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AN ALTERNATIVE BOILER FUEL IN A PAPER MANUFACTURING PLANT

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ราคาน้ำมันที่ขยับขึ้นสูงมากส่งผลกระทบอย่างหนักต่อต้นทุนในการผลิตของโรงงานกระดาษที่ศึกษา การวิจัยนี้จึงมีจุดประสงค์เพื่อหาเชื้อเพลิงอื่นเพื่อใช้แทนน้ำมันเตาในระบบหม้อไอน้ำ รวมทั้งเสนอเทคโนโลยีใหม่เพื่อใช้กับเชื้อเพลิงทดแทน โดยผลของการศึกษาจะช่วยให้โรงงานลดต้นทุนการผลิต และสามารถแข่งขันในตลาดได้

ขั้นตอนแรกเริ่มจาก การวิเคราะห์การทำงานและข้อกำหนดของระบบหม้อไอน้ำที่ใช้ในปัจจุบัน และศึกษาเทคโนโลยีของระบบหม้อไอน้ำ และเชื้อเพลิงที่เป็นทางเลือกมาวิเคราะห์ความเหมาะสมทั้งทางด้านเทคนิค วิธีปฏิบัติ ผลกระทบต่อสิ่งแวดล้อม และทางการเงิน

เชื้อเพลิงที่ได้รับการคัดเลือกคือถ่านหินบิทูมินัส เนื่องจากมีให้ใช้ได้ตลอดโดยไม่มีปัญหาขาดแคลน ระบบเผาไหม้ที่เหมาะสมกับถ่านหินบิทูมินัสในระบบหม้อน้ำปัจจุบัน เพื่อผลิตไอน้ำให้ได้ตามที่ต้องการมีสองระบบที่พิจารณาคือ ระบบ traveling grate spreader stoker (TGS) และระบบ circulating fluidized bed (CFB)

การวิเคราะห์เชิงเทคนิคพบว่า ประสิทธิภาพการเผาไหม้ของ CFB อยู่ระหว่าง 85-90% และ TGS อยู่ระหว่าง 78-85% CFB มีความสามารถรองรับความชื้นและขี้เถ้าในถ่านหินได้มากกว่า TGS นอกจากนั้นระบบ CFB ไม่ต้องการอากาศเกินเพิ่มมาก และยังสามารถควบคุมอากาศส่วนเกินที่เข้าในระบบเผาไหม้ได้ดีกว่า TGS ระบบเผาไหม้ทั้งสองต้องการจำนวนผู้ควบคุมเพิ่มขึ้นอีกหนึ่งคนจากปัจจุบันมีผู้ควบคุมสองคนเพื่อป้อนเชื้อเพลิงและนำขี้เถ้าออกจากระบบ ในด้านสิ่งแวดล้อม เนื่องจากอุณหภูมิในห้องเผาไม้ในระบบ CFB ต่ำกว่า จึงส่งผลให้การเกิด NO_x ปล่อยสู่อากาศน้อยกว่าระบบ TGS ทั้งสองระบบมีการปล่อย SO_x และ NO_x น้อยกว่าที่กำหนดทางกฎหมาย แต่ระบบ CFB สามารถกำจัด SO_x ได้ดีกว่า โดยผสมหินปูนขาวกับเชื้อเพลิงในห้องเผาไหม้ ในการวิเคราะห์ทางด้านการเงิน การลงทุนกับระบบ CFB มีมูลค่าปัจจุบัน (NPV) 239.63 ล้านบาท ซึ่งมากกว่าของ TGS ซึ่งเท่ากับ 236.34 ล้านบาท การศึกษานี้จึงสรุปว่า การใช้เชื้อเพลิงถ่านหินบิทูมินัส กับการดัดแปลงหม้อไอน้ำปัจจุบันเป็นระบบเผาไหม้แบบ CFB ถือเป็นทางเลือกที่ดีที่สุด และสามารถลดต้นทุนของสินค้าลงได้ 8.5%

ภาควิชา ศูนย์ระดับภูมิภาคทางวิศวกรรมระบบการผลิต
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ลายมือชื่อนิสิต.................................
ลายมือชื่ออ.ที่ปรึกษาวิทยานิพนธ์หลัก ....

MAJOR: ENGINEERING MANAGEMENT

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As the cost of production of the paper manufacturing plant in the case study has been impacted greatly by the skyrocketing price of fuel oil for its boiler, the objective of this research is to find an alternative fuel to replace fuel oil along with proposing appropriate technology to support the selected fuel. The study will help reduce the cost of production in order to increase competitiveness of the company in the market.

Related data were first gathered including the process and requirements of the current boiler, available boiler technologies and alternative fuels. The analysis of available alternatives resulted in proposed potential solutions for the case study company. The proposed alternatives were, then, analyzed in feasibility studies addressing technical, operational, environmental, and financial feasibility.

By weighting on availability and reliability, bituminous coal was proposed as the alternative fuel along with proposed combustion technologies that were suitable for a coal fire boiler and met the steam requirement of the case study company. Two technologies were identified and evaluated, namely traveling grate spreader stoker (TGS) and circulating fluidized bed (CFB).

In technical analysis, CFB has a higher burning efficiency of 85-90% compared to 78-85% for TGS. It is also more flexible to humidity and ash contents in the coal, more capability to control access air, less access air required, etc. Both technologies would require three operators compared to two operators for the fuel oil boiler. The extra operator would be needed for fuel handling and ash removal. In environmental analysis, as CFB has a lower temperature in the combustion chamber, the chance of NO_x emissions occurring is lower than for TGS. Also, CFB allows addition of limestone during the combustion process, whereby SO_x is better captured by CFB technology. However, both technologies meet the SO_x and NO_x emission regulations. Lastly, the financial analysis which calculated the cost efficiency of bituminous coal with each boiler technology showed that the NPV value of CFB is greater than TGS's value (239.63 million baht and 236.34 million baht, respectively). As a result, the best alternative is using bituminous coal and implementing CFB with which the cost of production can be reduced to 8.5% of the original cost.

Department Regional Centre for Manufacturing Systems Engineering

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Student signature.............................

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Chapter I
Introduction

This research paper is aimed at finding an appropriate alternative fuel for a steam boiler to replace fuel oil, due to the great impact of fuel oil price increases on production cost. Analysis based on system requirements along with data collected on available alternative fuels and boiler technology was conducted, and the most promising fuel and appropriate technology are proposed.

1.1 Background

The case study company is a paper manufacturer with capacity for producing around 80 tons of paper per day. It was established in 1991, and is located in Samut Prakan province. One of the essential factors in making paper is the steam, as it helps transform wet pulp into a sheet of paper. The steam is generated by a fuel oil boiler with capacity for 22 tons per hour of steam. In the past, the fuel oil boiler was the best option for the manufacturing plant considering the price of oil was very low, and the heating value was very high. However, the use of the fuel oil has become more and more a problem in terms of the expenses. From 2001 to 2005, the demand for fuel oil consumption in Thailand has increased from 4,581 to 6,227 million liters which is about 36% higher, according to the statistics on fuel oil from the Department of Alternative Energy Development and Efficiency, Ministry of Energy, Thailand. As the demand goes up, the price will rise in the same direction as well. In 2001 and 2007, the prices of fuel oil were 9.25 and 19.47 baht per liter, respectively.

1.2 Problem Statement

The case study company needs to find a way to cut spending on energy to remain profitable. This would preferably be accomplished by transitioning the company to alternative energy technology in order to become more independent from energy price fluctuations. Expenses for the case company associated with fuel oil have increased significantly since 2001. As a result, the cost of fuel oil expenses per kg of paper is 10.40% of the total cost of production which is approximately 18 baht per kg. With the rise in price and demand for fuel oil, more and more production costs are carried by the factory. This situation makes it hard to increase or even maintain the profit margin. Cutting costs will be the best way to survive this crisis. The use of an alternative source of energy will help reduce the production cost. According to the Department of Alternative Energy Development and Efficiency, Ministry of Energy, there are many possibilities for alternative energy such as Clean Coal Technology—solid, gasification, and liquefaction forms, rice husks, coco shells, etc.

1.3 Objective

The objective of this research is to conduct a feasibility study on alternative boiler fuels for the case study company in order to reduce production costs.

1.4 Scope of the Research

The feasibility study covers four areas – technical, operational, environmental, and financial – associated with the objective. As described in the literature review in chapter 2, these aspects were selected as the most significant factors in defining and addressing both the problem and the solution. Details on each area are as follows:

1) Technical Feasibility
    - Gathering information on available technology in the market
    - Analyzing the specifications
    - Recommending the most suitable boiler
    - Analyzing compatibility with existing production

2) Operational Feasibility
    - Researching the working process of each machine
    - Analyzing numbers of operators required
    - Designing operational structure including working process and infrastructure

3) Environmental Feasibility
    - Analyzing the toxins that might be released to the environment during the process
    - Making recommendations on the safety of the boiler

4) Financial Feasibility

- Calculating profitability of the project with Net Present Value (NPV), Internal Rate of Return (IRR), and payback period
- Conducting sensitivity analysis
- Recommending on project funding
- Forecasting on the demand and price of selected fuel
- Analyzing the results from calculations and make a recommendation

1.5 Research Procedure

Preparatory research was carried out on paper machine processes, boiler technology of the case company and available technology in the market, as well as available alternative fuels. Research further engaged a theoretical framework to help determine the optimal alternative fuel and boiler for the case factory, also taking into account the four areas of the feasibility study. Broken out, each piece of the research procedure follows.

1. Study related information on processes of paper machines.
2. Study and collect related information on the currently used fuel oil boiler including its specifications on steam and quantity of fuel oil consumption.
3. Study and collect related information on boiler technology in the market.
4. Gather information on available alternative fuels categorized into types, available quantity, heating value, etc.
5. Analyze and propose alternative fuels.
6. Analyze and propose boiler technology.
7. Recommend approach on the operational structure and safety of the boiler.
8. Analyze and justify the alternative fuel and boiler by feasibility study.
9. Conclude on the most suitable solution for the case company.

