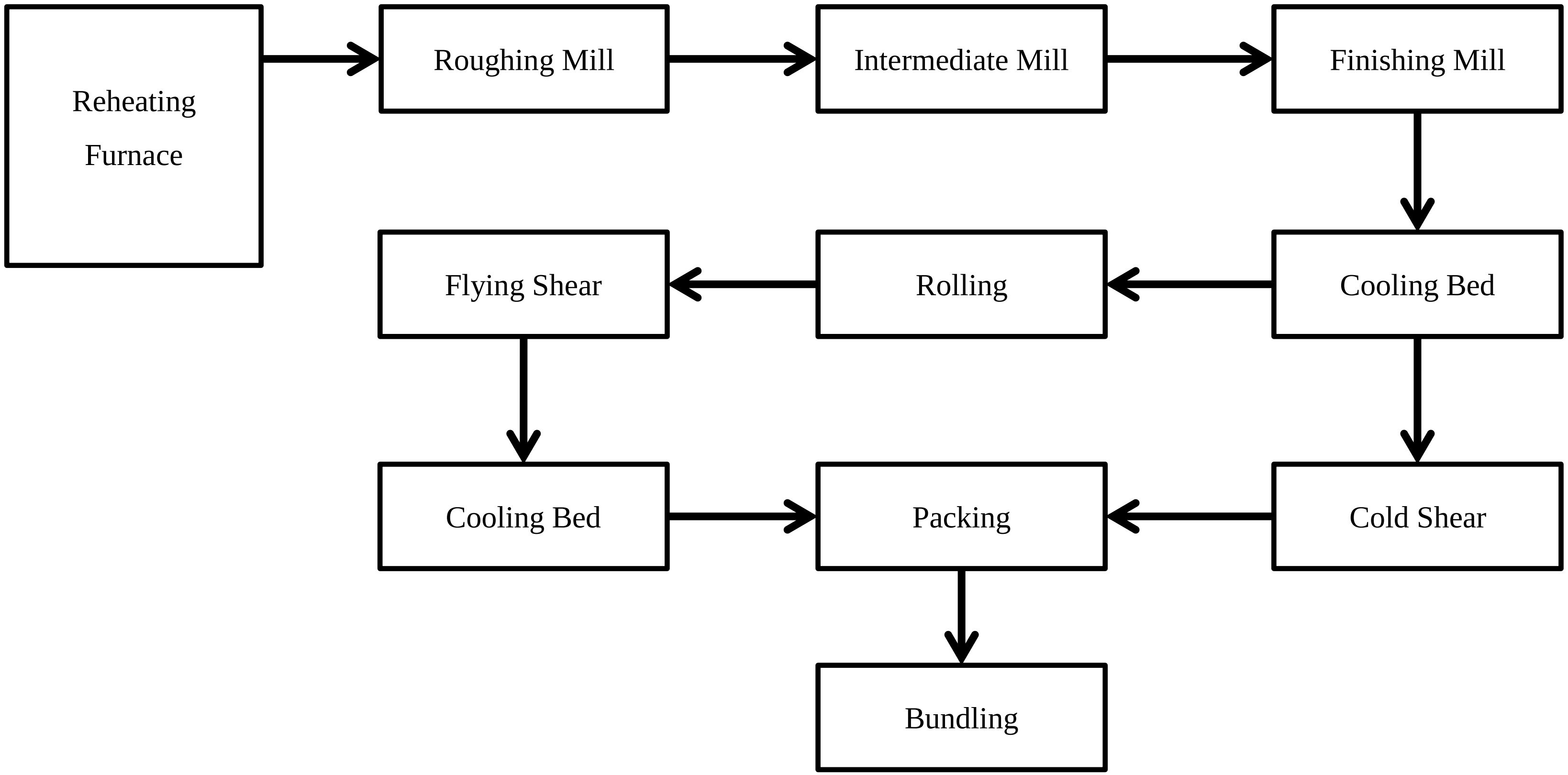


Figure 4-2 Production process diagram of Long product plant – Line 1

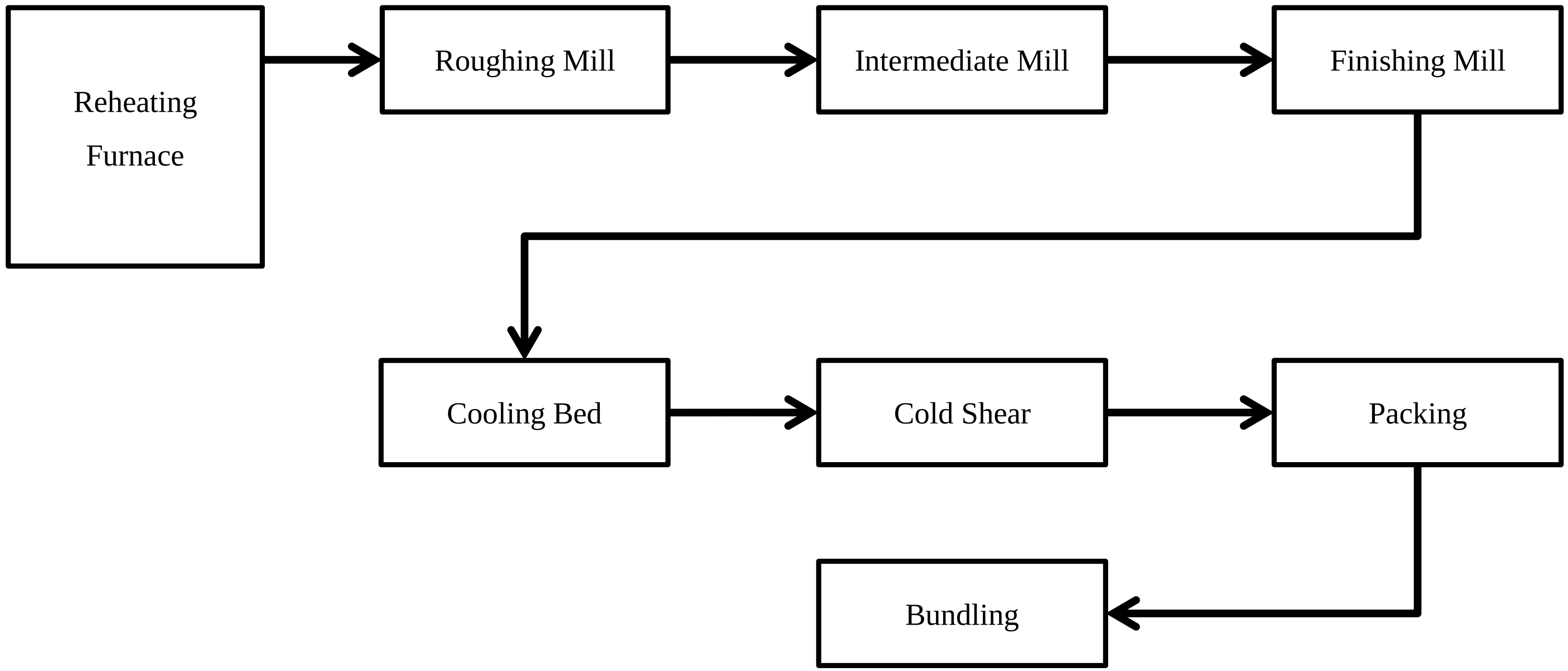


Figure 4-3 Production process diagram of Long product plant – Line 2

4.1.1 Production Data

Production data is shown in Table 4-2 for both plants. It could be seen from the production data that there were significantly different during years. This is in fact due to fluctuation in demand. For instance, in 2008, production of long steel peaked, but significantly dropped in 2009 while flat steel went in opposite direction.

Table 4-2 Production of plants in the study

Year	Flat product plant (Flat Steel)		Long product plant (Long Steel)	
	Production (metric ton)	Raw Material (metric ton)	Production (metric ton)	Raw Material (metric ton)
2007	1,133,026	1,179,923	62,465	64,371
2008	1,044,858	1,087,013	114,652	117,449
2009	1,884,897	1,932,695	88,515	90,623

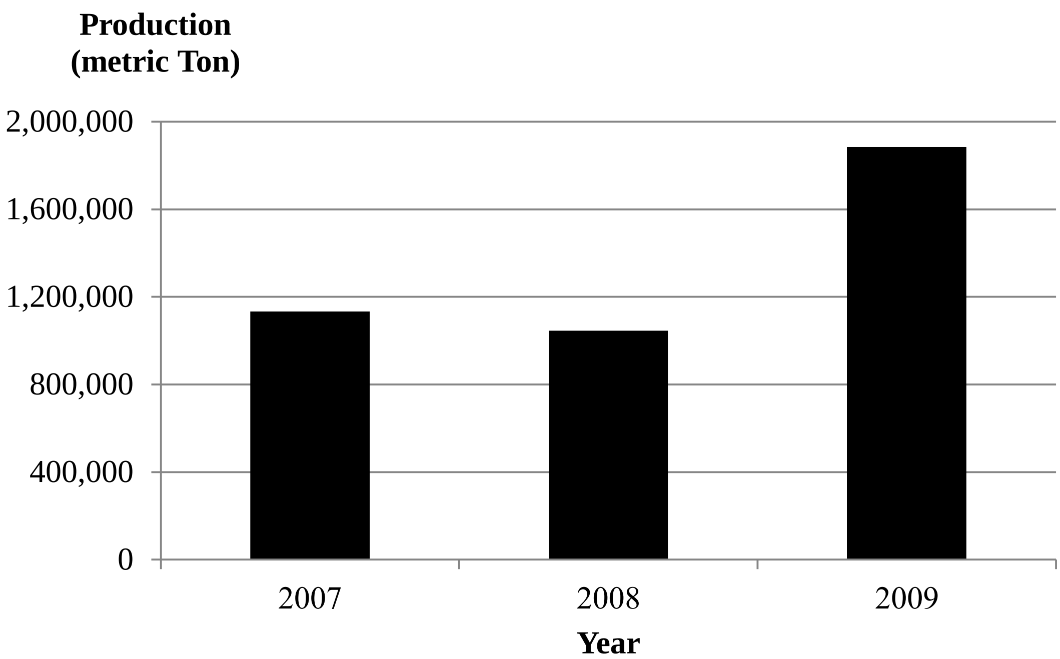


Figure 4-4 Production volume of Flat product plant

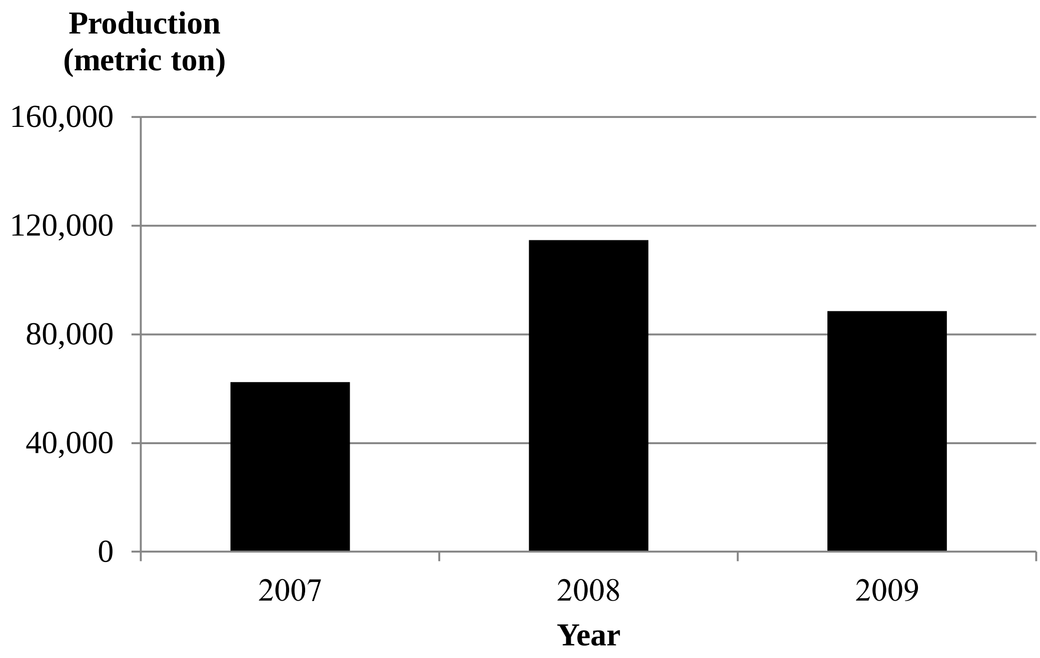
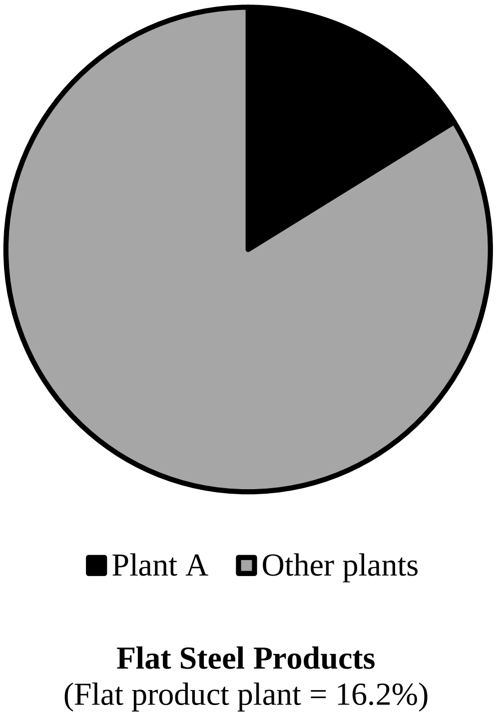


Figure 4-5 Production volume of Long product plant (Flat steel product)

It could also be noted that raw material consumption is slightly higher than the production, which is due to material losses during production. The process in Flat product plant, for example, involves the cropping that cut off two ends of steel bar. For Flat product plant, the losses are 4.0%, 3.9%, and 2.5% of the raw material while losses in Long product plant are 3.0%, 2.4%, and 2.3%. Smaller losses in Long product plant might be due to the fact that processes in smaller plants tend to be easier to control and optimize than those in the larger ones.