1.6 Expected Benefit

One of the major sources of energy inefficiency and high fuel bills, alongside the rapidly rising cost of fuel, is the performance level of the boiler. Considering alternative fuels is also an important strategy for creating a degree of independence from the price instability of fuel in the Thai market. Within this broader framework of goals, the aim of the research paper is to achieve the following:

1) Reduce production cost
2) Provide information on available alternative fuels and technology
3) Identify the most suitable fuel to replace fuel oil along with suitable boiler implementation
4) Analyze various aspects of boiler implementation in order to provide sufficient information for making the investment decision

1.7 Organization of Thesis Report

This thesis report is divided into five chapters. Firstly, Chapter I is the introduction of the research. Next, Chapter II is described relevant literature review and theoretical framework for the research. In Chapter III, current boiler's process and requirements are analyzed including analyzing on available alternatives of fuels and boiler technologies that are suitable for the case study company. In Chapter IV, fuel alternatives and boiler technologies are proposed. In addition, the feasibility analysis including technical, operational, environmental, and financial areas are studied. The conclusion and recommendation of the research are stated in Chapter V.

Chapter II
Theoretical Framework

This chapter will cover the relevant literature review and theoretical framework for the research. The guidance of previous feasibility studies will be evaluated for the appropriate theories for this case study. The framework based on these theories will provide justification for the methodology and be valuable for proposing the best solution.

2.1 Feasibility Study Guidelines

The objective of the feasibility study is to evaluate possible alternatives, on various aspects of the subject and implementation, in order to provide the best alternative to the decision maker to weigh the project. The aspects to evaluate in feasibility studies depend on the subject.

In the feasibility study of waste exchange in the bangpoo industrial estate, technical, economic, and financial analysis are conducted (Ungcharoen, 1998). According to Rattanavaraha **(**1994), the feasibility study related to setting up an automobile brake factory covers the study of marketing, technical, organizational, and financial aspects. In addition, a feasibility study of possibilities of airline investment in Thailand (Jiramahakun, 2001) focuses only on marketing, engineering, and financial aspects. One feasibility study of machine replacement also covers areas of marketing, technical, and financial analysis, along with using a scoring tool which weights factors based on their levels of importance to the studied company (Teoh, 2007).

According to Baum, Warren, Tolbert, and Stoke (1995), most feasibility studies do not contain the same areas of study, but the analysis is surely similar. In designing the analysis, the research postulated that answers to the following questions are essential to be verified:

1) Does the project act in accordance with development objectives?
2) Is the relevant policy framework compatible with achievement of the project's objectives?
3) Is the project technically sound and is it the best available technical option?
4) Is the project economically justified and will it be financially successful in operation?

5) Is the project environmentally sound?
6) Is the project compatible with the traditions and customs of the beneficiaries?

2.2 Feasibility Study Framework

After study and evaluation of the subject of this research, a formation of theories included in the research paper's framework will consist of technical, operational, environmental, and financial analysis. The coverage of each area will be illustrated in following.

2.2.1 Technical Feasibility

The technical feasibility analysis helps determine the most suitable fuel and boiler by identifying and evaluating criteria specific to fuels and to boilers as follows.

Alternative Fuel Analysis

Interviews with experts and data collection on available fuels will illustrate fuel availability, quantity, burning properties, harvesting season, and prices. Information will be evaluated in terms of cost efficiency and availability in long-term utilization.

Boiler Analysis

This analysis addresses boiler flexibility on fuels, operational efficiency, and space requirements. The study will include the evaluation of the compatibility with the existing boiler.

2.2.2 Operational Feasibility

Operational feasibility involves the study of the boilers' operating processes to design the proper numbers of operators and the suitability of warehouse and material handling.

2.2.3 Environmental Feasibility

Analysis of environmental feasibility was designed as study of the release of NO_x and SO_2 emissions during the burning of biomass and/or coal fuels, compared to the emission requirements of the Ministry of Natural Resources and Environment, Thailand. In addition, analysis of the cause and prevention of toxins will be studied and recommended.

2.2.4 Financial Feasibility

The financial study will focus on the calculations of initial investments and annual expenses of the boiler with the options on alternative fuels in order to measure the project's profitability by financial tools – Net Present Value (NPV), Internal Rate of Return (IRR), and payback period. The forecast of fuels' prices and project funding will also be covered.

NPV compares the value today of money to the value of that same money in the future. If the NPV of a prospective project is positive, it should be accepted, and rejected when it turns negative since it shows that the cash flow is negative. The NPV formula is as follows:

$$NPV = \sum_{t=0}^{n} \frac{B_t}{(1+i)^t} - \sum_{t=0}^{n} \frac{C_t}{(1+i)^t} \text{ OR } NPV = \sum_{t=0}^{n} \frac{B_t - C_t}{(1+i)^t}$$

Where: B_t = Benefits in year t

C_t = Costs in year t

n = Final year of consideration

i = Discount rate (WACC)

When: WACC = Cost of Debt x %weight of debt + Cost of Equity x %weight of equity

Cost of Equity = Capital Asset Pricing Model (CAPM)

CAPM = Risk-Free Rate + ($\beta_{leveraged}$ x Equity Premium)

$\beta_{leveraged} = \beta_{unleveraged}$ x [1+ (1-Taxes) x Cost of Debt / Cost of Equity

IRR is the discount rate that makes net present value equal to zero or net present value of total benefits equal to net present value of total costs. The formula for this method is as follows:

$$\sum_{t=0}^{n} \frac{B_t - C_t}{(1+i)^t} = 0 \text{ OR } \sum_{t=0}^{n} \frac{B_t}{(1+i)^t} = \sum_{t=0}^{n} \frac{C_t}{(1+i)^t}$$

Payback Period (PB) is the period required to return the total investment, and it can be calculated as follows:

$$PB = \frac{\text{Total Investment}}{\text{Annual Net Saving}}$$

In summary, while other related feasibility studies are valuable and help inform this research paper, it is important to also tailor feasibility analysis specifically to the subject at hand. This helps ensure that the questions and problems that arise regarding actual implementation can be sufficiently addressed. It was determined that the aspects of feasibility study most relevant to the subject are technical, operational, environmental, and financial analysis. Technical analysis involves study of the physical and market aspects of alternative fuels, as well as new boiler system specifications and compatibility with the existing boiler. Operational feasibility involves study of the required number of operators and suitability of warehouse and material handling. Environmental feasibility concerns the expected emissions and toxins compared to regulations and guidelines. Finally, financial feasibility study considers project investment and projects costs to analyze profitability. Together, the theoretical framework and multi-disciplinary analysis provided can help build a more comprehensive and solid recommendation for the case company regarding its approach to energy technology and its broader goals, including profitability.

Chapter III
Framework for Proposed Alternatives

This chapter covers the analysis of the requirements and processes of currently utilized fuel oil boiler to provide necessary background knowledge for further study of the most suitable technology among available boiler technologies. In addition, information on available alternative fuels will also be covered in this chapter. Formation of possible alternatives for both boiler technology and fuels for the case study company are stated at the end of chapter, for further evaluation in the feasibility analysis.

3.1 Current Boiler and System Requirements

In the past, oil boiler systems had widespread use in the paper industry and resulted in a substantial consumption of energy and water. With higher demand leading to a much higher price, the use of fuel oil is now unsupportable. Improving the efficiency of fuel use in boiler can significantly decrease energy costs. Further assessment and evaluation of fuel oil boiler systems is essential.

Steam Requirements

As the paper machine runs around the clock, steam is continuously fed to the production line with a pressure of approximately 8 bar and an amount of 22 tons of steam produced hourly under a temperature of 180C. The boiler consumes daily around 20,000 liters of fuel, and up to 60,000 liters are kept in stock to prevent a shortage of fuel.

Boiler Process

Simply think of boilers as big fuel-burning appliances that generate hot water or steam under pressure, which is then usable for transferring heat to the process of the production system. Water plays an important role in a boiler process. A large quantity of water is used for transferring heat during the process and is also conductively proximate to the combustion chamber. Figure 1 below shows the design of a combustion boiler that uses the chemical energy in fuel to increase the energy content of water to use it for heating and steaming applications.

Before water can be used in the boiler, it is necessary to reduce dissolved gases, especially Oxygen and Carbon Dioxide. And so some chemical substances need to be added in order to achieve the condition called feed water. For instance, the chemical is Sulfide for eliminating Oxygen which is the main cause of corrosion, and Trisodium phosphate for preventing the pileup of calces inside the boiler. The water will then be kept in the boiler feed water tank in which it will be mixed with water that is passing through steam or condensate water. The tank is shielded for maintaining the temperature in the water. Next, the water will go through an economizer which is installed in the path of flue gases for pre-heating the water before entering the boiler. The combustion chamber will burn fuel oil to produce heat which is sent to the steam drum, located on top of the water-tube boiler for collecting steam. After that, the heat will then enter the economizer to warm the water. Steam will then be released through the stack by the help of an induced draft fan to speed up the release. Just before releasing the flue gas, a flue gas desulfurization process is used to address the release of Sulfur Dioxide from the combustion process. This process reduces the amount of emissions.

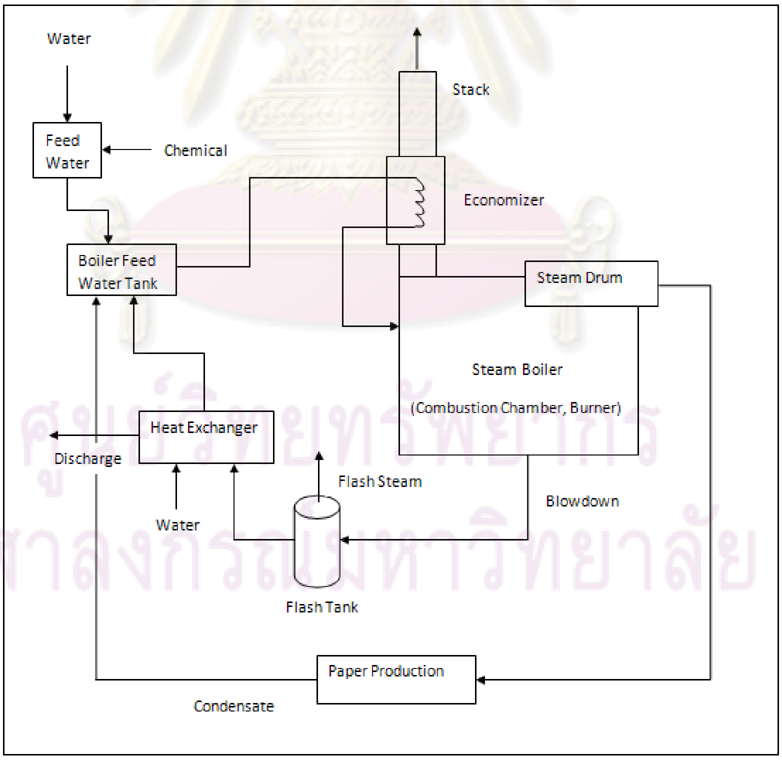

Figure 1: Boiler Process

Boilers from time to time need to blowdown. In large-sized boilers is usually installed a solid detector to monitor the level of solids dissolving in the water and to signal the controller to blowdown. The flash tank will then receive steam from blowdown and release steam with low pressure to pre-heat the water by the heat exchanger machine.