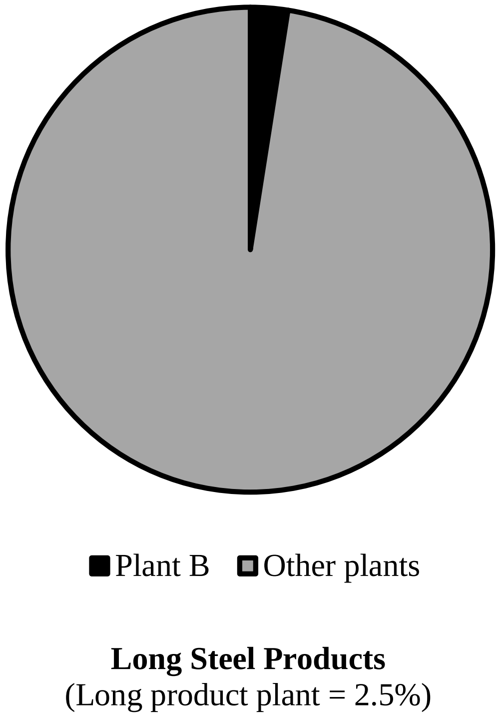


Figure 4-6 The portion of National steel production(2008) that the studied plants contribute**.**

Considering the production volume, it could be implied that one should <u>not</u> universally applies the finding from this research. First of all, production volume of the studied plant are not high compared to national ones (refers to Figure 4-6) and are not representative for the whole national level. Production processes used in each plant are also varied. Most plants in Thailand, for example, produce heat energy using natural gas as fuel while the plants studied use only fuel oil (ISIT, 2009); some plants also produce steel from electric-arc furnace, which consumes far greater energy and more electricity-reliant than Flat product plant and Long product plant that use only reheating. Therefore, emission should be considered on plant-by-plant basis.

4.1.2 Fuel Consumption

Data regarding fuel consumption are shown in Table 4-3, Figure 4-7, and Figure 4-8. Bunker oil class C is used as the only source of heat energy for both plants, so 42.808 MJ/liter, which is the higher heating value of bunker oil C, was used to convert the value into the absolute energy consumption.

Table 4-3 Fuel Consumption of Flat product plant and Long product plant

Year	Flat product plant		Long product plant	
	Fuel consumption (Liters)	**Energy consumption (GJ)**	**Fuel consumption (Liters)**	**Energy consumption (GJ)**
2007	43,046,977	1,842,754.99	2,237,347	95,776.35
2008	40,712,156	1,742,805.97	3,934,526	168,429.19
2009	76,839,848	3,289,360.21	3,002,880	128,547.29

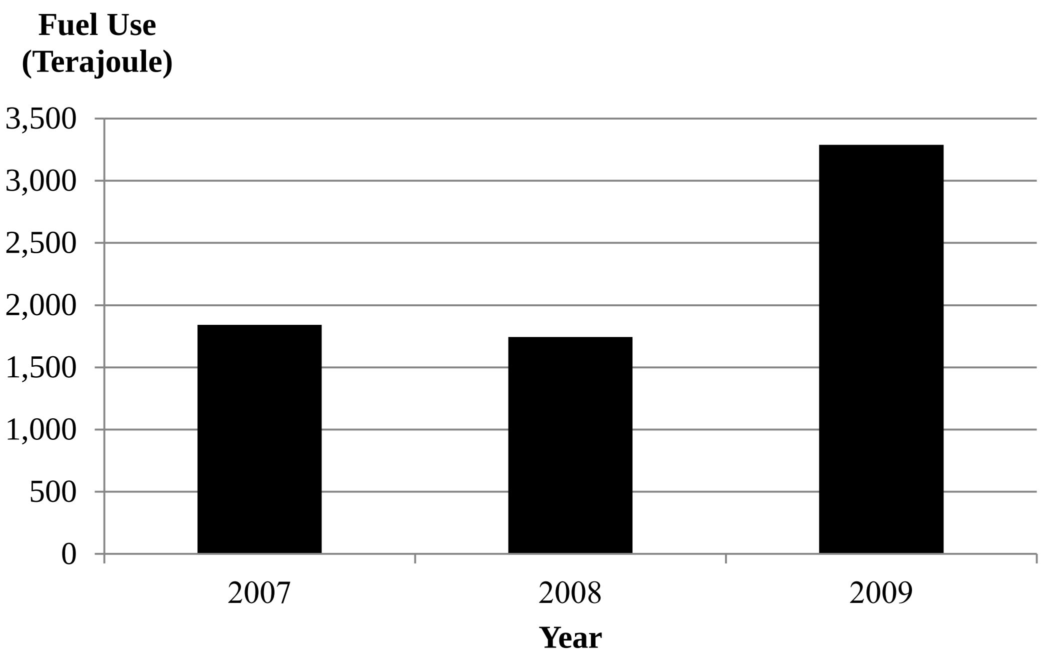


Figure 4-7 Fuel-based energy consumption in Flat product plant

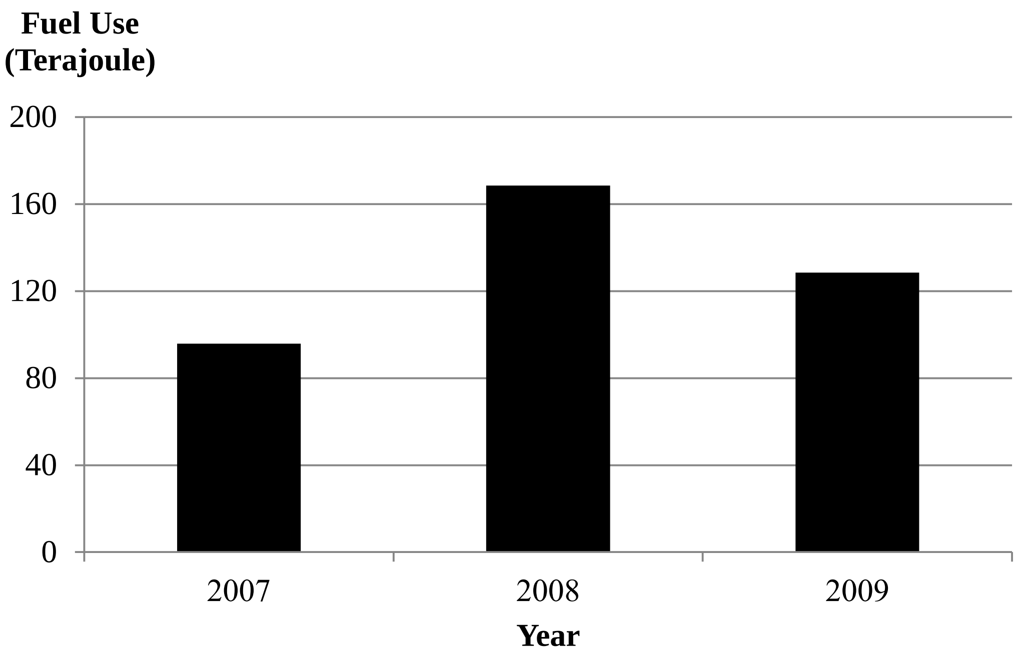


Figure 4-8 Fuel-based energy consumption in Long product plant

4.1.3 Electricity Use

Regarding electricity, amount used for each plant is shown in Table 4-4. The figures in kWh-unit were converted in energy unit of joule for consistency.

Table 4-4 Electricity consumption of studied Plants

	Flat product plant		Long product plant	
Year	Electricity Use (kWh)	Electricity Use (GJ)	Electricity Use (kWh)	Electricity Use (GJ)
2007	134,709,777	484,955.20	6,693,759	24,097.53
2008	124,264,190	447,351.09	11,373,759	40,945.53
2009	197,290,599	710,246.16	7,881,112	28,372.00

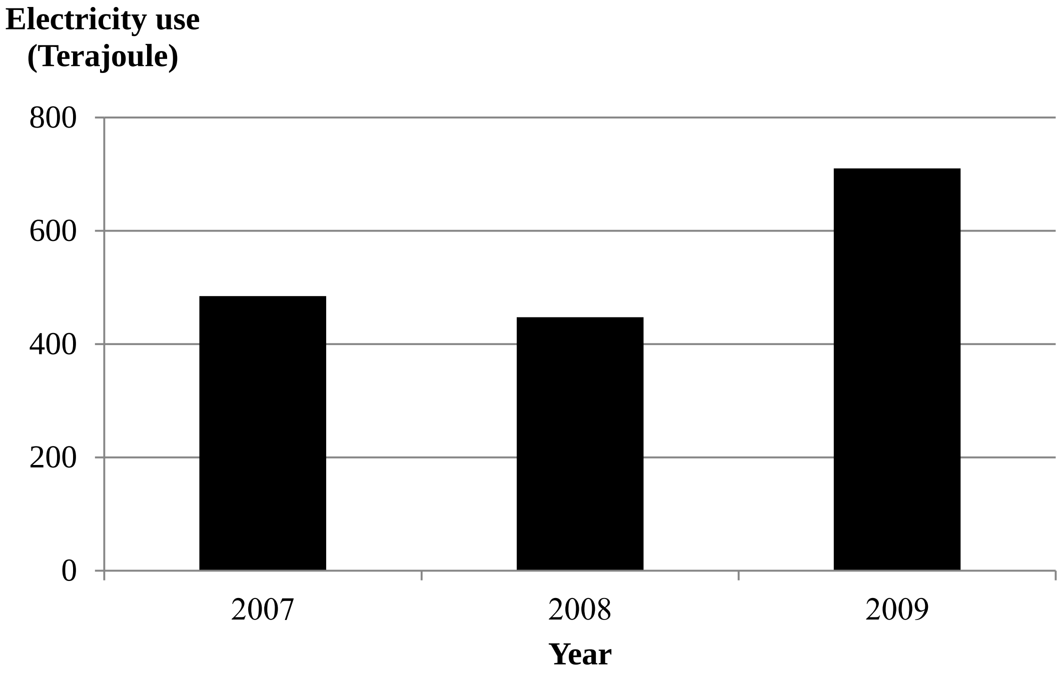


Figure 4-9 Energy consumption in form of electricity in Flat product plant

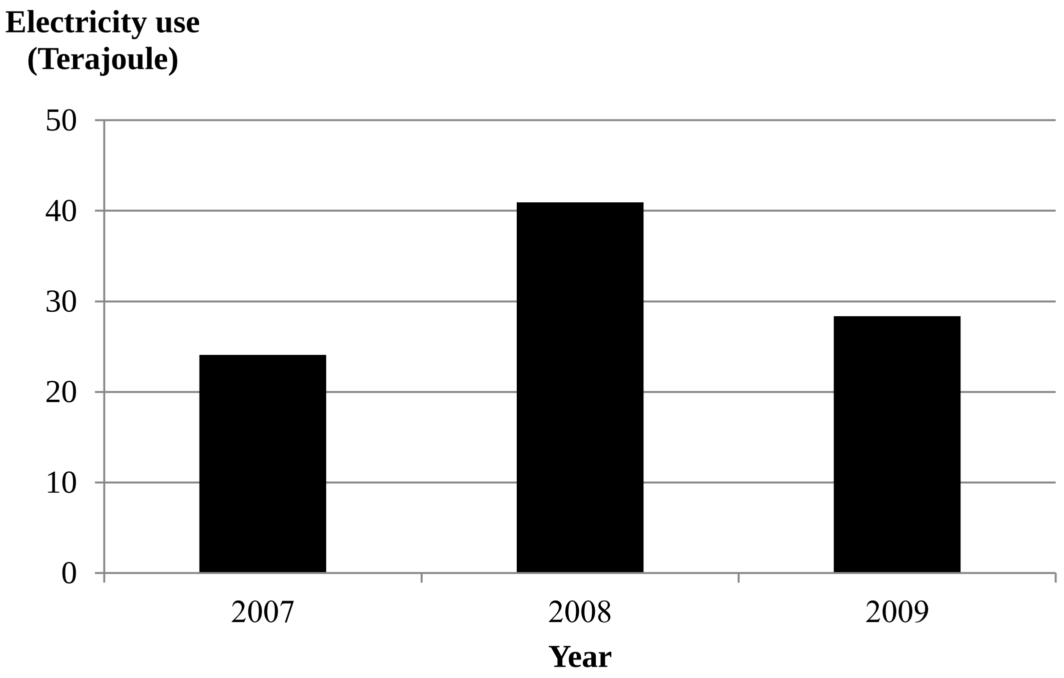


Figure 4-10 Energy consumption in form of electricity in Long product plant

4.1.4 Absolute energy consumption

In this section, two portions of energy use are displayed together to get the overall picture of energy use. The results are shown in Table 4-5Table 4-5 and Table 4-6.