4.1 System Improvement Policy

Normally, the average usage and boiler life is about 20-25 years. However, even though this boiler has been utilized for 18 years, the boiler is still in good condition. Its usage life might be even more than 25 years; however, for this research it is assumed the remaining life of boiler is 7 years. The improvement of the boiler in order to cut cost involves only the change of fuel used and the modification of the current system to accommodate the change.

3.2 Available Alternatives Analysis

Alternative fuels will be first evaluated by weighing their availability and reliability. Next, technological availability will be studied and sorted out for compatibility with potential alternative fuels.

3.2.1 Fuel Considerations

The most common fuels used in boilers are petroleum-based oils, coal, and biomass—organic-based fuel such as wood, agricultural crops, trees and plants. Also, there are potential fuels generated from the paper production which are wastepaper and sludge. However, since the price of pulp has increased greatly, wastepaper has also become an alternative raw material for pulp replacement at a certain quantity. Therefore, the best use of wastepaper is not necessarily as a fuel. Natural gas is also used to produce electricity and heat; however, as the route of natural gas pipelines has not passed near the factory location, it will not be included in the research. As a result, the main fuels to place emphasis on are coal and biomass as alternative fuel options.

Properties of Fuel

As outlined in Energyefficiencyasia (2006), the properties of fuel can be divided into two categories—physical properties and chemical components. The physical properties include heating value or gross calorific value (GCV), volatile matter, moisture content, and ash content. In addition, carbon, hydrogen, nitrogen, oxygen, sulphur, etc. are included in the chemical components.

The heating value is related directly to the amounts of fixed carbon and volatile matter. The heat in the combustion process is mainly from the fixed carbon while volatile matter helps ignite the fuel easily. Also, in relation to the design of the furnace grate, combustion volume, pollution control equipment, and the ash handling systems of a furnace are related to the ash content.

1) Fixed carbon

%fixed carbon = 100 – (%moisture + %volatile matter + %ash)

When volatile matter and moisture in fuel are eliminated, solid fuel is left in the combustion chamber, which compounds mostly carbon along with other materials such as hydrogen, oxygen, sulphur, and nitrogen. Its percentage, then, can be determined through excluding the percentage of ash. Fixed carbon is important since it generates heat during combustion, which could give the rough estimate of the heating value.

2) Volatile matter

Volatile matter is the fuel's elements and components such nitrogen, carbon dioxide, carbon monoxide, methane, hydrocarbons, hydrogen, etc. However, moisture is included in the volatile matter. The important characteristics of volatile matter are to help ignite the fuel easily and increase the length of the flame.

3) Ash content

Ash content is unburnable residue rejected in the combustion process. The percentage of ash depends on the type of fuel. The approximate amount of ash in coal is around 3-40% depending on the type of coal. And the amount of ash produced from burning most biomass is around 1-3%; however, some types of biomass such as rice husks and straw produce high amounts of ash as well, around 10-20%. The impact of ash on burning is that the burning capacity is reduced, including the efficiencies of combustion and the boiler. In addition, ash also can cause the occurrence of slag and clinker in the combustion chamber.

4) Moisture content

As the combustible substance in fuel is replaced by moisture, the heating capacity decreases as well. The range of moisture averages 0.5-10% in coal, and in agricultural products reaches higher amounts of moisture. For instance, cassava has a level of moisture between 80-90%, and so it has to undergo dewatering to reduce moisture before entering the combustion chamber. The loss of heat will increase with the occurrence of moisture evaporation during burning.

5) Sulphur content

Sulphur content is often found in fuel in the form of organic sulfur, iron pyrites, and gypsum. The chemical reaction between Sulphur and Oxygen releases Sulphur Dioxide. Without proper equipment to eliminate certain substances, this can be harmful to people and the environment.

Coal

Introduction

According to The World Coal Institute (WCI) and Energy Information Administration (EIA), coal is formed over hundreds of millions of years from the piled up dead plants of swamp ecosystems. The plants were rapidly covered with large amounts of mud and sand which slow down decomposition, and they gradually transformed into black or brownish-black coal as the rise in pressure and heat contributed to their physical and chemical changes. The coal is composed primarily of carbon and hydrocarbons along with other elements such as sulfur. The trapping of the energy in dead plants is also transferred into the coal.

Table 1: Time-scale of Historical Geology (Source: World Coal Institute, 2009)

Period	Alleged Age/Mya
Quaternary	0–1.8
Tertiary	1.8–65.0
Cretaceous	65.0–142.0
Jurassic	142.0–205.7
Triassic	205.7–248.2
Permian	248.2–290.0
Carboniferous	290.0–354.0
Devonian	354.0–417.0
Silurian	417.0–443.0
Ordovician	443.0–495.0
Cambrian	495.0–545.0
Precambrian	>545.0

According to WCI in Table 1, coal can be found in almost all periods from the Devonian to the Tertiary. However, the most favorable coal creation conditions were in the Carboniferous period, between 290 to 354 million years ago. Types of coal found from this period are bituminous and sub-bituminous coal, whereas from the Tertiary period finds are mostly lignite coal which contains low carbon. The deeper the coal is buried, the more carbon concentration it obtains. However, early maturity of coal is possible by colliding tectonic plates leading to heating effects. This includes coal deposited 55-65 million years ago from Colombia and Venezuela and 20 million years ago from Indonesia. Lastly, those recently deposited around 10,000 years ago are called peat. Peat is not truly coal since it is not deeply buried. It is the first step of forming and transforming into coal under precise conditions.

Coal Types and Formation

According to IEA, coal can be described by rank and grade. The rank is weighted on the percentage of carbon content, and the grade refers to the amount of ash from combustion. Coal can be ranked into six types—graphite, anthracite, bituminous, sub-bituminous, lignite, and peat. In addition, there are three types of coal formation— gasification, liquefaction, and solidity.

1) Gasification

According to the U.S. Energy Department and the Gasification Technologies Council, coal gasification is the first step in the coal liquefaction process. Coal gasification is achieved by carefully raising the temperature and pressure of coal to almost combustible levels and then adding steam and a controlled amount of oxygen, resulting in the production of syngas. The syngas is a mixture of components, mostly carbon monoxide (CO) and hydrogen (H_2). With more steam as a reactant, the carbon monoxide component could be converted to carbon dioxide (CO_2) while H_2 will be produced in the same amount as CO converting it into CO_2.

In the past, coal gasification was the main energy form used as it was piped to industries or households for heating, cooking, etc., until the discovery of natural gas, which has a higher heating value and is cleaner. However, South Africa has still been using it for its petrochemical needs. For the future, the return of coal gasification consumption is possible since the burning of cleaned-up syngas is cleaner than burning coal and is comparable to natural gas.

Regarding the greenhouse gases released into the atmosphere, if a coal gasifier uses oxygen instead of air, CO_2 will be released in the form of gas steam in syngas at a high temperature in which it can be more easily captured and stored with lower costs. Comparing burning coal to this process, the former releases up to 80% nitrogen and a small amount of carbon dioxide, which is more costly to separate.

2) Liquefaction

The benefits of liquid coal are no sulphur, low levels of nitrogen oxides, and a 20% reduction of carbon dioxide compared to oil products. According to WCI, there are direct and indirect processes of converting coal to liquids (CTL). For the direct process, a solvent is added to liquefy coal at a high temperature and pressure. This is a very efficient way to produce liquid coal; however, a further process of adding hydrogen is required to achieve a higher grade of fuel.

In the indirect process, coal is first steamed to form a syngas, which is a combination of hydrogen and carbon monoxide without sulphur. The syngas is then condensed by the Fischer-Tropsch process, which is to convert syngas into liquid hydrocarbons, yielding high quality and ultra-clean products. In figure 2, diesel fuel, LPG, and electricity are some sample products that are derived from coal from the Fischer-Tropsh indirect liquefaction process (National Mining Association, 2009).

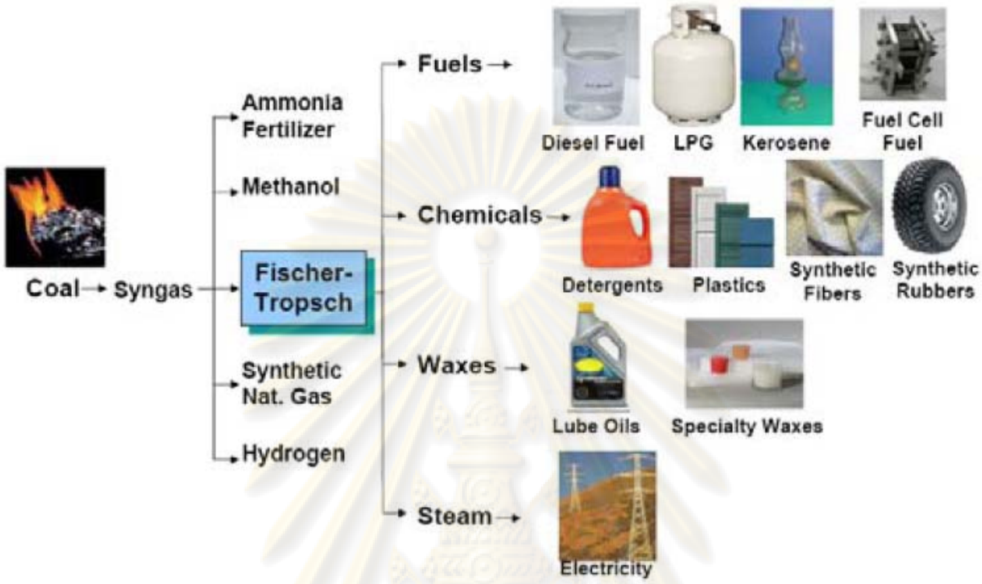

Figure 2: CTL's Products (Source: National Mining Association, 2008)

3) Solidity

Peat

Peat is not truly coal since it is not deeply buried. It is the first step of forming and transforming into coal under precise conditions. Peat contains high fibrous debris and contains the least amount of carbon content and much more moisture content among the other types of coal. The average heating value of peat is around 21 MJ/Kg.