Table 4-5 Absolute energy consumption of Flat product plant

Year	As fuel (GJ)	As electricity (GJ)	Absolute Energy Use (GJ)
2007	1,842,754.99	484,955.20	2,327,710.19
2008	1,742,805.97	447,351.09	2,190,157.06
2009	3,289,360.21	710,246.16	3,999,606.37

Table 4-6 Absolute energy consumption of Long product plant

Year	As fuel (GJ)	As electricity (GJ)	Absolute Energy Use (GJ)
2007	95,776.35	24,097.53	119,873.88
2008	168,429.19	40,945.53	209,374.72
2009	128,547.29	28,372.00	156,919.29

Figure 4-11 comparatively shows the production activity and energy use in both plants. A few points could be observed; first, energy consumption in fuel and electricity form follows the similar trends; secondly, all forms of energy use (fuel, electricity, and total) also follow the similar trend with production amounts.

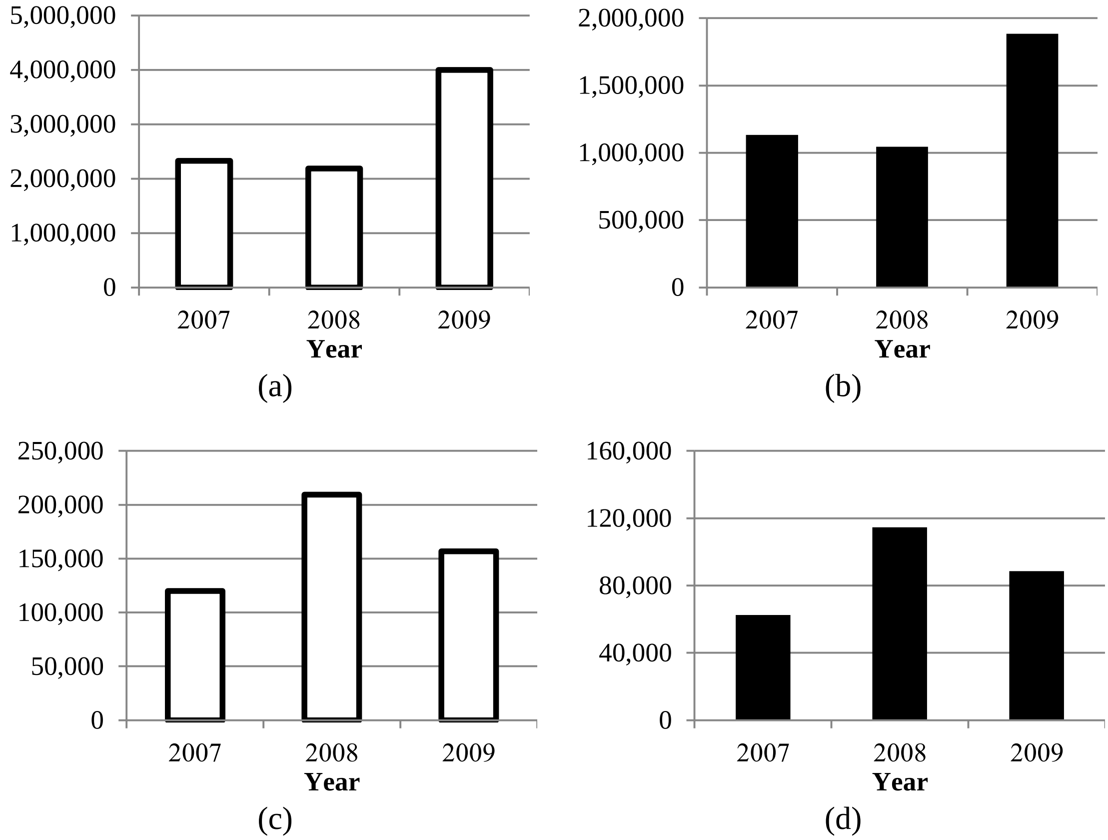


Figure 4-11 (a) Absolute energy consumption of Flat product plant in Terajoule (b) Production of Flat product plant in metric ton (c) Absolute energy consumption of Long product plant in Terajoule (d) Production of Long product plant in metric ton

4.1.4.1 Energy intensity

Energy consumption values were calculated over the production volume and the result are shown in Figure 4-12, Figure 4-13, and Table 4-7.

Table 4-7 Energy intensity of Product

Year	Flat product plant			Long product plant		
	Fuel	Electricity	Total	Fuel	Electricity	Total
	GJ/Ton					
2007	1.626	0.428	2.054	1.533	0.386	1.919
2008	1.668	0.428	2.096	1.469	0.357	1.826
2009	1.745	0.377	2.122	1.452	0.321	1.773

Table 4-8 Energy intensity of Product, percentage

Year	Flat product plant		Long product plant	
	Fuel	Electricity	Fuel	Electricity
2007	79.2	20.8	79.9	20.1
2008	79.6	20.4	80.4	19.6
2009	82.2	17.8	81.9	18.1

It could be seen from the chart that energy intensity values are closes together, but there are some slight increase over the years in case of Flat product plant and slight decrease in Long product plant. However, it is clear that energy required by flat steel product is significantly greater than that required by long steel product (Student’s t-test gave P value of 0.002). This might be due to a variety of factors; for example, plant age (4-year difference between plants), machines conditions, nature of products, technologies applied, operation practices and management.

Nevertheless, the whole flat steel plant requires greater amount of energy due to the fact that its production capacity is greater.

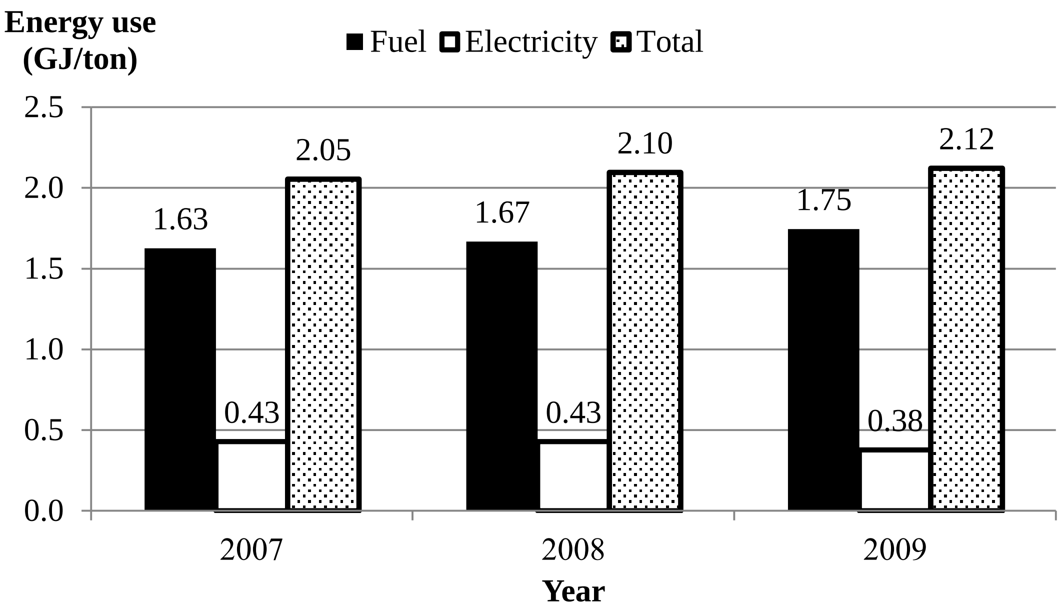


Figure 4-12 Energy intensity from Flat product plant

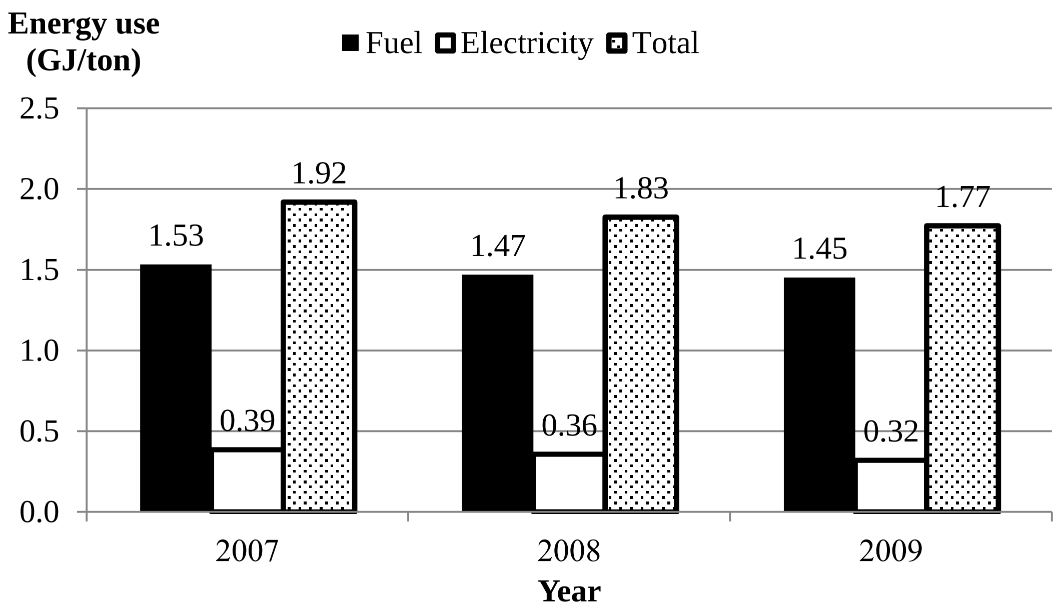


Figure 4-13 Energy intensity from Long product plant

4.1.4.2 Use of linear regression

To better understand the consumption pattern and to be able to make a better prediction, this study attempted to apply mathematical relation models using simple averaging, regression, and slightly more complex linear equations.

In this section, linear regression was used on the energy consumption data. Plotting energy consumption against product volume would lead to a linear trend with slope equals to energy required per a ton of product along with associated R-number.

Table 4-9 Slope and interception obtained using linear regression

		Slope	**Intercept**	**R^2**
		GJ/ton product	GJ	
Flat product plant	Fuel	1.873	-245,463	0.9986
	Electricity	0.308	130,731	0.9986
	Total	2.181	-114732	0.9993
Long product plant	Fuel	1.392	7,643.3	0.9969
	Electricity	0.323	2,545.1	0.9257
	Total	1.715	10188	0.9904