Lignite

Lignite is also called brown coal, which is quite a young coal with 25-35% carbon content. Having high moisture content between 30-70%, it crumbles easier than more consolidated coal such as bituminous coal. The average heating value is around 25 MJ/Kg.

Sub-Bituminous

The carbon content is normally around 35-45% with an average of 10% moisture. It is used mainly to produce steam for electric power generation. Also, since sub-bituminous coal contains a high percentage of moisture, it is similar to lignite in being crumbly. The average heating value is around 27 MJ/Kg.

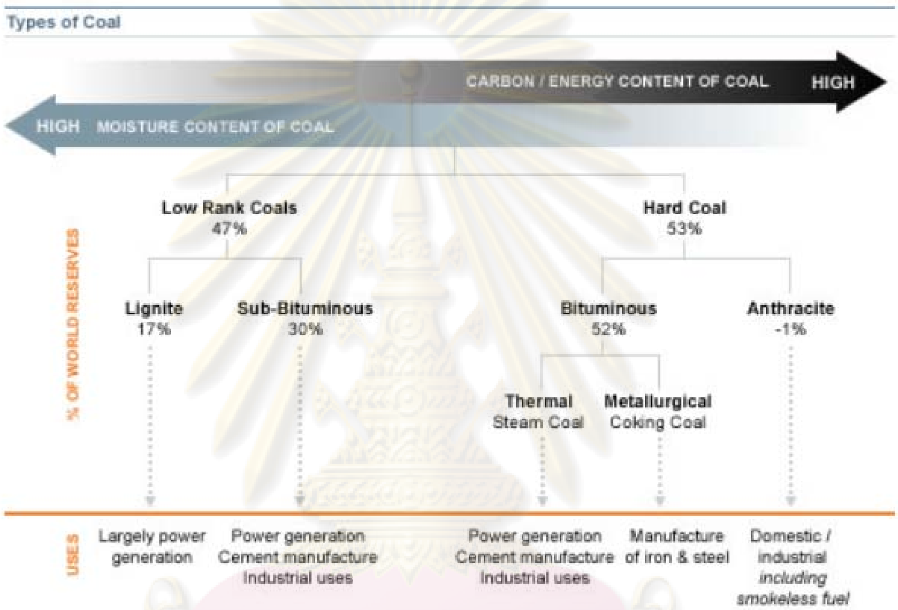

Figure 3: Types of Coal (Source: World Coal Institute, 2009)

Bituminous

This coal is usually dark brown to black. The carbon content is approximately 45-86%, around two to three times higher than lignite. Bituminous coal is widely used in middle to large scale boilers. The moisture content is approximately 1.5-7%. Bituminous coal is divided into two types, weighted by the usage, which includes steam coal and coke. The average heating value is around 31-35 MJ/Kg.

1) Steam coal

This is the bituminous coal used to produce steam for electric power generation and for use in industry, such as the concrete and paper industries. Steam coal is easier to ignite as it has more volatile matter but less fixed carbon, which means the heating value is less than coke. The average heating value is around 31 MJ/Kg.

2) *Coke*

Coke is derived from bituminous coal baking at 2,000 degrees Celsius in furnaces in order to eliminate volatile components. Even though its lower volatile matter can impact fuel ignition, energy per unit volume is higher. The normal usage of coke is smelting iron ore into iron since the heat from burning coke is very high and this gives strength and flexibility to the steel. In addition, coke is also used in manufacturing ferro-alloys, lead, and zinc. The average heating value is around 35 MJ/Kg.

3) *Anthracite*

Anthracite is shiny black. Usually it consists of carbon at around 86-98%, with low moisture content and volatile matter, which make it hard to ignite. Also, the average heating value is around 29 MJ/Kg.

4) *Graphite*

An alternative name for graphite is meta-anthracite. It is considered the highest grade of coal. According to the United States Geological Survey (USGS) – a scientific agency of the United States government – the formation of carbon in graphite is considered the most stable. As a result, “it is used in thermo chemistry as the standard state for defining the heat of formation of carbon compounds.” However, graphite has little value as a fuel since it is difficult to ignite. The average heating value is around 34 MJ/Kg.

Top Coal Producers

Table 2: Coal Production by country and year (Source: British Petroleum, 2007)

Country	2003	2004	2005	2006	Change in 2006 from 2005	2006 Share of Total
China	1722.00	1992.30	2204.70	2380.00	7.95%	38.42%
United States	972.30	1008.90	1026.50	1053.60	2.64%	17.01%
India	375.40	407.70	428.40	447.30	4.41%	7.22%
Australia	351.50	366.10	378.80	373.80	-1.32%	6.03%
Russian Federation	276.70	281.70	298.50	309.20	3.58%	4.99%
South Africa	237.90	243.40	244.40	256.90	5.11%	4.15%
Germany	204.90	207.80	202.80	197.20	-2.76%	3.18%
Indonesia	114.30	132.40	146.90	195.00	32.74%	3.15%
Poland	163.80	162.40	159.50	156.10	-2.13%	2.52%
Others	768.80	782.60	796.20	826.00	3.74%	13.33%
Total	**5187.60**	**5585.30**	**5886.70**	**6195.10**	**5.24%**	**100.00%**

According to the Department of Alternative Energy Development and Efficiency (DEDE) and British Petroleum, Ministry of Energy in Table 2, the total amount of coal produced in the world from 2003 to 2006 are 5187.6, 5585.3, 5886.7, and 6195.1 million tons respectively. In 2006, the production of coal increased 5.24% in order to serve the higher demand for energy. The top countries that contributed to the higher coal production were China, the United States, India, Australia, the Russian Federation, South Africa, Germany, Indonesia, and Poland. Many of these countries increased their production quantities in 2006, such as a 7.95% increment in China production leading to a 38.42% total worldwide share and a 32.74% increment in Indonesia production leading to a 3.15% total worldwide share.

Coal Reserves

Table 3: Coal Reserves Worldwide (Source: British Petroleum , 2007)

Country	Total (Mtons)	2006 Share of Total
United States	246,643.00	27.10
Russia	157,010.00	17.30
China	114,500.00	12.60
India	92,445.00	10.20
Australia	78,500.00	8.60
South Africa	48,750.00	5.40
Ukraine	34,153.00	3.80
Kazakhstan	31,279.00	3.40
Poland	14,000.00	1.50
Brazil	10,113.00	1.10
Germany	6,739.00	0.70
Colombia	6,611.00	0.70
Canada	6,578.00	0.70
Czech Republic	5,552.00	0.60
Indonesia	4,968.00	0.50
Turkey	4,186.00	0.50
Greece	3,900.00	0.40
Hungary	3,357.00	0.40
Pakistan	3,050.00	0.30
Bulgaria	2,187.00	0.20
Thailand	1,354.00	0.10
North Korea	600.00	0.10
New Zealand	571.00	0.10
Spain	530.00	0.10
Zimbabwe	502.00	0.10
Romania	494.00	0.10
Venezuela	479.00	0.10
TOTAL	**909,064.00**	**100.00**

According to DEDE and the Survey of Energy Resources in Table 3, World Energy Council, at the end of 2006 the amount of coal reserves in the world is 909,064 million tons. The five countries that have the highest coal reserves include the United States, which has 246,643 million tons or 27.10% of the total reserves. Russia has 157,010 million tons or 17.30% of the total reserves. China has 114,500 million tons or 12.60% of the total reserves. The fourth highest coal reserve is in India, which has 92,445 million tons or 10.20% of the total reserves. The last of the top five countries is Australia which has 78,500 million tons or

8.60% of the total reserves. The estimate of available coal to be utilized globally is around 200 years, when assuming that the current rate of production will continue.

Top Coal Exporters

Table 4: Exports of Coal by country and year (million tons) (Source: British Petroleum, 2007)

Country	2003	2004	2005	Change in 2005 from 2004
Australia	238.10	247.60	257.60	4.04%
Indonesia	107.80	131.40	147.60	12.33%
China	103.40	95.50	79.00	-17.28%
South Africa	78.70	74.90	77.50	3.47%
South America	57.80	65.90	68.80	4.40%
Former Soviet Union	41.00	55.70	62.30	11.85%
United States	43.00	48.00	49.90	3.96%
Canada	27.70	28.80	31.00	7.64%
Poland	16.40	16.30	16.40	0.61%
Vietnam	0.00	10.30	14.10	36.89%

According to British Petroleum in Table 4, the countries with the highest production of coal do not necessarily export the most coal. The fourth ranked coal producer—Australia, was the biggest coal exporter in 2005. China, which is the largest coal producer, was in third rank for exporting coal from 2003 to 2005, and the quantity of China's exports in 2005 reduced by 17.28%. The statistics show increased amounts of export year over year except China for two straight years, and South Africe and Poland in 2004. This implies that the demand for energy has shifted more to coal.

Thailand Coal

According to DEDE, coal mines have been discovered in northern and southern Thailand. The largest and most important coal producer is Mae Mo mine in Lampang province. The types of Thailand coal are mostly lignite and some sub-bituminous and bituminous from the Tertiary period. Since 2003, coal has been used to produce electricity equal to 6.989 million tons produced by fuel oil. The coal reserves in Thailand are not less than 1,354 million tons of which 82% is located in Mae Mo mine.

Thailand Coal Import

In Table 5, according to the Customs Department, Thailand, the top importing coal countries to Thailand in 2007 are: Indonesia, Australia, Laos, Vietnam, and China. There are two countries which import by far the most coal to Thailand: Indonesia, importing 10.18 million tons, following by 2.85 million tons of coal from Australia. There are four types of imported coal—anthracite, bituminous, charcoal briquettes, and coke and semi-coke.

Table 5: Imports of Coal by country (Source: Customs Department, Thailand, 2007)

Country	Tons
Indonesia	10,184,346.40
Australia	2,848,274.81
Lao	395,050.00
Vietnam	351,073.05
China	70,912.08
Singapore	8,199.14
Japan	3,434.80
Taiwan	2,352.29
Malaysia	2,035.10
Germany	1,824.52
Sweden	983.00
Canada	475.00
Hong Kong	136.83
Netherlands	23.50
United States	2.68
Korea	0.41
United Kingdom	0.34
India	0.30
Philippines	0.20
South Africa	0.02
Total	**13,869,124.46**

Price

Table 6: Coal Price (Source: DEDE and Energy for Environment Foundation, 2009)

Product	Annual Prices (Baht/kg)								
	2000	2001	2002	2003	2004	2005	2006	2007	2008
Bituminous Coal	1.40	1.40	1.50	1.60	1.60	1.80	2.00	2.10	1.90

According to DEDE and the Energy for Environment Foundation in Table 6, the price of bituminous coal shows that in recent years coal price has started to increase. In 2000, the price was 1.40 baht per kg, and it continues to increase. In 2007, it was 2.10 baht per kg, although it decreased to 1.90 baht in 2008.