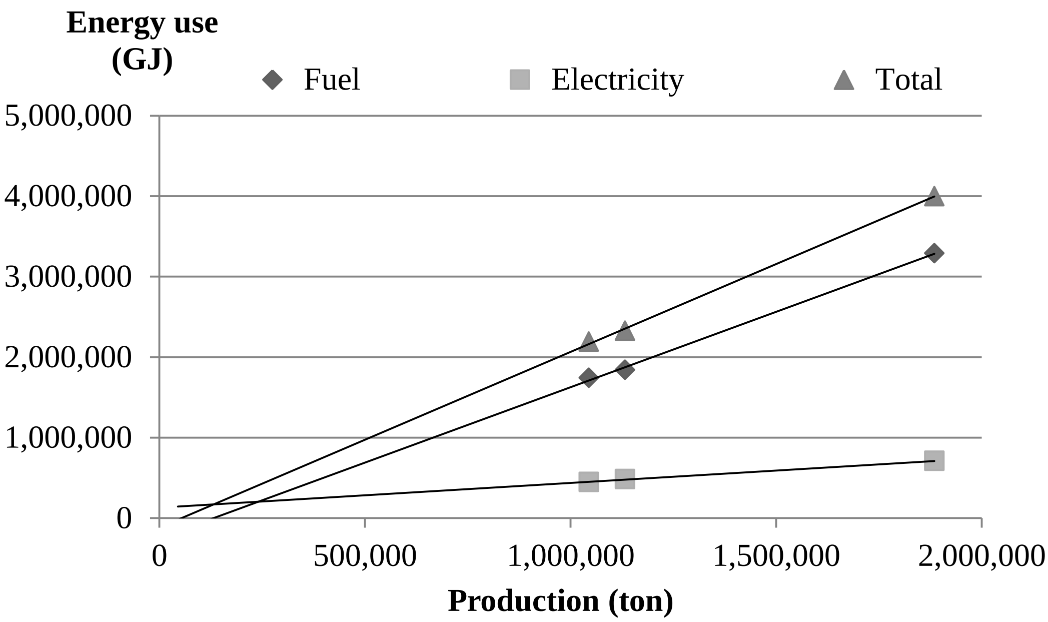


Figure 4-14 Energy use plotted against production in Flat product plant

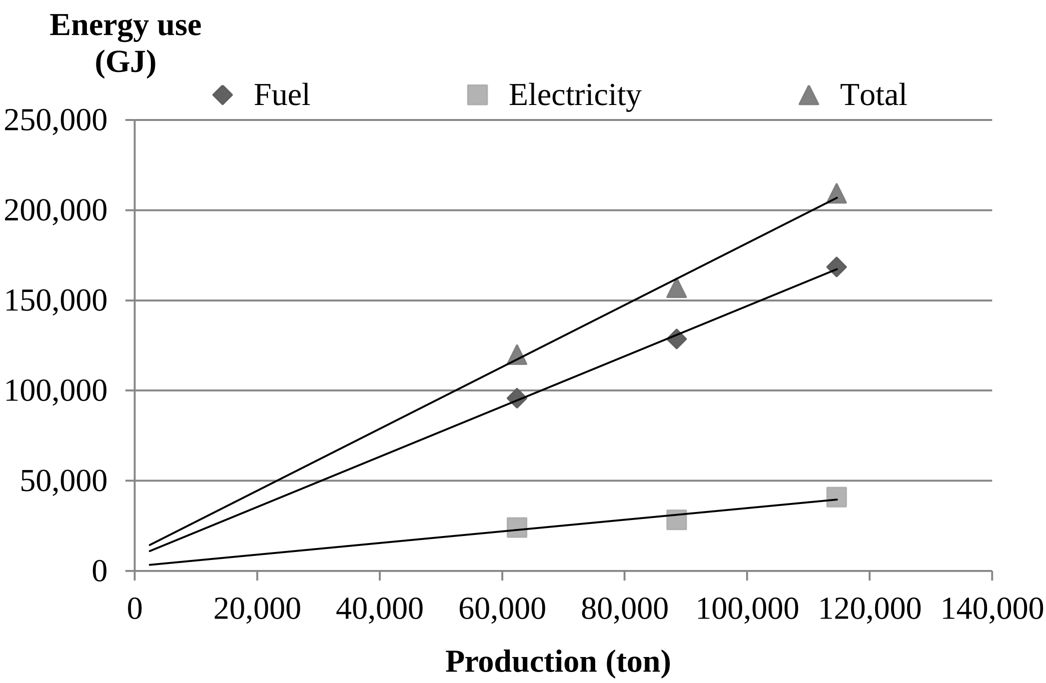


Figure 4-15 Energy use plotted against production in Long product plant

Table 4-9 reports the resulting slopes, interceptions, and corresponding R^2 values. All R^2 values are close to unity which means good correlation. Slope, representing energy consumption by a ton of product, is 1.873 GJ of fuel and 0.308 GJ of electricity for Flat product plant, and 1.392 GJ of fuel and 0.323 GJ of electricity for Long product plant. Note that the values are significantly lower than those obtained by averaging due to the presence of interception term, except in case of Flat product plant with negative interception points. Note that, in fact, negative interception point is practically impossible, since it mean that the plant ‘gains energy’ when nothing is produced. This may be due to inadequacy of the number of the samples used. Therefore, interpretation of negative or positive interception values may not yield meaningful results.

Non-zero interception points that were obtained in linear regression could possibly be implied that the energy used could not be predicted only by the production volumes and there were actually other factors that influence the energy used. These factors will be further identified and discussed in the section regarding emission intensity.

4.2 Carbon dioxide Emission

In this section, greenhouse gas emissions in each case were calculated and then added together, resulting in overall emission from a ton of steel product.

4.2.1 Carbon dioxide intensity

Both fuel and electricity related emissions from Flat product plant and Long product plant are reported in this section. Table 4-10 and Table 4-11 shows the values that were derived using simple averaging.

Table 4-10 CO_2 intensity of flat product plant

Year	**Emission**				
	Fuel		**Electricity**		**Total**
	kg CO_2/ton		kg CO_2/ton		kg CO_2/ton
2007	125.83	64.64%	68.84	35.36%	194.67
2008	129.05	65.48%	68.03	34.52%	197.07
2009	135.01	68.98%	60.71	31.02%	195.72

Producing flat steel product in Flat product plant released 194.67, 197.07 and 195.72 kg CO_2 per ton of product during 2007, 2008 and 2009, respectively. Fuel-based emission contributes to the major portion (65.5-69.0%) as shown in Figure 4-16.

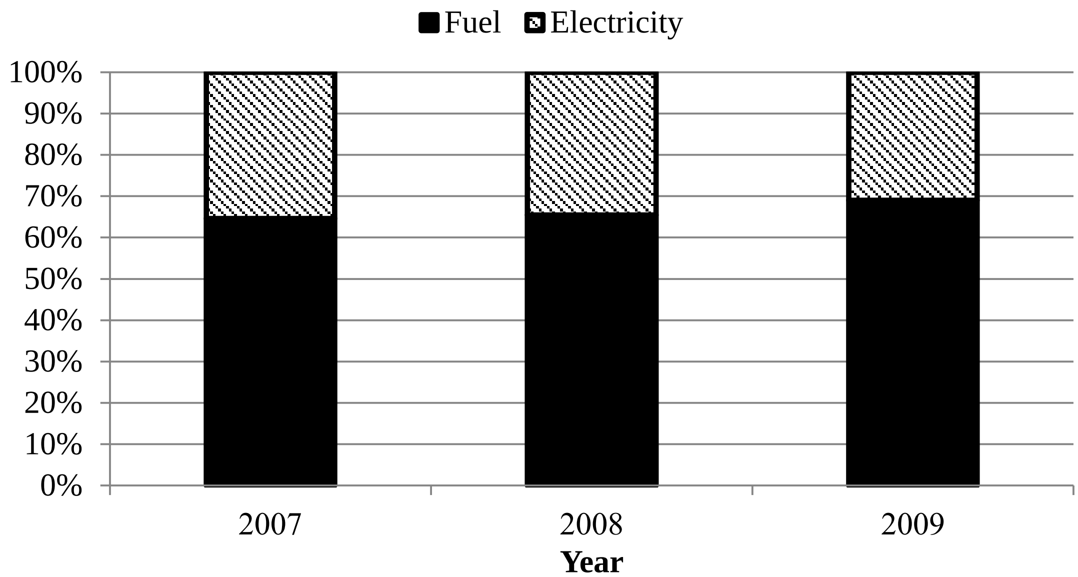


Figure 4-16 Emission contribution from fuel and electricity in Flat product plant

Table 4-11 CO_2 intensity of Long product plant

Year	Emission				
	Fuel		Electricity		Total
	kg CO_2/ton		kg CO_2/ton		kg CO_2/ton
2007	118.62	65.66%	62.05	34.34%	180.67
2008	113.66	66.70%	56.74	33.30%	170.40
2009	112.36	68.51%	51.64	31.49%	164.00

Producing long steel product in Long product plant released 180.67, 170.40 and 164.00 kg CO_2 per ton of product during 2007, 2008 and 2009, respectively. Fuel-based emission, too, contributes to the major portion (65.7-68.5%) as shown in Figure 4-17. Ratio of energy uses is highly similar in both Plants; this might be inherent nature of the industry.

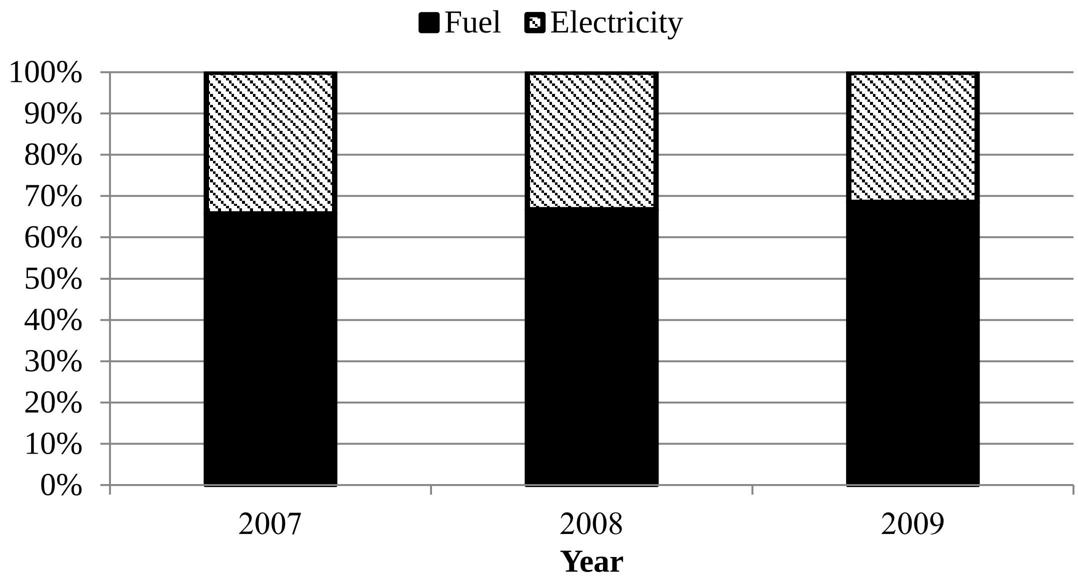


Figure 4-17 Emission contribution from fuel and electricity in Long product plant

Note that averaged emission value of Long product plant displays larger fluctuation than Flat product plant. This might have caused by greater tonnage production volume of Flat product plant that helps average the variation caused by reheating cycles.

4.2.2 Possible factors that influence the emission intensity

Apart from production volume, one of the factors that might have the major impact on energy consumption and carbon dioxide emission is ‘furnace reheating’. Normally, the furnaces that reheat the steel billet and slab need a heat-up period prior to use. The furnace temperature would be increased from room temperature to the operating range, which is 1200-1500˚C. The process, which takes hours, consumes a great amount of energy and may significantly contribute to the consumption and the emission.

Ideally, a plant requires furnace heating to high temperature only once, and then it need comparatively lower energy to maintain it, but when the production line shut down in absence of demand, the furnace cooled down and need to be heated up again to operate.

On the other hand, there also exists the ‘furnace capacity efficiency’ which is the actual furnace efficiency that differs from the efficiency at full capacity. For instance, assume that there is a furnace with 1000 ton capacity operating at 700 ton, these 700-ton of steel will consume as much energy as the amount used for 1000-ton. This will result in nearly 50% increase in energy consumption for this batch.

Thus, it could be said that energy consumed and emission is influenced by at least the amount of production, number of reheating cycles, and capacity efficiency. This could be defined as a function:

$$Energy\ Intensity = f_1(product, efficiency, reheat\ )$$

$$Emission\ Intensity = f_2(product, efficiency, reheat\ )$$

Table 4-12 Explanation for Variables in Energy/emission function

Variable	Description	Unit
Energy Intensity	Energy consumption by producing a ton of steel	GJ
Product	Amount of production	Ton
Efficiency	Energy-related efficiencies including the ‘capacity efficiency’	-
Reheat	Number of reheating cycle in that year	Times

To illustrate the impact of reheating, Table 4-13 shows the production period of each plant. It shows that Long product plant has four cycles in 2007, four in 2008, and two in 2009.

Table 4-13 Operation Period of Long product plant

Year	Month												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	R
2007	R		R		R	O					R		4
2008	R	O	O		R	O	O	O		R		R	4
2009		R	O						R	O	O		2

Note: R is the month with plant running after plant shutdown.

When compare the number of plant shutdown with the emission intensity in each year of Long product plant, it is found to be closely correlated. In 2007 and 2008 where four cycles occurred, emission intensities (180.7 and 170.4 $kgCO_2$/ton) are greater than in 2009 (164.0 $kgCO_2$/ton) where there are only two cycles.

It could be implied from this trend that, years with more plant shutdown tends to have greater carbon dioxide intensity because of high amount of energy required by restarting the process.

To reduce this shutdown-related intensity, a comprehensive annual strategy should be established to reduce the frequency of shutdown as much as possible. This, however, requires cooperation from the whole supply line from the suppliers to consumers, which require intensive efforts.

4.2.3 Absolute plant emission

With CO_2 intensity, total greenhouse gases emission from both Flat product plant and Long product plant are calculated and shown in Table 4-14.

Table 4-14 Absolute CO_2 emission (Unit is in ton CO_2)

Year	Flat product plant			Long product plant		
	Fuel	Electric	Total	Fuel	Electric	Total
2007	142,569	77,998	220,566	7,410	3,876	11,286
2008	134,839	71,082	205,921	13,031	6,505	19,537
2009	254,480	114,432	368,912	9,946	4,571	14,516

Compared with the 2009 statistic (IEA, 2011), Flat product plant and Long product plant contributes to 0.35% and 0.014% of emission from Thailand's industry-related emission and contributes to 0.16% and 0.0064% of national emissions. This value might be minimal, but considering overall steel products in Thailand which is 6.4 megaton of flat steel and 4.6 megatons of long steel, total contribution might be at least three megatons of carbon dioxide.

Benchmarking the emission value with steel industries in other countries is, unfortunately, impractical. Virtually all steel production data are based on the whole life-cycle that involves primary steel productions that are more energy-intensive. Steel production in China, for instance, emitted 2,200 kg of CO_2 per ton of steel. Developed countries, too, produces less amount averaged at 1,800 kg per ton of steel. (Xu and Cang, 2010)

Emission from fuel in this study contributes to approximately two-thirds of overall emission, because fuel is used intensively in heating the steel prior to processing. Electricity, on the other hand, was used primarily in steel machineries.

4.3 Carbon dioxide emission reduction measures

This study chose data from year 2009 to be the case study how the emission could be reduced. Emission from steel production could be classified into two sources: fuel combustion, which is controlled solely by the steel plant, and electricity use, which is controlled by electricity generation entities. This study will discuss the measure to reduce each portion of the emission.

4.3.1 Reduction through energy efficiency

As discussed in section 4.2.3, greenhouse gases emission from HRC steel production, according to EU's benchmark, could be as low as 100 kg/ton, which is nearly 50% lower than emission from the studied plant.