Biomass

From DEDE, table 7 shows various types of biomass and their source, such as husks and straw produced from rice, sawdust and chips produced from para rubber, etc. In addition, Table 8 shows the availability of fifteen types of biomass according to the agricultural statistics of 2006-2007, Office of Agricultural Economics.

Table 7: Types of Biomass (Source: DEDE, 2007)

Plant	Biomass
Rice	Husk Straw
Para rubber	Sawdust Chip
Oil Palm	Empty bunches Fiber Shell Frond Male bunches
Cassava	Stalk Rhizome
Maize	Cob Stalk Top Leaf
Sugar cane	Trashier (leaf) Bagasse Top
Soybean	Stalk Leaf Shell
Pineapple	Stump
Coconut	Husk Shell Empty bunches Frond
Wood	Charcoal Fuel wood Frond Leaf Husk Seed
Eucalyptus	Chip Sawdust

1) Rice

Husks

The total rice yield in 2006-2007 was approximately 30 million tons, and the proportion of rice husks to the total production is about 23% which is equivalent to 6.8 million tons. The consumption of rice husks as a biomass fuel was about 5 million tons with about 1.7 million tons remaining as unutilized fuel. The heating energy of the remaining rice husks with a heating value of 14.54 MJ/Kg results in 24,915.16 Tera-joules or 589.99 Ktoe.

<u>*Straw*</u>

The proportion of rice straw to the total production is about 35.2 million tons. The consumption of rice straw as a biomass fuel was 18 million tons with about 17.26 million tons remaining as unutilized fuel. The heating energy of the remaining rice straw with a heating value of 13.80 MJ/Kg results in 238,123.36 Tera-joules or 5,638.77 Ktoe.

2) Para Rubber

<u>*Sawdust*</u>

The total para rubber yield in 2006-2007 was approximately 14.34 million tons, and the proportion of para rubber sawdust to the total production is about 3% which is equivalent to 0.43 million tons. The consumption of para rubber sawdust as a biomass fuel was 0.06 million tons with about 0.3 million tons remaining as unutilized fuel. The heating energy of the remaining para rubber sawdust with a heating value of 6.57 MJ/Kg results in 1,945.46 Tera-joules or 46.07 Ktoe.

<u>*Chips*</u>

The total para rubber yield in 2006-2007 was approximately 14.34 million tons, and the proportion of para rubber chips to the total production is about 10% which is equivalent to 1.43 million tons. The consumption of para rubber chips as a biomass fuel was 1.2 million tons with about 0.21 million tons remaining as unutilized fuel. The heating energy of the remaining para rubber chip with a heating value of 6.56 MJ/Kg results in 1,380.38 Tera-joules or 32.69 Ktoe.

3) Oil Palm

Fiber

The total oil palm yield in 2006-2007 was approximately 6.7 million tons, and the proportion of oil palm fiber to the total production is about 13% which is equivalent to 0.87 million tons. The consumption of oil palm fiber as a biomass fuel was 0.50 million tons with about 0.37 million tons remaining as unutilized fuel. The heating energy of the remaining oil palm fiber with a heating value of 11.40 MJ/Kg results in 4,251.68 Tera-joules or 100.68 Ktoe.

Shells

The total oil palm yield in 2006-2007 was approximately 6.7 million tons, and the proportion of oil palm shells to the total production is about 12% which is equivalent to 0.81 million tons. The consumption of oil palm shells as a biomass fuel was 0.042 million tons with about 0.76 million tons remaining as unutilized fuel. The heating energy of the remaining oil palm shells with a heating value of 16.90 MJ/Kg results in 12,908.29 Tera-joules or 305.67 Ktoe.

Empty Bunches

The total oil palm yield in 2006-2007 was approximately 6.7 million tons, and the proportion of oil palm empty bunches to the total production is about 20% which is equivalent to 1.3 million tons. The consumption of oil palm empty bunches as a biomass fuel was 0.084 million tons with about 1.13 million tons remaining as unutilized fuel. The heating energy of the remaining oil palm empty bunches with a heating value of 7.24 MJ/Kg results in 8,203.69 Tera-joules or 194.26 Ktoe.

Fronds

The total oil palm yield in 2006-2007 was approximately 6.7 million tons, and the proportion of oil palm fronds to the total production is about 28% which is equivalent to 1.88 million tons. The consumption of oil palm fronds as a biomass fuel was 1 million tons with about 0.88 million tons remaining as unutilized fuel. The heating energy of the remaining oil palm fronds with a heating value of 1.76 MJ/Kg results in 1,549.17 Tera-joules or 36.68 Ktoe.

4) Sugarcane Bagasse

The total sugarcane yield in 2006-2007 was approximately 50 million tons, and the proportion of sugarcane bagasse to the total production is about 0.204% which is equivalent to 10.2 million tons. The consumption of sugarcane bagasse as a biomass fuel was 0.41 million tons with about 6.85 million tons remaining as unutilized fuel. The heating energy of the remaining sugarcane bagasse with a heating value of 9.24 MJ/Kg results in 63,336.27 Tera-joules or 1,499.81 Ktoe.

5) Cassava Rhizome

The total cassava yield in 2006-2007 was approximately 22.58 million tons, and the proportion of cassava rhizome to the total production is about 20% which is equivalent to 4.5 million tons. The consumption of cassava rhizome as a biomass fuel was 0.004 million tons with about 3.6 million tons remaining as unutilized fuel. The heating energy of the remaining cassava rhizome with a heating value of 7.45 MJ/Kg results in 26,915.36 Tera-joules or 637.36 Ktoe.

6) Maize Cobs

The total maize yield in 2006-2007 was approximately 3.7 million tons, and the proportion of maize cobs to the total production is about 24% which is equivalent to 0.89 million tons. The consumption of maize cobs as a biomass fuel was 0.2 million tons with about 0.62 million tons remaining as unutilized fuel. The heating energy of the remaining maize cobs with a heating value of 11.30 MJ/Kg results in 6,988.03 Tera-joules or 165.48 Ktoe.

7) Eucalyptus Chips and Sawdust

The total eucalyptus yield in 2006-2007 was approximately 15 million tons, and the proportion of eucalyptus chips and sawdust to the total production is about 10% which is equivalent to 1.5 million tons. The consumption of eucalyptus chips and sawdust as a biomass fuel was 0.5 million tons with about 0.8 million tons remaining as unutilized fuel. The heating energy of the remaining eucalyptus chips and sawdust with a heating value of 4.92 MJ/Kg results in 3,936 Tera-joules or 93.20 Ktoe.

8) Coconut

Shells

The total coconut yield in 2006-2007 was approximately 1.4 million tons, and the proportion of coconut shells to the total production is about 25% which is equivalent to 0.35 million tons. The consumption of coconut shells as a biomass fuel was 0.30 million tons with about 0.04 million tons remaining as unutilized fuel. The heating energy of the remaining coconut shells with a heating value of 18.26 MJ/Kg results in 752.63 Tera-joules or 17.82 Ktoe.

Husks

The total coconut yield in 2006-2007 was approximately 1.4 million tons, and the proportion of coconut husks to the total production is about 57% which is equivalent to 0.81 million tons. The consumption of coconut husks as a biomass fuel was 0.71 million tons with about 0.095 million tons remaining as unutilized fuel. The heating energy of the remaining coconut husks with a heating value of 16.41 MJ/Kg results in 1,559.09 Tera-joules or 36.92 Ktoe.

9) Soy Beans

The total soy bean yield in 2006-2007 was approximately 0.12 million tons, and the proportion of soy bean stalks, leaps and shells to the total production is about 118% which is equivalent to 0.14 million tons. The consumption of soy beans as a biomass fuel was 0.87 million tons with about 0.04 million tons remaining as unutilized fuel. The heating energy of the remaining soy beans with a heating value of 16.23 MJ/Kg results in 625.52 Tera-joules or 14.81 Ktoe.

10) Pineapples

The total pineapple yield in 2006-2007 was approximately 2.6 million tons, and the proportion of pineapple biomassto the total production is about 59% which is equivalent to 1.53 million tons. The consumption of pineapples as a biomass fuel was 1.33 million tons with about 0.18 million tons remaining as unutilized fuel. The heating energy of the remaining pineapples with a heating value of 15.76 MJ/Kg results in 2,773.48.17 Tera-joules or 65.68 Ktoe.

Table 8: Biomass Fuel Chart (Source: DEDE, 2007)

No.	Product	Yield (T/Yr)	Biomass Factor	Biomass	Biomass (T/Yr)	Consumption (Ton/Yr)	Remaining Factor (%)	Remain (Ton/Yr)	Heating value (MJ/Kg)	Heating Energy (TERA, joule)	Ktoe
1	Rice	29,592,379.00	0.23	Husk	6,806,247.17	4,902,291.54	90	1,713,560.06	14.54	24,915.16	589.99
			1.19	Straw	35,214,931.01	17,959,614.82	50	17,255,316.19	13.80	238,123.36	5,638.77
2	Para Rubber	14,338,046.00	0.03	Sawdust	430,141.38	60,000.00	80	296,113.10	6.57	1,945.46	46.07
3			0.10	Chip	1,433,804.60	1,200,000.00	90	210,424.14	6.56	1,380.38	32.69
4	Oil Palm	6,715,036.00	0.13	Fiber	872,954.68	500,000.00	100	372,954.68	11.4	4,251.68	100.68
5			0.12	Shell	805,804.32	42,000.00	100	763,804.32	16.9	12,908.29	305.67
6			0.20	Empty Bunch	1,343,007.20	84,000.00	90	1,133,106.48	7.24	8,203.69	194.26
7			0.28	Fronds	1,880,210.08	1,000,000.00	100	880,210.08	1.76	1,549.17	36.68
8	Sugarcane	50,000,000.00	0.204	Bagasse	10,200,000.00	407,750.43	70	6,854,574.70	9.24	63,336.27	1,499.81
9	Cassava	22,584,402.00	0.20	Rhizome	4,520,000.00	4,000.00	80	3,612,800.00	7.45	26,915.36	637.36
10	Maize	3,696,341.00	0.24	Cob	887,121.84	200,000.00	90	618,409.66	11.30	6,988.03	165.48
11	Eucalyptus	15,000,000.00	0.10	Chip, Sawdust	1,500,000.00	500,000.00	80	800,000.00	4.92	3,936.00	93.20
12	Coconut	1,433,041.00	0.25	Shell	353,961.13	302,439.07	80	41,217.65	18.26	752.63	17.82
13			0.57	Husk	809,668.17	714,659.86	100	95,008.31	16.41	1,559.09	36.92
14	Soy Bean	812,053.00	1.18	Stalk, Leap and Shell	955,786.38	873,824.17	70	57,373.55	16.23	931.17	22.05
15	Pineapple	2,598,000.00	0.588		1,527,624.00	1,332,088.13	90	175,982.28	15.76	2,773.48	65.68

Biomass Power Generation Statistics

According to the Energy for Environment Foundation in Table 9, there were 46 biomass power plants established throughout Thailand by the end of 2006. Fuels from some plants are from the waste rejected from their production process such as the sugarcane bagasse from sugar refineries, oil palm wastes from palm oil extraction plants, and rice straw and husks from rice mills.