Energy efficiency, in fact, is the simplest and probably the most cost-effective means to reduce the consumption as well as carbon dioxide emission. The techniques required are also commonly known and easy to implement.

A study regarding energy consumption of iron and steel industries in Thailand have found that simple fixes in pilot plants could reduce energy consumption up to 10%, depending on the product type. Flat steel product (similar to Flat product plant) could save 0.09% of energy while Long steel product (similar to Long product plant) could save 1.9%. However, according to a case study from the USA, energy consumption in hot rolling processes could be reduced up to 30%.

Table 4-15, Table 4-16, and Table 4-17 presents energy-saving projects that Flat product plant conducted during 2007-2009; however, these extensive attempts resulted in only 32,295 GJ of fuel and 49,119 GJ of electricity saved, which worth only 5% of the plant's overall consumption in only one year. Therefore, alternative long-term strategy should be applied to achieve that goal of greenhouse gas reduction.

Table 4-15 Attempts to increase energy efficiency in Flat product plant during 2007

Project details	Result			
	Saved Fuel Oil		Saved electricity	
	Litres	GJ	kWh	GJ
1.Controlled lightings	-	-	141,580	509.69
2. Cancel the 'On heater two days prior to starting the furnace' practice	-	-	59,904	215.65
3. Adjusting Automatic Excess Air	-	-	258,877	931.96
4. Modify Center guide FIM F1	-	-	61,200	220.32
5. Modify coupling of RM. Entry Descaling header (top)	-	-	60,750	218.7
6. Installation Secondary Y-Strainer for WR. Cooling Sys. F6	-	-	62,100	223.56
7. VSD for Scrubber Fan at PO Line	-	-	138,240	497.66
8. VSD Cooling Tower CT001	-	-	263,899	950.04
9. Dry Diaphragm	111,422	4769.75	-	-
10. Variable Speed Drive for Combustion Air Fan FUR#1,2	-	-	1,871,555	6737.60

Table 4-16 Attempts to increase energy efficiency in Flat product plant during 2008

Project details	**Result**			
	Saved Fuel Oil		**Saved electricity**	
	Litres	**GJ**	**kWh**	**GJ**
1. Installing Clean Air, Blow Condensing Air at Pulpit	-	-	19,710	70.956
2. Duct modification at RM Motor Room	-	-	185,000	666
3. Reducing Over flow of Laminar tank using VSD command based on LV2 data (VEP003_D,E,F and VEP005_A,B,C)	-	-	2,024,611	7288.60
4. Motor speed controls at pump VEP003 Strip cooling	-	-	690,048	2484.17
5. Motor speed controls at pump VEP005	-	-	136,373	490.94
6. Reducing size of pump CP001	-	-	278,638	1003.10
7. Utilizing Furnazzo chemical enhancer	524,678	22460.42	-	-
8. Installing insulation at Charge-side furnace door	3,287	140.71	-	-
9. Reducing operation time by proportional valve furnace 2	36,600	1566.77	-	-
10. Motor speed controls at pump CP004 (12 bar)	-	-	3,038,119	10937.23
11. Reducing Stage of well No.4 Pump	-	-	866,514	3119.45
12. Electronic Ballast for Office	-	-	12,870	46.33

Table 4-17 Attempts to increase energy efficiency in Flat product plant during 2009

Project details	Result			
	Saved Fuel Oil		Saved electricity	
	Litres	GJ	kWh	GJ
1.Dry Diaphragm Furnace 2	78,433	3357.55	-	-
2.Saving energy of Descaling system by reduce loss in system	-	-	3,169,911	11411.68
3. Motor speed controls at pump CP002 D (Make Up)	-	-	244,877	881.56
4.Installing transparent roof at PO Line	-	-	59,616	214.62

4.3.2 Reduction through fuel switching

As major portion of greenhouse gas emission from steel production could be accounted to fuel burning, switching fuel to the one that emits less carbon dioxide would has a significant impact on total emission. This section will consider two scenarios regarding short-term and long-term plan.

4.3.2.1 Natural Gas

According to the guideline issued by IPCC (2006), natural gas is the fossil fuel with lowest emission. Its default value at 56.1 kg CO_2/GJ is lower than 77.4 kg CO_2/GJ of fuel oil, which means that full substitution would lead to 27.5% decrease in fuel-related emission. Table 4-18 and Table 4-19 displays the emission expected after different level of substitution.

Note that this calculation didn't take any change in energy efficiency due to fuel type into account.

Table 4-18 CO_2 intensity at different substitution levels - flat product, natural gas

Emission	**Emission at fuel substitution level (kg CO_2/ton)**				
	None	**25%**	**50%**	**75%**	**100%**
Fuel	135.01	125.73	116.46	107.18	97.90
		(-6.9%)	(-13.7%)	(-20.6%)	(-27.5%)
Electricity	60.71	60.71	60.71	60.71	60.71
Total	195.72	186.44	177.17	167.89	158.61
		(-4.7%)	(-9.5%)	(-14.2%)	(-19.0%)

Table 4-19 CO_2 intensity at different substitution levels - long product, natural gas

Emission	**Emission at fuel substitution level (kg CO_2/ton)**				
	None	**25%**	**50%**	**75%**	**100%**
Fuel	112.36	104.64	96.92	89.19	81.47
		(-6.9%)	(-13.7%)	(-20.6%)	(-27.5%)
Electricity	51.64	51.64	51.64	51.64	51.64
Total	164.00	156.28	148.56	140.83	133.11
		(-4.7%)	(-9.4%)	(-14.1%)	(-18.8%)

In case of Flat product plant, fuel substitution would lead to up to 19.0% reduction in greenhouse gas emission from original value at 195.72 kg CO_2 to 158.61 kg CO_2 per ton of product. On the other hand, Long product plant could reduce its overall emission up to 18.8% from the original level at 164.00 to 133.11 kg CO_2/ton. Such reduction would possibly lead to 70,000-ton-lower level of plant-wide CO_2 emission, which could be highly significant considering the carbon tax that might be imposed in the future.

Although this study has proven that substituting the fuel oil with natural gas could help reducing the carbon footprint of certain steel product. Natural gas itself has more issue to be concerned over. Natural gas supply in Thailand cannot sustain prolong uses, and needed to be imported. Use of natural gas won’t fully eliminate the fuel-related footprint of steel product. Therefore, it could only be used as a short-term solution to tackle the climate change issue while in long term better alternative must be devised.

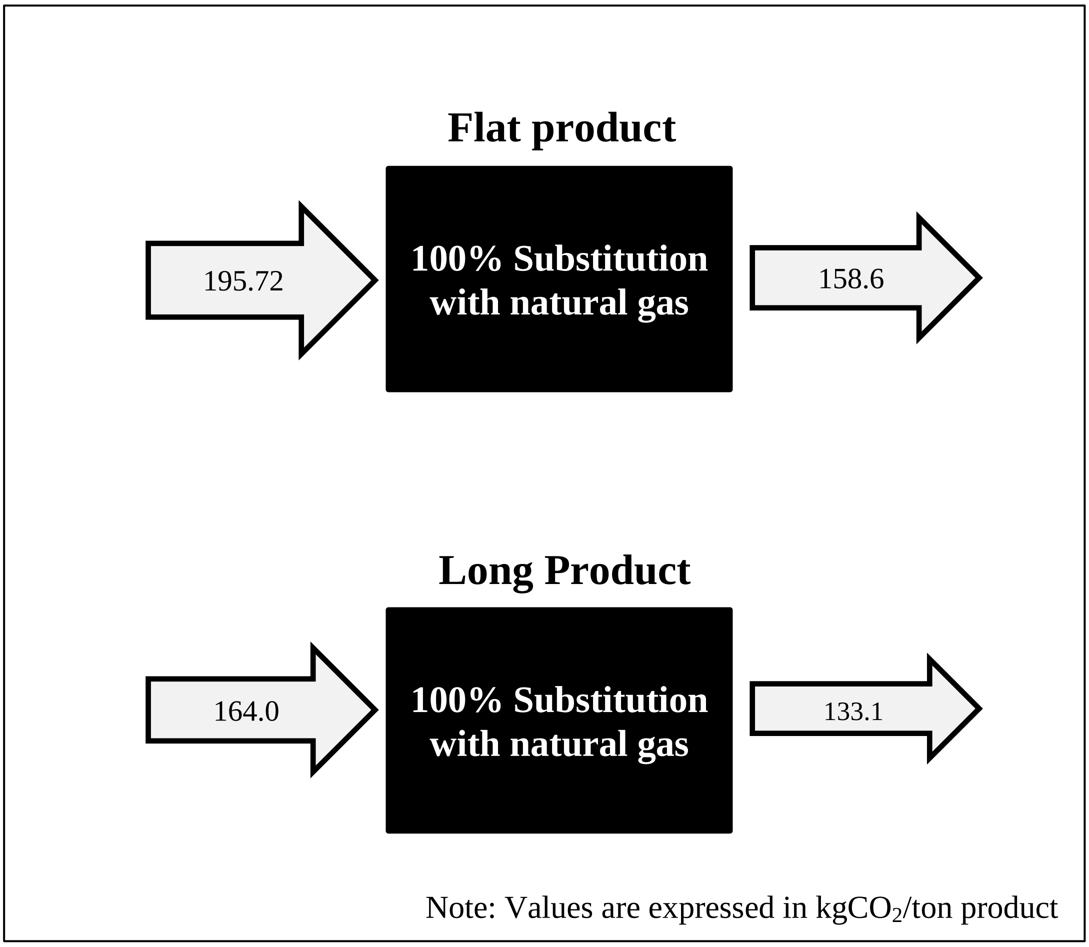


Figure 4-18 CO_2 reduction diagram of natural gas substitution

4.3.2.2 Biomass

DEDE has estimated that Thailand has over a hundred megatons of biomass with energy potential, which is equivalent to 1,382 PJ. However, only 39% of this bulk is commercially consumed, and 61% is still unmanaged and ends up in garbage dump.

Data from DEDE also shows that (refer to Figure 4-19) biomass energy utilization slowly rises in Thailand. However, the potential also grows at a higher rate which might due rising price of palm oil and rubber. Nevertheless, it is clear that utilization need to have a higher growth to catch up with the potential. The potential could also be enhanced by better agricultural management and practice such as improved water management, logistics, disaster prevention, soil improvement, and better land use management.

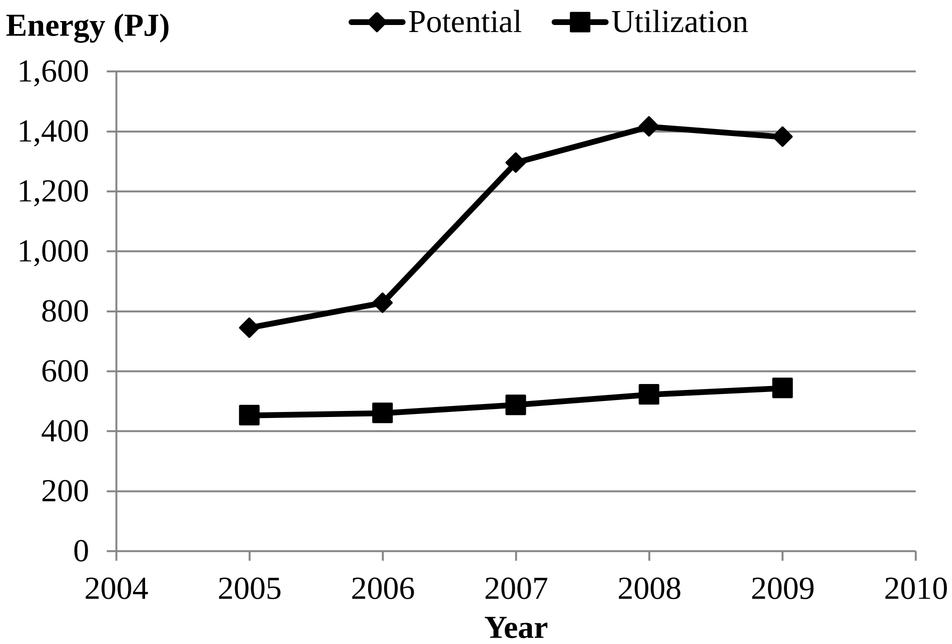


Figure 4-19 Energy potential of biomass and actual usage in Thailand

In steel industry, reduction potential that could be obtained from switching the fuel to biomass is limited only by the proportion of fuel energy in the production. In this study, emission contribution of fuel combustion is as high as two-thirds of total emission that could be entirely eliminated by the switch. That mean emission from flat steel product could be reduced as much as 69.0 % and emission from long product could be reduced as much as 68.5%. Table 4-20 and Table 4-21 show the emission value that could be obtained from such substitutions.

Table 4-20 CO_2 intensity at different substitution levels - Flat product, biomass

Emission	**Emission at fuel substitution level (kg CO_2/ton)**				
	None	**25%**	**50%**	**75%**	**100%**
Fuel	135.01	101.26	67.50	33.75	0
		(-25.0%)	(-50.0%)	(-75.0%)	(-100.0%)
Electricity	60.71	60.71	60.71	60.71	60.71
Total	195.72	161.97	128.21	94.46	60.71
		(-17.2%)	(-34.5%)	(-51.7%)	(-69.0%)

Table 4-21 CO_2 intensity at different substitution levels - long product, biomass

Emission	**Emission at fuel substitution level (kg CO_2/ton)**				
	None	**25%**	**50%**	**75%**	**100%**
Fuel	112.36	84.27	56.18	28.09	0
		(-25.0%)	(-50.0%)	(-75.0%)	(-100.0%)
Electricity	51.64	51.64	51.64	51.64	51.64
Total	164	135.91	107.82	79.73	51.64
		(-17.1%)	(-34.3%)	(-51.4%)	(-68.5%)

This study selected the biomass on energy content basis and local availability, so palm shell (30.6 GJ/ton) and rubber charcoal (28.6 GJ/ton) were selected. Table 4-22 expressed the amount of biomass that would be required to satisfy current level of energy consumption and compare it with the total amount biomass in the region (in '%Local' column). The result shows that Flat product plant will need as much as 14-15% of Southern biomass product while Long product plant needs only a minuscule volume (<1%).

Diagram shown in Figure 4-20 to Figure 4-22 visualize the effect of each reduction measure to the emission intensity (in the unit of $kgCO_2$/ton product).

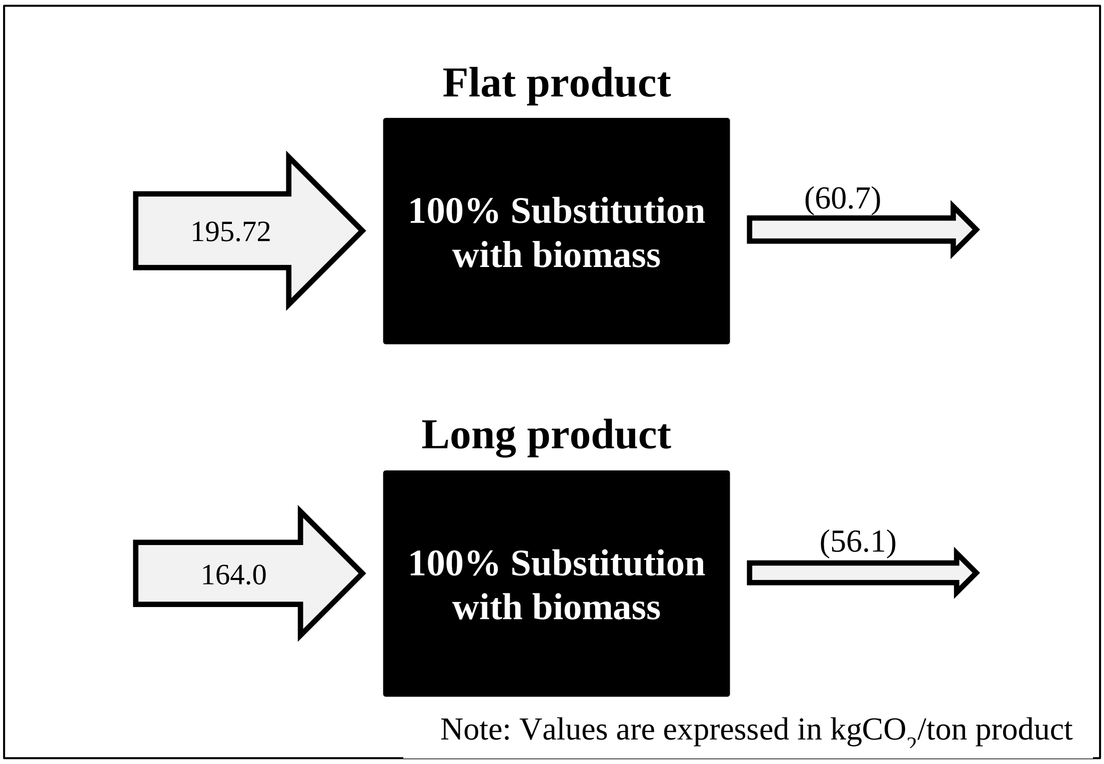


Figure 4-20 CO_2 reduction diagram of biomass fuel substitution

Table 4-22 Amount of biomass required for full fuel substitution

Plant	Energy	Biomass	Amount	%Local
	GJ		Ton	
Flat product	3,289,360	Palm Shell	107,495	14.52
		Rubber charcoal	115,013	15.27
Long product	128,547	Palm Shell	4,201	0.44
		Rubber charcoal	4,494	0.47

It could be implied that in order to successfully use biomass in Flat product plant, an extensive supply chain of biomass should be established. This could pose a challenge considering the geographic obstacle of the region. Alternatively, the industry might opt for naval supply line instead of the land-based route. This also has another advantage, that is naval commerce has comparatively lower carbon footprint than land-based one.

4.3.3 Reduction through electricity shifts

4.3.2.3 Electricity generation from biomass

This scenario is based on an assumption that both steel plants managed to obtain all electricity from biomass, disregarding whether they are from the utilities or generating on-site.

Similar to fuel substitution, impact caused by using biomass-based electricity is limited by the portion of electricity energy used in both plants, 30-35% in this case. However, the point of concern is the amount of biomass required to supply such amount of energy.

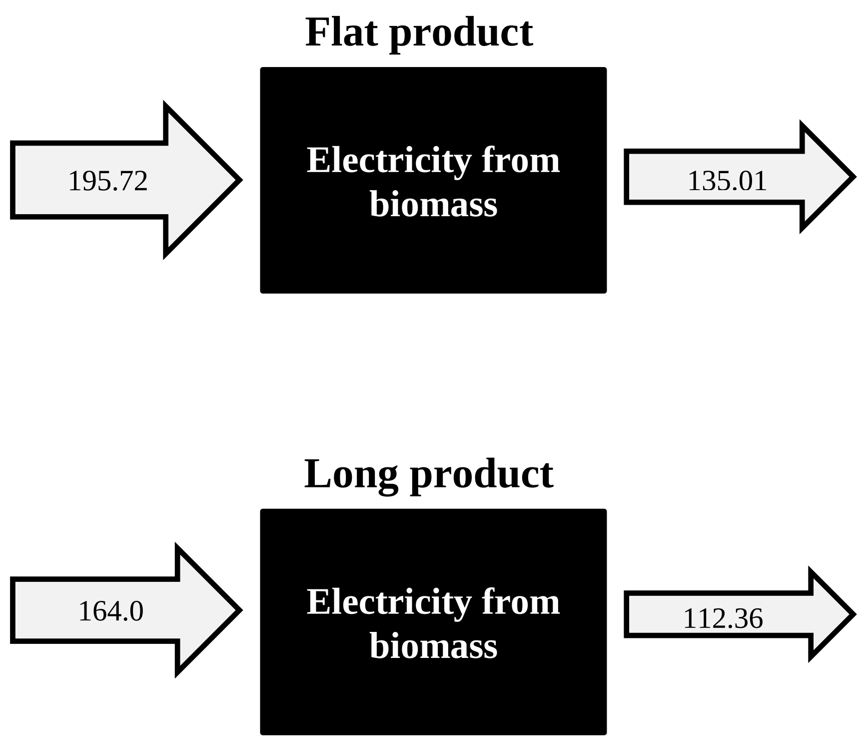
Electricity generation from biomass using conventional techniques usually have efficiency around 20-25%; that is, every 100 GJ worth of biomass burned will results in 20-25 GJ of electricity. This fact means that on GJ-by-GJ basis, electricity generation will consume biomass as much as five times more than heat generation from fuel.

This part, too, selected the biomass on energy content basis and local availability, so palm shell (30.6 GJ/ton) and rubber charcoal (28.6 GJ/ton) were selected. Table 4-23 shows the similar result that Flat product plant will need a somewhat large portion of Southern biomass product while Long product plant needs only a minuscule volume and extensive supply chain should be established.

Note that, some biomass processing techniques might increase the efficiency to 33%, which will result in approximately 40% decrease of required biomass amount.

Table 4-23 Amount of biomass required for complete electricity generation

Plant	Energy	Biomass	Amount	%Local
	GJ		Ton	
Flat product	3,551,230	Palm Shell	116,053	12.05
		Rubber charcoal	124,168	16.48
Long product	141,860	Palm Shell	4,635	0.48
		Rubber charcoal	4,960	0.66



Note: Values are expressed in $kgCO_2$/ton product

Figure 4-21 CO_2 reduction diagram of biomass electricity

4.3.2.4 Reduction according to Power Development Plan

The Ministry of Energy had announced the Power Development Plan (PDP) 2010 which was formulated based on two major purposes: to enhance the energy security of Thailand and to mitigate the global warming effects. The plan was approved by the National Energy Policy Council on March 12, 2010, and validated by the Thai cabinet, on March 23 of the same year. The PDP aims to reduce dependency on natural gas use from 68.1 percent in 2010 to 24.8 percent in 2030. During the same period, it will promote electricity from renewable sources from 12.3 percent to 25.5 percent, and nuclear power from 0 to 11 percent. Such changes in energy proportion will cause a positive effect on the grid emission factor.

Table 4-24 and Table 4-25 shows CO_2 emission from the production of steel product that would result from the implementation of PDP2010. Emission factors for each year are obtained from the PDP report.

Table 4-24 Emission expected from PDP2010 implementation, Flat product plant

	Emission (kg CO_2/ton)			
	2009	**2015**	**2021**	**2030**
Fuel	135.01	135.01	135.01	135.01
Electricity	60.71	46.89	39.15	38.52
		(-22.8%)	(-35.5%)	(-36.5%)
Total	195.72	181.9	174.16	173.53
		(-7.0%)	(-11.0%)	(-11.3%)

Table 4-25 Emission expected from PDP2010 implementation, Long product plant

	Emission (kg CO_2/ton)			
	2009	**2015**	**2021**	**2030**
Fuel	112.36	112.36	112.36	112.36
Electricity	51.64	39.89	33.30	32.77
		(-22.8%)	(-35.5%)	(-36.5%)
Total	164.00	152.25	145.66	145.13
		(-7.2%)	(-11.2%)	(-11.5%)

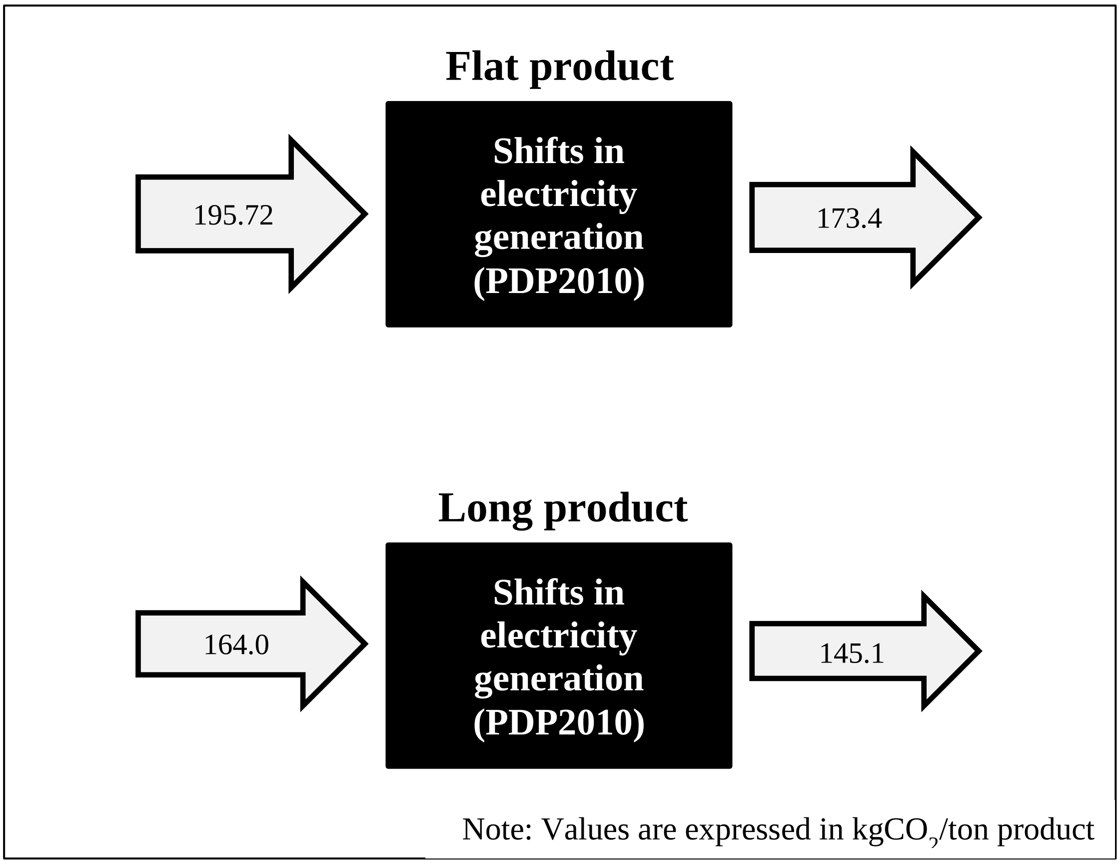


Figure 4-22 CO_2 reduction diagram according to PDP2010 plan

Implementation of PDP 2010 would reduce CO_2 emission to 173.53 kg CO_2 per ton of flat steel product in Flat product plant in 2030 or 11.5 percent reduction from the 2008 level or 36.55 percent reduction from the 2009 electricity-related emission. For long steel product in Long product plant, Implementation of PDP 2010 would reduce CO_2 emission to 145.13 kg CO_2 per ton of long steel product in 2030, which equal 11.5 percent reduction from the 2008 level or 36.54 percent reduction from the 2009 electricity-related emission. These values are considered low compared to those reduced by fuel switching, but if considered nationally, this could amount to another megaton of CO_2 that could be reduced.