Table 9: Biomass Power Generation Statistics (Source: Energy for Environment Foundation, 2008)

Fuel	No.Plants	Installed capacity (MW)
Rice husk/Eucalyptus bark	2	134.60
Rice husk	7	37.73
Rice straw	3	1.64
Sugarcane Bagasse	23	460.50
Black liquor	1	32.90
Oil palm wastes	1	1.50
Biogas	7	3.97
Municipal Solid Waste	2	1.20
Total	**46**	**674.033**

Local Availability

According to the study by Thaingpanit (2004), the advantages and disadvantages of biomass fuel can be broken down into the following:

Advantages

1) The growth in local economies from biomass fuel development in industries leads to increased income earnings associated with job creation.
2) Much less contribution to the Greenhouse Effect
3) Reducing the harmful effects of sulfur
4) Cheaper than other commercial fuel that has the same heat value
5) In-country production

Disadvantages

1) The causes of fluctuations in production quantity derive from:
   a. The weather
   b. The production based on the demand for the products
   c. The loss of agricultural areas into a town
   d. The difficulty of collecting dispersed sources of fuels

2) The collection of non-local sources of fuel results in:
   a. The increment in shipping and handling costs, especially the low bulk density biomass materials
   b. The risk of being unable to collect the required quantity
   c. The high requirement for investment in multi-fuel technology

3) The relative lack of financial support occurs because of:
   a. Instability in biomass supply
   b. The lack of belief in consistently available technology
   c. The lack of qualified workers in relevant technical and operational professions

According to research by Tabprayoon (2007) on critical success factor analysis of the commercial rice husk biomass power plants in Thailand, besides price and availability, some crucial success factors are the ability to access the resource and the possession of fuel in order to guarantee quantity. As the rice husk is one of multiple biomass types which are also a limited resource, the success factors should be similar or have a high tendency to apply to other types of biomass as well.

Therefore, it is reasonable to focus in this case on the local availability where the factory is located. According to the Energy for Environment Foundation, the agricultural product in Samut Prakan province is rice. In 2006-2007, total quantity of biomass residue was around 33.68 tons, consisting of 10,102.68 tons of rice husks and 23,572.92 tons of rice straw. However, the quantities of both biomasses have already been utilized as fuels. As a result, the possibility of the case company using biomass as an alternative fuel is ruled out.

Conclusion

The only possible alternative fuel for case company is bituminous coal. Regarding coal types, anthracite and graphite have high carbon, low volatile matter, and low moisture content but are hard to ignite. On the other hand, peat and lignite coals are easy to ignite but have high moisture, volatile matter, and low carbon content. Therefore, bituminous coal is commonly used for producing steam. For biomass alternatives, as the location is one of the critical factors, the focus in finding alternative fuel is to analyze local availability. And the result from the findings shows that the existing amounts of rice straw and rice husks are already taken.

3.2.2 Technology

The study of boiler technology will be based on compatibility with burning bituminous coal as the alternative fuel. According to the Department of Alternative Energy Development and Efficiency (DEDE), there are three types of combustion technologies supporting coal firing which are fixed-bed combustion, transportation bed combustion or moving bed combustion, and fluidized bed combustion.

Burning Theory

With the rising cost of fuel and global environmental concerns, much biomass boiler research has been conducted, including on combustion technologies. Some paper manufacturers have implemented the biomass technology after long research, cost assessment, and testing. Many combustion facilities can burn various types of biomass fuel, including wood, agricultural residues, and wood pulp.

According to Sukanjanajtee, the goal of combustion in the boiler is to convert biomass fuels into steam resulting from the heat released from the chemical reaction between fuel and oxygen. The unit of heat is calorific value or heating value. Two main chemical elements are carbon (C) and hydrogen (H_2). In the burning process, 1 mole of carbon reacting with 1 mole of oxygen produces 1 mole of carbon dioxide (CO_2). And 2 moles of hydrogen reacting with 1 mole of oxygen produces 2 moles of steam (H_2O). The formula can be written as:

$$C_nH_{2n+2} + (2n)O_2 \text{ ----> } (n)CO_2 + (2n)H_2O + heat$$

Without a balanced mixture of oxygen and fuel or a low quantity of oxygen in the burning process, release of carbon monoxide (CO) will occur due to incomplete combustion. CO is the unburned carbon (UBC) which still can circulate back to the combustion chamber in order to completely burn by 2 moles of CO reacting with oxygen.

$$2CO + O_2 \text{ ----> } 2CO_2$$

Excess Air

Excess air forced to enter the combustion chamber is essential for increasing the percentage of success in the burning process, but if it is too much, heat will lose along with its release via the flue gas. Therefore, a crucial measurement is to determine the minimum use of excess air.

Air Pollution

Both hot water and steam boilers emit air pollution resulting from fuel combustion which affects both humans and the natural environment over a wide area. The amount of pollution emitted into the atmosphere depends on various factors such as the types and consumption of fuel, as well as the characteristics of the boiler and the combustion. The major by-products from combustion boilers are Nitrogen Oxides (NO_x) and sulfur dioxide (SO_2).

Similar to other forms of renewable energy like solar and wind, biomass fuel produces less emissions than its fuel oil counterparts. The reason why the use of biomass fuel does not result in 100% clean air is biomass fuel still contains sulfur.

- Nitrogen Oxides (NO_x)

According to the United States Environmental Protection Agency, Office of Air Quality, Planning and Standards, emissions of NO_x from combustion are primarily in the form of Nitric Oxide (NO). There are two possible occurrences of NO, the first of which is the reaction of oxidation of nitrogen in fuel. Second is the reaction of nitrogen with oxygen in high temperatures. NO can be generated at up to 200,000 ppm when there is limited available oxygen and at air temperatures above 1,300C or 2,370F. In temperatures below 760C or 1,400F, the occurrence of NO happens much less frequently or not at all. Therefore, the lower the burning temperature, the lower the release of NO to the air will be.

- Sulfur Dioxide (SO_2)

While burning, the chemical reaction between sulphur and oxygen will release heat and produce SO_2 which not only corrodes the boiler's equipment such as the air heater, economizer, chimney, etc., but also is a suffocating odor to humans. SO_2 dissolves easily in water vapor, but it will then form acid. The interaction of this acid with other gases and particles in the air will form sulfates and some other elements that can harm people and the environment.

Types of Combustion

The three types of combustion are categorized by the fuel burning position inside the combustion chamber:

1. Fixed -bed combustion

In this technology, inserted fuel sits above the grate. Only the grate moves throughout the combustion process. The most common boiler using this combustion technology is the traveling-grate stoker (TGS).

Inside the combustion chamber, the particles will be inserted from the hopper onto the horizontal moving grate by a distributor. It uses a multi-fuel combustion from low to high grade of particle, except the particle that has a large fuel ratio such as anthracite. The bigger the size of the particle, the farther the distance it will be overthrown. The combustion process will start from the top to the bottom layers. The primary air passing above the grate will help increase completion of the burning process. The efficiency of burning is approximately 78-85%. The ash and incompletely burnt particles will fall into the ash pit below.

The speed of the grate is controllable to match with particular circumstances. However, the system is not suitable for fluctuation of moisture in the particles. Moreover, as the smoke and fly ash produced is high, some additional components such as a cyclone and scrubber are required for reducing dust and for fuel gas desulfurization before releasing into the environment. Usage of this combustion technology is for middle to large scale boilers.

2. Transportation bed combustion or moving bed combustion

Burning fuel in the air is the technological accomplishment of this system. By doing so, fuel is crushed into very small pieces. With light weight particles, they will float inside the combustion chamber, and so this approach helps mix particles and oxygen which leads to a high percentage of completely burnt particles. The best known boiler for this technology is the pulverized boiler.

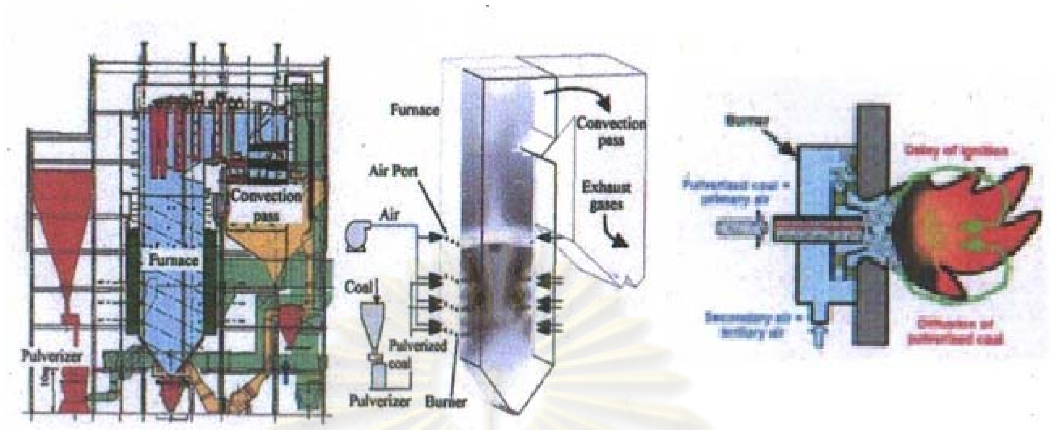

Figure 4: Pulverized Boiler (Source: DEDE, 2008)

The particles need to be crushed to around 0.003 inches, in order to float in the air while burning. The particles after resizing will mix with the primary air before being sprayed into the furnace. The benefit of the size of particle is that the heat from the combustion can increase up to 90%. And the efficiency of burning is approximately 88-91%. For the coal particle, the system is flexible for any grade of coal. And the slag that occurs will be removed from the combustion chamber by the disposal system. The temperature in the chamber goes up to 1200-1500C. With combustion at a high temperature, the production of Nitrogen Oxides (No_x) will occur more than at a lower temperature. In addition, the cyclone and scrubber are used just before releasing into the air since the ash is in high quantity and uncontrollable. Usage of this combustion is for a large scale boiler. Usually, it is utilized for producing steam under a pressure of 16-24 MPa.