Maximum reduction scenario applies both 2030 national grid emission and biomass substitution. The results are shown in Table 4-26 and Table 4-27.

Table 4-26 Maximum possible reduction of Flat product plant

	Baseline (2009)	**PDP2010 with fuel switching at 2030**	**Reduction from baseline**
	kg CO_2/ton	kg CO_2/ton	
Fuel	135.01	0	100%
Electricity	60.71	38.52	36.55%
Total	195.72	38.52	80.31%

Table 4-27 Maximum possible reduction of Long product plant

	Baseline (2009)	**PDP2010 with fuel switching at 2030**	**Reduction from baseline**
	kg CO_2/ton	kg CO_2/ton	
Fuel	112.36	0	100%
Electricity	51.64	32.77	36.55%
Total	164.00	32.77	80.01%

4.3.4 Summary

Ideally, when biomass is used as the sole energy source, the overall amount of GHG emission would be minimized at the cost of a very large amount of biomass that should be supplied. Flat product plant, in this case, must avoid such over-reliance on one type of biomass by utilizing a variety of fuel in the supply chain. Plant owner, moreover, should make sure that the plants are prepared for different fuel types.

Table 4-28 shows the amount of biomass that would be required for the complete substitution of biomass into energy aspect of the production process. The amount may be high compared to the local stock (nearly 30%), but the supply overstretch could be prevented by better resource allocation due to the fact that Thailand also has many other residue-based biomass sources.

Table 4-28 Biomass required to completely substitute the energy of steel production

Plant	Energy required	Biomass	Amount	%Local
	GJ		Ton	
Flat product	3,551,230	Palm Shell	223,549	29.7
		Rubber charcoal	239,182	31.8
Long product	141,860	Palm Shell	8,837	0.92
		Rubber charcoal	9,455	0.98

Figure 4-23 illustrate the possible CO_2 reduction measures for steel products that were discussed in this study. It is clear that since most emission is fuel-related, this part of the bulk should be addressed as a first priority. However, in other plants with different characteristics (EAF plant, for example), the strategy should be revised prior to the application due to different in emission pattern.

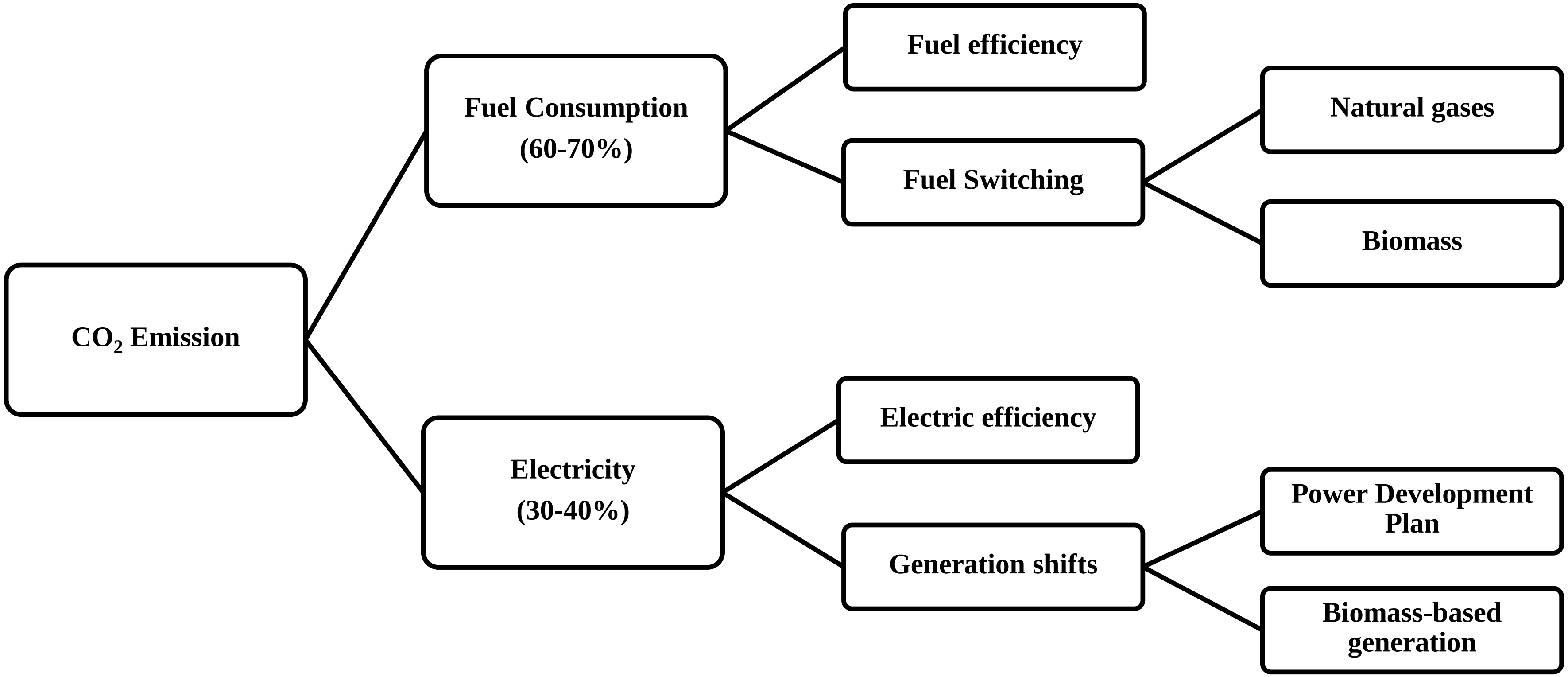


Figure 4-23 Strategies to reduce CO_2 emission from steel product

4.4 Calculation formula for the expected reduction

In the previous sections, expected after-substitution emission values were calculated in case-by-case basis. However, a pattern is found during the calculation: fuel-related and total emission linearly decrease with the substitution level. This section is an attempt to define this pattern using mathematical derivation.

4.4.1 Derivation

Table 4-29 shows the nomenclature used in this derivation.

Table 4-29 Nomenclatures used in the derivation

Names	Description
$E_{fuel,base}$	Pre-substitution baseline emission from fuel burning
$E_{fuel,sub}$	Post-substitution resulting emission from fuel burning
$E_{total,base}$	Pre-substitution baseline total emission from the production
$E_{total,sub}$	Post-substitution resulting total emission from the production
$f_{fuel,oil}$	Fraction of fuel energy that are supplied by fuel oil
$f_{fuel,sub}$	Fraction of fuel energy that are supplied by fuel substitute
f_{fuel}	Fraction of emission from fuel burning
$f_{electricity}$	Fraction of emission from electricity use
EF_{oil}	Emission-related factor of fuel oil (in this case: carbon content of 21.1 kg C/GJ)
EF_{sub}	Emission-related factor of substitution (in this case: carbon content of 15.3 kg C/GJ for natural gas or 0 kg C/GJ for biomass)
$Reduction_{fuel}$	Fractional reduction of emission from fuel burning
$Reduction_{total}$	Fractional reduction of total emission

Fuel-related emission after substitution ($E_{fuel,sub}$) could be defined as

$$E_{fuel,sub} = E_{fuel,base} f_{fuel,oil} + E_{fuel,base} f_{fuel,sub} \frac{EF_{sub}}{EF_{oil}}$$

$$E_{fuel,sub} = E_{fuel,base} \left(f_{fuel,oil} + f_{fuel,sub} \frac{EF_{sub}}{EF_{oil}} \right)$$

And fractional reduction could be defined as

$$Reduction_{fuel} = 1 - \frac{E_{fuel,sub}}{E_{fuel,base}}$$

$$Reduction_{fuel} = 1 - (f_{fuel,oil} + f_{fuel,sub} \frac{EF_{sub}}{EF_{oil}})$$

Substituting $f_{fuel,oil}$ with (1 - $f_{fuel,sub}$) and the EF with their real values gives

If substitute with natural gas:

$$Reduction_{fuel} = 1 - \left(\left(1 - f_{fuel,sub}\right) + f_{fuel,sub} \frac{15.3}{21.1} \right)$$

$$Reduction_{fuel} = 1 - \left(1 - f_{fuel,sub} + 0.725 f_{fuel,sub}\right)$$

$$Reduction_{fuel} = 0.275 f_{fuel,sub}$$

If substitute with biomass

$$Reduction_{fuel} = 1 - \left(\left(1 - f_{fuel,sub}\right) + f_{fuel,sub} \frac{0}{21.1} \right)$$

$$Reduction_{fuel} = 1 - \left(1 - f_{fuel,sub}\right)$$

$$Reduction_{fuel} = f_{fuel,sub}$$

Considering the whole emission:

$$E_{total,base} = E_{fuel,base} + E_{electricity}$$

The emission after fuel substitution would equals to

$$E_{total,sub} = E_{fuel,base}(1 - Reduction_{fuel}) + E_{electricity}$$

Note that both E_{fuel} and $E_{electricity}$ could be expressed as the fraction of baseline total emission

$$E_{fuel,base} = E_{total,base} f_{fuel}$$

$$E_{electricity} = E_{total,base} f_{electricity}$$

Where

$$f_{electricity} = 1 - f_{fuel}$$

Which means that

$$E_{electricity} = E_{total,base}(1 - f_{fuel})$$

Substituting these into the first equation:

$$E_{total,sub} = E_{total,base} f_{fuel}(1 - Reduction_{fuel}) + E_{total,base}(1 - f_{fuel})$$

$$E_{total,sub} = E_{total,base}\left(f_{fuel}(1 - Reduction_{fuel}) + (1 - f_{fuel})\right)$$

$$E_{total,sub} = E_{total,base}(f_{fuel} - f_{fuel} Reduction_{fuel} + 1 - f_{fuel})$$

$$E_{total,sub} = E_{total,base}(1 - f_{fuel} Reduction_{fuel})$$

And the reduction in total emission could be defined as

$$Reduction_{total} = 1 - \frac{E_{total,sub}}{E_{total,base}}$$

$$Reduction_{total} = 1 - (1 - f_{fuel} Reduction_{fuel})$$

If substitute with natural gas, $Reduction_{fuel}$ would be replaced with natural gas term:

$$E_{total,sub} = E_{total,base}(1 - 0.275 f_{fuel} f_{fuel,sub})$$

$$Reduction_{total} = 1 - \left(1 - 0.275 f_{fuel} f_{fuel,sub}\right)$$

$$Reduction_{total} = 0.275 f_{fuel} f_{fuel,sub}$$

If substitute with biomass, $Reduction_{fuel}$ would be replaced with biomass term:

$$E_{total,sub} = E_{total,base}\left(1 - f_{fuel} f_{fuel,sub}\right)$$

$$Reduction_{total} = 1 - \left(1 - f_{fuel} f_{fuel,sub}\right)$$

$$Reduction_{total} = f_{fuel} f_{fuel,sub}$$

The formulae were summarized in Table 4-30.

Table 4-30 Formulae to calculate emission and reduction after fuel substitution

	Fuel-related emission	**Total emission**
Natural gas		
Emission	$E_{fuel,base} \times (1 - 0.275 \times f_{fuel,sub})$	$E_{total,base} \times (1 - 0.275 \times f_{fuel,sub} \times f_{fuel})$
Reduction	$0.275 \times f_{fuel,sub}$	$0.275 \times f_{fuel,sub} \times f_{fuel}$
Biomass		
Emission	$E_{fuel,base} \times (1 - f_{fuel,sub})$	$E_{total,base} \times (1 - f_{fuel,sub} \times f_{fuel})$
Reduction	$f_{fuel,sub}$	$f_{fuel,sub} \times f_{fuel}$

4.4.2 Sample calculation

This section will illustrate how to use the formulae in Table 4-30 to calculate the emission.

Case 1: Plant A, 25% substitution of natural gas

$E_{fuel,base}$ = 135.01 kg CO_2/ton

$E_{total,base}$ = 195.72 kg CO_2/ton

$f_{fuel,sub}$ = 0.25 (25% substitution)

f_{fuel} = 135.01/195.72 = 0.6898

Fuel-based emission $= E_{fuel,base} \times (1 - 0.275 \times f_{fuel,sub})$

$= 135.01 \times (1 – 0.275 \times 0.25)$

$= 135.01 \times 0.93125 = 125.73$ kgCO_2/ton

Total emission $= E_{total,base} \times (1 - 0.275 \times f_{fuel,sub} \times f_{fuel})$

$= 195.72 \times (1 – 0.275 \times 0.6898 \times 0.25)$

$= 195.72 \times 0.95258 = 186.44$ kgCO_2/ton

Which are the same values presented in the Table 4-18.

Case 2: Plant B, 75% substitution of biomass

$E_{fuel,base}$ = 112.36 kg CO_2/ton

$E_{total,base}$ = 164.00 kg CO_2/ton

$f_{fuel,sub}$ = 0.75 (75% substitution)

f_{fuel} = 112.36 /164.00 = 0.6851

Fuel-based emission $= E_{fuel,base} \times (1 - f_{fuel,sub})$

$= 112.36 \times (1 – 0.75)$

$= 112.36 \times 0.25 = 28.09$ kgCO_2/ton

Total emission $= E_{total,base} \times (1 - f_{fuel,sub} \times f_{fuel})$

$= 164.00 \times (1 – 0.6851 \times 0.75)$

$= 164.00 \times 0.48618 = 79.73$ kgCO_2/ton

Which are the same values presented in the Table 4-21.

4.5 Data Quality Discussion

Data used to calculate the carbon footprints in this study is secondary data, and could subjected to uncertainties that were partly listed in Table 4-31.

Table 4-31 Possible uncertainties in the calculation of greenhouse gas emission

Portions	Variables	Uncertainties
Fuel-based	Energy Content (DEDE, 2010)	The values are globally averaged without considering regional variations
	Carbon Content (IPCC, 2006)	The values are globally averaged without considering regional variations
	Other greenhouse gases	Other greenhouse gases, which were not included in the calculation, could be produced from incomplete combustion or other events
Electricity-based	Grid emission factors (EGAT,PDP2010)	The factors were calculated from various electricity sources of different types and sizes; each of them has their own uncertainties and variations

Ideally, direct real-time measurement of greenhouse gas emission would give the actual value, assuming that the measurement tools are properly calibrated and validated. However, greater cost and effort requirements are considered prohibitive.

There are also “middle ground” methods that include well-planned timed sampling according to data quality standard.

Nevertheless, the method employed in this study could still be used with the uncertainties minimized. Uncertainties in the fuel-related variables (fuel energy content and carbon content), for example, could be reduced by testing and measuring the fuels that were actually used by the plants. The values obtained are then used to calculate the emission instead of the globally averaged ones that were used in this study.

Uncertainties in electricity-related emission, on the other hand, are harder to determined due to the fact that the emission factors given by the power companies does not have any accompanied uncertainties values. Moreover, the variation and number of plants are not likely to be incorporated into the formulation of these factors, and this aspect of the emission should be treated carefully.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

In this section, the key points of this study regarding carbon footprint of steel products were summarized as follows:

1. During 2007-2009, average footprint of flat product is equal to 195.81 kg CO_2 per ton product, while the average footprint of long product is equal to 171.69 kg CO_2 per ton product. Producing flat steel in this period results in 8-18% greater emission amount than the long steel, which might be due to the difference in technologies employed in the studied plants.
2. Emission related to fuel combustion forms the major constituency in the footprint. This might amount as much as 60-70% of total value. This is due to the fact that great amount of fuel was consumed to reheat the materials to the desirable working temperature at 1500˚C.

Then, this study has assessed possible methods to reduce the footprint of such products. The points found regarding carbon footprint reduction were:

1. Even though the energy efficiency improvements might have reduced the energy consumption, they cause minimal impact to the footprints (approximately 5% reduction over three-year worth of improvements). To cope with growth in production, more substantial footprint reduction techniques should be established.
2. Fuel switching from bunker oil into natural gas could reduce CO_2 emission by as much as 19% in both products. However, the future of continuous natural

gas supply is doubtful, so it should be used for only a short-term while longer-term solution should be devised.

3. Switching to biomass, which is stated to be zero-emission, could virtually eliminate all fuel-related emission from the carbon footprint, which is as much as 68%. Biomass also holds advantages on vibrant supply and variety in Thailand. Moreover, biomass could be used as electricity-generating fuel which will further reduce the footprint of the product. However, care should be taken in the utilization of biomass. Issues of land uses, forest carbon sink, bioethical, economics, and society should also be addressed and minimized.
4. Power development plant (PDP2010) shows that Thailand already focuses on the cleaner development. If successfully implemented, carbon footprint of steel could be reduced as much as 11.5%. This is due to more emphasis on nuclear power and renewable energy.

This study has found that, in order to reduce the overall footprint of steel products, two possible means are available. One of them, the almost painless shift to energy efficiency and cleaner conventional fuels, requires long timeframe with multiple small-to-medium-scale efforts which will result in marginal improvement. Another mean, which require some major makeovers of the industry basis, will eventually eliminate most of the footprint of the product. The latter is, in fact, harder to implements and requires greater systematic changes as well as financial investments. If there is collective wills to pull off such changes, the impacts caused by the products would be minimized, and this would be one of the flagship case for other industries to follow toward the sustainability.

REFERENCES

Asia-Pacific Partnership on Clean Development and Climate. 2010. **The State-of-the-Art Clean Technologies (SOACT) for Steelmaking Handbook**. 2nd ed. Washington DC: American Iron and Steel Institute.

Barz, M., and Delivand, M.K. 2011. Agricultural Residues as Promising Biofuels for Biomass Power Generation in Thailand. **Journal of Sustainable Energy & Environment** Special Issue:21-27.

Baumert, K.A., Herzog, T., and Pershing, J. 2005. **Navigating the Numbers Greenhouse Gas Data and International Climate Policy**. USA: World Resources Institute.

Carlos, R.M., and Khang, D.B. 2008. Characterization of biomass energy projects in Southeast Asia. **Biomass and Bioenergy** 32 (6):525-532.

Department of Alternative Energy Development and Efficiency, M.o.E. 2009. **Electric Power in Thailand 2008**. Bangkok.

Department of Alternative Energy Development and Efficiency, M.o.E. 2010. **Thailand Alternative Energy Situation 2009**. Bangkok.

Department of Livestock Development, M.o.A.a.C. 2009. **Livestock Infrastructure Information** 2010 [cited 30/6/2012 2009].

Electricity Generation Authority of Thailand. 2010. **Environmental Annual Report of 2009**. Bangkok.

Electricity Generation Authority of Thailand. 2010. **Summary of Thailand Power Development Plan for 2010-2030**. Bangkok.

Electricity Generation Authority of Thailand. 2012. **Environmental Annual Report of 2011**. Bangkok.

Energy Research Institute. 2007. **The Study of Specific Energy Consumption of Steel Industry**. Bangkok.

Gielen, D., and Moriguchi, Y. 2002. CO_2 in the iron and steel industry: an analysis of Japanese emission reduction potentials. **Energy Policy** 30 (10):849-863.

Houser, T., Bradley, R., Staley, B.C., Werksman, J., and Heilmayr, R. 2008. **Leveling the Carbon Playing Field: International Competition and US Climate Policy Design**. Washington DC: Peterson Institute for International Economics and the World Resources Institute.

Hu, C.-q., Chen, L.-y., Zhang, C.-x., Qi, Y.-h., and Yin, R.-y. 2006. Emission Mitigation of CO_2 in Steel Industry: Current Status and Future Scenarios. **Journal of Iron and Steel Research International** 13 (6):38-42.

IISI Committee on Economic Studies. 2007. **Steel Statistical Yearbook of 2007**. Brussels: Internation Iron and Steel Institute.

Intergovernmental Panel on Climate Change. 2006. **IPCC Guidelines for National Greenhouse Gas Inventories**. Kanagawa: Institute for Global Environmental Strategies

Intergovernmental Panel on Climate Change. 2007. **Climate Change 2007: The Physical Science Basis**. New York: Cambridge University Press.

International Energy Agency. 2007. **Tracking Industrial Energy Efficiency and CO_2 Emissions**. Paris: Stedi Media.

International Energy Agency. 2009. **Energy Technology Transitions for Industry: Strategies for the Next Industrial Revolution**. Paris: Stedi Media.

Iron and Steel Institute of Thailand. 2009. **Statistical yearbook 2009**. Bangkok: Iron and Steel Institute of Thailand.

Japan Iron and Steel Federation. 2010. **Steel Industry Measures to Combat Global Warming**.

Klass, D.L. 2004. Biomass for Renewable Energy and Fuels. In **Encyclopedia of Energy**: Elsevier.

Lindroos, T.J. 2009. **Sectoral Approaches in the Case of the Iron and Steel Industry**. Finland: VTT Technical Research Centre of Finland.

National Oceanic and Atmospheric Administration. 2009. **State of the Climate Global Analysis 2008** 2008 [cited 2009]. Available from http://www.ncdc-.noaa.gov/sotc/global/2008/13.

National Research Council. 2006. **Surface Temperature Reconstructions for the Last 2,000 Years**. Washington DC: The National Academies Press.

Oda, J., Akimoto, K., Sano, F., and Homma, T. 2009. Diffusion of CCS and energy efficient technologies in power and iron & steel sectors. **Energy Procedia** 1 (1):155-161.

Office of Agricultural Economics, M.o.A.a.C. 2009. **Major agricultural statistics** 2010 [cited 2009]. Available from http://www.oae.go.th/oae_report/stat_agri/form_search.php.

Office of National Economic and Social Development Board, T. 2009. **Study report of policies for promotion of primary iron production investment for high quality steel production**. Bangkok: National Economic and Social Development Board.

Ozawa, L., Sheinbaum, C., Martin, N., Worrell, E., and Price, L. 2002. Energy use and CO_2 emissions in Mexico's iron and steel industry. **Energy** 27 (3):225-239.

Papong, S., Yuvaniyama, C., Lohsomboon, P., and Malakul, P. 2004. **Overview of Biomass Utilization in Thailand**. Bangkok.

Prasertsan, S., and Sajjakulnukit, B. 2006. Biomass and biogas energy in Thailand: Potential, opportunity and barriers. **Renewable Energy** 31 (5):599-610.

Saidur, R., Abdelaziz, E.A., Demirbas, A., Hossain, M.S., and Mekhilef, S. 2011. A review on biomass as a fuel for boilers. **Renewable and Sustainable Energy Reviews** 15 (5):2262-2289.

Sawangphol, N., and Pharino, C. 2011. Status and outlook for Thailand's low carbon electricity development. **Renewable and Sustainable Energy Reviews** 15 (1):564-573.

Schmidt, J., Leduc, S., Dotzauer, E., Kindermann, G., and Schmid, E. 2010. Cost-effective CO_2 emission reduction through heat, power and biofuel production from woody biomass: a spatially explicit comparison of conversion technologies. **Applied Energy** 87 (7):2128-2141.

Sodsai, P., and Rachdawong, P. 2012. The current situation on CO_2 emissions from the steel industry in Thailand and mitigation options. **International Journal of Greenhouse Gas Control** 6:48-55.

Thailand Greenhouse Gas Management Organization. 2009. **Guideline to the assessment of Product Carbon Footprint**. Bangkok: Thailand Greenhouse Gas Management Organization.

Thailand Greenhouse Gas Management Organization. 2012. **Carbon footprint** 2011 [cited June 2012]. Available from http://thaicarbonlabel.tgo.or.th/carbonfootprint/.

Thailand's Ministry of Energy. 2009. **Thailand's renewable energy and its energy future: opportunities and challanges**. Bangkok: Ministry of Energy.

The Carbon Trust. 2007. **Carbon footprinting: An introduction for organizations**. UK: The Carbon Trust.

The Carbon Trust. 2008. **Guide to PAS 2050: How to assess the carbon footprint of goods and services**. London: The Charlesworth Group.

Tongpool, R., Jirajariyavech, A., Yuvaniyama, C., and Mungcharoen, T. 2010. Analysis of steel production in Thailand: Environmental impacts and solutions. **Energy** 35 (10):4192-4200.

United Nations. 1998. **Kyoto Protocol to the United Nations Framework Convention on Climate Change**, edited by U. Nations.

United Nations. 2011. **Report of the Conference of the Parties on its sixteenth session, held in Cancun from 29 November to 10 December 2010.**

United Nations Industrial Development Organization. 2007. **Industrial Biotechnology adn Biomass Utilisation**. Vienna: United Nations Industrial Development Organization.

Wang, K., Wang, C., Lu, X., and Chen, J. 2007. Scenario analysis on CO_2 emissions reduction potential in China's iron and steel industry. **Energy Policy** 35 (4):2320-2335.

World Steel Association. 2008. **Fact Sheet: Energy**: World Steel Association.

World Steel Association. 2009. **Steel statistical yearbook of 2008**. Brussels.

Worrell, E., Price, L., and Martin, N. 2001. Energy efficiency and carbon dioxide emissions reduction opportunities in the US iron and steel sector. **Energy** 26 (5):513-536.

Xu, C.C., and Cang, D.-q. 2010. A Brief Overview of Low CO_2 Emission Technologies for Iron and Steel Making. **Journal of Iron and Steel Research** 17 (3):1-7.

Zeng, S., Lan, Y., and Huang, J. 2009. Mitigation paths for Chinese iron and steel industry to tackle global climate change. **International Journal of Greenhouse Gas Control** 3 (6):675-682.

BIOGRAPHY

Name: Mr Niwat Tontakul

Date of Birth: April 10, 1985

Place of Birth: Nakhon Sawan

Nationality: Thai

Education:

1998-2003 Nakhon Sawan School in major of Science and Math field, Naknon Sawan, Thailand

2004-2007 Bachelor's degree from Faculty of Engineering, Environmental Engineering, Chulalongkorn University, Bangkok, Thailand

2008-2012 Master's degree of science in environmental management (international postgraduate programs), the national center of excellence for environmental and hazardous waste management (NCE-EHWM), Chulalongkorn University, Bangkok, Thailand

Presentation :

Tontakul N., Rachdawong P., "CO_2 emissions of steel products Manufactured in Thailand" Proceeding of International Conference on Sustainable Environmental Technology (ICSET), Century Park Hotel, Bangkok, Thailand, April 26-27, 2012