3. *Fluidized bed combustion*

The inserted particles can float inside the combustion chamber because float sand, which is blown by nozzles install at the bottom of combustion chamber, acts like a bed to hold fuel in the air. The most commonly implemented boiler for this combustion type is the Circulating fluidized bed (CFB).

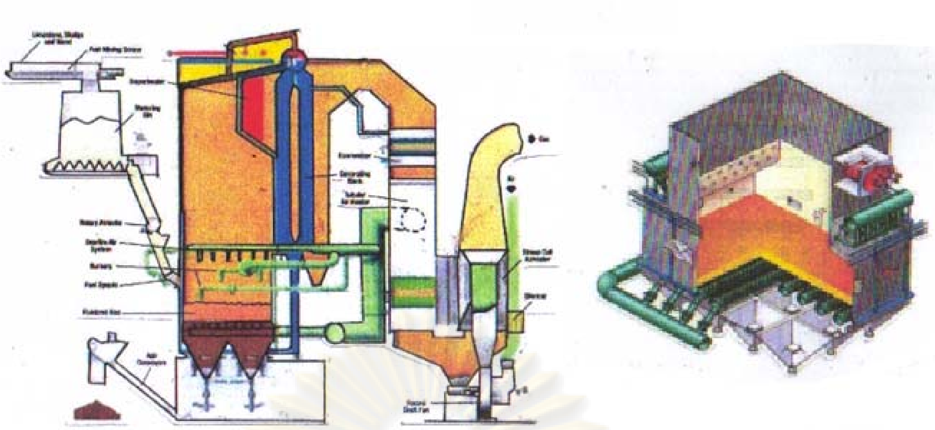

Figure 5: Circulating Fluidized Bed Combustion (Source: DEDE, 2008)

The bed for the CFB is made up of sand with hundreds of high-pressure nozzles below the bed. The fuel can stay long inside the sand bed until totally finished combusting, with the size of particles around 0-12 mm, and combustion efficiency from 85-90%. The solid fuel type, the quality, and the humidity of the particles are not limited as the system is flexible enough to withstand the fluctuation. The temperature of the sand bed helps stabilize and make consistent every area throughout the furnace. The steam’s temperature in the furnace is from 750 to 950C with a pressure of 1 to 25 atm. Therefore, the particles are completely burnt in a short period of time and do not cause the occurrence of clinker since the temperature will not go above the ash melting point. The limestone used as a particle bed is inserted to control sulfur dioxide released in the process of combustion. Also, a benefit of this system occurs when shutting down the bed. After shutting down, the bed usually can maintain enough heat or remain above 600C for 1-2 hours, and the remaining particles will still mix with the sand bed and be ready to burn for the next startup. There is no waste in remaining fuel unlike other burners. Usage of this combustion is for middle to large scale boilers.

3.2.3 Conclusion

There are two issues that must be addressed in selecting alternative fuel. They are the selection of technology and the selection of fuel types. The following concludes on the alternatives for each selection.

1) Technology

As pulverize combustion system are only available as large scale boilers, it is not applicable to the case study company as it is a high-pressure boiler and the company's boiler is a low-pressure boiler.

As a result, the proposed technology alternatives are as follows:

- Alternative 1 – Traveling Grate Spreader Stoker (TGS)
- Alternative 2 – Circulating Fluidized Bed (CFB)

2) Fuel Alternatives

The result from data analysis shows that the only feasible alternative fuel to propose for fuel oil replacement is bituminous coal. For coal type selection, sub-bituminous and bituminous coals are mainly utilized for steam generators; however, bituminous coal is more common to use due to its properties of higher heating value and lower percentage of moisture, ash, and sulfur than sub-bituminous coal. Other types of coal, such as anthracite and graphite, are hardly used as a fuel since they are difficult to ignite. Peat and lignite coals are still at an early stage of transforming into coal and contain high moisture with low carbon content. In addition, coal liquefaction and coal gasification are not applicable for analysis since they are still in early research.

For biomass, by the study of Tabprayoon (2007) and Thaingpanit (2004), one factor that helps promote success in utilizing biomass as a fuel is geography. To locate close to the source of energy is essential for ease of gathering fuel, to increase the power of ownership, lower cost of shipping and handling, etc. Thus, the research analyzed local agriculture and possible available biomass, and the study discovered that all potential biomass in the local areas was already utilized. In conclusion, bituminous coal is the only alternative fuel to be used in any types of combustion systems.

Chapter IV
Feasibility Analysis

This chapter describes the feasibility analysis of the proposed alternatives. The analyses cover technical, operational, environmental, and financial areas in order to confirm and justify the most suitable alternative. In the technical area, two combustion types—CFB and TGS—are studied in terms of their functionality and efficiency. In operational analysis, the study of work processes, operator requirements, and operation safety are covered. Concerns such as emission of NO_x and SO_2 from the process and emission control equipment are covered in the environmental analysis. In the financial analysis, calculations of NPV, IRR, and the payback period of alternatives are covered.

4.1 Proposed Alternatives

The alternatives for fuel replacement can be identified as three options:

Option 1: Continue using existing fuel oil boiler

Option 2: Convert current fuel oil combustion system to Circulating Fluidized Bed (CFB) and use bituminous coal as a fuel

Option 3: Convert current fuel oil combustion system to Traveling Grate Spreader Stoker (TGS) and use bituminous coal as a fuel

4.2 System Configuration for the Proposed Alternatives

Most components of CFB and TGS are similar, and the main difference is the combustion chamber. Also, given the technology of TGS, the required induced/forced draft fans are less due to the position of the fuel burnt in the chamber. Other than that, the feeding system, dust filter system, ash rejection system, etc. are similar. The list of some common components that can be reused, and others that are required to be installed follows:

Reusable Components

- Feed water pump
- Feed water tank
- Pipes feeding steam
- Valves/mountings
- Water drum
- Heat Recovery System
- Wet scrubber
- Stack

Required Installation

- Furnace parts and accessories
- Economizer
- Silica sand vibration screen (CFB)
- Multi-cyclone for dust collecting
- Electrostatic precipitator
- Coal crusher
- Electricals for power control sections
- Induced/forced draft fans and valves
- Coal handling system
  - Coal hopper
  - Coal bunker
  - Screw feeders
- Ash handling system
  - Ash conveyors
  - Ash hoppers

4.3 Technical Analysis

The following is a performance comparison of CFB verses TGS:

1) Technology

In Table 10, according to Sukarnjanajtee the general performances of CFB and TGS combustion systems can be evaluated as follows:

Table 10: Performance Comparison (Source: DEDE, 2008)

	Fluidized Bed Combustion	Traveling-Grate Spreader Stoker Combustion
Start-up system	Approx. 40-120 mins.	Approx. 30-60 mins.
Fuel type	Wide range of fuels	Wide range of fuels
Fuel size	0-12 mm.	10-20 mm.
Multi-Fuel Utilization	Difficult	Possible
Respond to changing heat demands	Slow	Fast
Fuel range (ash + moisture), %	< 60%	10-50%
Unburned carbon loss, %	0.25%	2-4%
Combustion temperature	750-950c	900-1100c
Particle residence time in the boiler	2-5 sec.	1.5-2 sec.
Excess air required, %	20-25%	50%
Excess air control	Possible	Difficult
Heat release rate, Btu/hr-ft2	300,000	700,000
Combustion efficiency, %	85-90%	78-85%

Advantages of CFB over TGS

- Flexibility in percentage of moisture and ash in fuels is more acceptable in CFB
- The lost of unburned carbon is lower
- Having low combustion temperature helps reduce emission of NO_x
- Particles are sustained inside the combustion chamber longer resulting in more complete burning before being ejected with the flue gas or ash
- Requiring less excess air and having more excess air control helps CFB to reduce the amount of heat lost with the flue gas
- CFB has a much lower heat release rate as it can more easily fire fuels, has better aerodynamics in the furnace volume, and a lower temperature resulting in lower amounts of emitted NO_x
- Combustion efficiency is higher, calculated from total heat released in combustion, subtracting heat lost in the flue gas

Advantages of TGS over CFB

- Startup time consumes only 30-60 minutes
- Multi-fuel utilization is possible
- Adjusting temperature in the combustion chamber can be done faster

The result of the performance comparison in Table 10 shows that CFB has more performance efficiency than TGS. Even though there are some advantages of TGS over CFB, they are less significant in contributing to the performance of the combustion system. For instance, TGS has more ability to burn multi-fuel, but for the case study company there is only one potential alternative fuel proposed. And so, although the multi-fuel flexibility function is supported, the case company is unlikely to have multi-fuel injected into the combustion chamber. Startup time and faster response on temperature adjustment are both less significant than the gain of less heat loss along with the flue gas. In addition, as particles reside in the combustion chamber longer, the percentage of lost unburned particles is lower than TGS.

The electrical power consumption of CFB is approximately 240 kW compared to 260 kW for TGS. On the other hand, electric power fuel oil boiler consumption is only about 150 kW. This power consumption is accumulated from all the fans—induced draft fan, secondary over fire fan, and pump, damper, feeder, etc.

Plant Layout

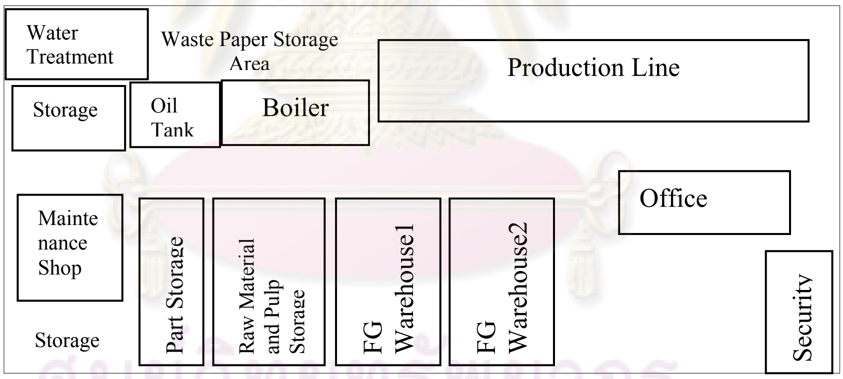

Figure 6: Plant Layout

The plant layout is shown in Figure 6. The space required for a new installation of CFB is around 13 x 20 x 16 M. and 9 x 25 x 11 M. for TGS. The fuel oil boiler dimensions are around 13 x 20 x 14 M. The dimension of the oil tank area is around 6 x 7 M; therefore, by combining the current boiler dimension and oil task areas, either of both implementations can be fit into the available space.

2) Alternative Fuel

The paper machine is operated around the clock: it requires assurance and consistency of steam generation. The reliability and availability of fuels in the short-run and long-run will illustrate the potential of the fuel. First identified is the amount of fuel monthly required and compared to the available amount. Second, analysis of each fuel for its reliability is conducted.

Coal Properties

According to the Energy for Environment Foundation, coal properties categorized into a proximate analysis and an ultimate analysis are as illustrated in Table 11. This research paper assumed that the heating value of coal is equal to the gross heating value in order to find the maximum quantity and space that will be required.

According to the Rural Technology Initiative (2008), the calculation of the Gross Heating Value (GHV) of fuel will show the highest possible heating value by taking into account the presence of water in fuel. The formula is:

$$GHV = HHV\ (1 - \text{Moisture Content(MC)} / 100)$$

In Table 11, the result from calculation of GHV is 29.93 MJ/Kg. The next step is to calculate the required quantities of coal in both CFB and TGS. The calculation is based on the output of water temperature of 180C to produce 22 tons of steam under pressure of 8 bar including their differences on combustion efficiencies. As a result, the required monthly quantity for CFB and TGS are 672 tons and 720 tons, respectively.

Lastly, by assuming a constant rate of coal production, which is currently around 909,000 million tons, it is calculated that the world's supply of coal will run out in approximately 200 years.

Table 11: Coal Properties (Source: DEDE, 2008)

	Fuel Oil	Bituminous Coal
Proximate analysis		
Moisture, %	N/A	14.50
Ash, %	N/A	3.00
Volatile Matter, %	N/A	43.00
Fixed Carbon, %	N/A	39.50
Ultimate Analysis		
Carbon, %	0.87	73.80
Hydrogen, %	0.10	4.90
Oxygen, %	N/A	20.30
Nitrogen, %	0.003	0.90
Sulfur, %	0.02	0.10
Chlorine, %	N/A	0.01
Ash, %	0.001	3.00
Moisture, %	N/A	26.00
Other Characteristics		
Bulk Density (kg/m3)	N/A	850
Higher heating value (MJ/kg)	43.00	35.00
Lower Heating value (MJ/kg)	41.58	31.00
Gross heating value (MJ/kg)	**41.58**	**29.93**

4.4 Operational Analysis

Generally, the CFB and TGS working processes are similar except for the combustion technology where for CFB, the fuels are burned in the air above the float sand bed by the pressurized air from nozzles below. Compared to TGS, fuel is inserted into the combustion chamber via the spreader where the smaller sizes are thrown a shorter distance than the larger sizes. For TGS, the moving grate in the bed for burning coal moves horizontally from one end to the other. When reaching the other end, any ash and unburned particles are all rejected to an ash hopper below.

For coal handling in the process, first coal is loaded into a hopper located above a belt conveyor which automatically transports the fuel and loads it to a bucket elevator on the boiler side. The elevator will then load the fuel to screw conveyors which directly connect to the combustion furnace. The speed of the feeding system is adjusted automatically according to the temperature and pressure in the furnace. The captured fly ash is ejected in three areas: under the combustion chamber, multi-cyclone, and ESP. The waste from the wet scrubber is drained to water treatment areas and cycles back to the wet scrubber after it has been treated.

Operators Required

Three boiler operators in every shift are required for both TGS and CFB, whereas the fuel oil boiler requires only two operators. There are two working processes for TGS and CFB that are unnecessary for a fuel oil boiler: fuel and ash handling. As coal has less heating value than fuel oil and is not liquid, the level of fuel quantity waiting to be fed to the combustion chamber needs to be monitored and refilled. Also, during the burning process, fly ash is generated in a quantity depending on the type of coal, combustion technology, and the dust control equipment. Therefore, one extra multi-skilled staff is required, including for fuel feeding and ash removal.

Safety of Operation

Boiler control and safety should include installations of controllers of float water level, a sand bed temperature alarm and lockout, a pressure switch for cutting firing at low steam demand, a steam safety valve, a temperature indicating controller for flue gas, etc. In addition, for CFB technology the temperature inside the combustion chamber has to be below 1500C since 1500-1700C is the sand's melting point resulting in the occurrence of clinkers. Clinkers can be harmful to the combustion chamber, such as blocking the air flow of the nozzles. For operators and staff, training courses will be important for assigning current fuel-oil operators to operate in the new system.

Coal Storage

As coal contains a certain amount of dust, controlling coal transportation will be important to reduce the spread of dust in the plant. Therefore, coal storage should be located near the boiler. In Figure 7, there is a storage area next to the oil tank. It normally stored some machinery parts and spares for the paper machine. From observation, these parts can be managed to fit into the indoor and outdoor storage near the maintenance shop, and so the storage, then, can be converted to coal storage which covers an area of 14 x 19 x 6 M. As the required monthly quantity for CFB and TGS are 672 tons and 720 tons, respectively, the approximate maximum coal supply that can be stocked is 23 days' supply for CFB and 17 days' supply for TGS, using a bulk density of 850 Kg/m^3.

Safety of Storage

In the storage, it is suggested to install a fire sprinkler system since spontaneous combustion is possible. Spontaneous combustion is the slow process of the formation of heat released from coal which reacts with oxygen in the air at one point. To prevent these incidents, the coal stack should have good air flow in order to reduce the concentration of heat released from coal. This approach is suitable for similar sizes of coal in the stack. If the coal contains a high amount of dust in the stack, to prevent spontaneous combustion, it is necessary to block air flow into the stack and keep the coal packed densely.

However, if there is smoke coming from the stack, pull coal which is in the smoking area out and spray water until the fire is out. The next step is to dry the wet coal approximately 5-10 minutes before using them. However, do not spray them with water if they are not intended to be used right after they are dried off.

4.5 Environmental Analysis

Regarding environmental concerns, pollution and emissions from the burning process will be analyzed and a recommendation will be made on environmental safety for both the boiler and the operators.

Dust Pollution Control Equipments

In both technologies, multi-cyclone and electrostatic precipitators (ESP) are installed for collecting dust that is generated from the combustion chamber. After particles have flown from the combustion chamber, they will enter a multi-cyclone before passing though an ESP. According to the Energy for Environment Foundation, the efficiency of multi-cyclones is up to 85%. The smallest particles that can be captured are 5 micrometers.

ESP efficiency includes very high performance on capturing dust, up to 99%. According to Wikipedia, “ESP is a particulate collection device that removes particles from a flowing gas using the force of an induced electrostatic charge.” A negative voltage of 30,000-60,000 volts is charged between wires and grounded plates. When the particles pass through the electric field, their property is changed to ionized particles after which they stick to the grounded plate. After that, the particles are removed from the plate by the automatic rapper to the hopper below (Wikipedia, 2009).

Coal Ash Disposal

From both technologies, ash is injected in three areas which are from the combustion chamber and dust collectors. Monthly ash content in coal is calculated at 3%, resulting in approximately 20 tons and 21 tons ejected from CFB and TGS each month.

There are some benefits from coal ash such as increasing resistance to corrosion in cement, providing a raw material for making light weight bricks, etc. However, coal ash has an alkaline property which has to be treated before reuse. For an alternative option on coal ash disposal, the case study company can hire waste management companies for handling this matter. The cost is 2,000 baht per ton of any kind of waste including shipping and handling.

Flue gas Pollution Control Equipment

According to the United States Environmental Protection Agency (EPA), NO_x is significantly harmful air pollution. The formation of ozone (O_3) and acid rain occur in reaction with the atmosphere. “NO_x present in flue gas generally comes from two sources: the oxidation of nitrogen compounds in the fuel (fuel nitrogen oxides) and reaction between the nitrogen and oxygen in the high temperature of combustion air (thermal nitrogen oxides)” (Anderson, Kavidass, and Norton, 2000). SO_2 only occurrs by chemical reaction between sulphur and oxygen.

According to the US EPA, a wet scrubber inside the stack can simultaneously remove NO_x, SO_2, and fly ash. The water in a wet scrubber flows downward facing upward flue gas. The water is mixed with limestone and either alkali or hydrogen peroxide as the liquid to capture SO_2 and NO_x. However, CFB can capture more SO_2 due to the ability to mix limestone with fuel before inserting it in the combustion chamber. In addition, as pressurized water is sprayed, some particles that are attached to the chamber wall will go down the drain pipe. The water in the drain pipe connects to a treatment pool which consists of three stages. The first stage is to leave the dirt to settle before the water cleaning process in the second stage. And lastly, the treated water will be pumped back to use in the scrubber.

Law and Regulation

Table 12: Emission Control (Source: Ministry of Natural Resources and Environment, 2009)

	Ministry of Natural Resources and Environment	Fluidized Bed Combustion	Traveling-Grate Spreader Stoker Combustion
SO2 Emissions, ppm	360	< 200	< 250
Nox Emissions, ppm	200	< 100	< 100

According to the Ministry of Natural Resources and Environment has not issued law and regulations on a maximum CO_2 emission level yet. However, there are regulations for SO_2 and NO_x emission in which the emission level must be less than 360 ppm and 200 ppm, respectively. Both technologies meet the emission control standard. For a 22-ton steam CFB, the released pollution levels are far more efficient than the guidelines in which sulfur dioxide must be less than 200 ppm, and nitrogen oxides less than 100 ppm. Also, for a 22-ton steam TGS, sulfur dioxide is controlled to release less than 250 ppm, and nitrogen oxides are less than 100 ppm.

Environmental Safety

There are some processes that could help reduce pollution emissions as follows:

- For lower NO_x emission
  - Reduce peak temperature
  - Reduce residence time at high combustion temperatures
  - Control excess air
  - Use solvent such as limestone

- For lower SO_2 emission
  - Using a solvent such as limestone in combustion chamber and in wet scrubber

- For lower CO_2 emission
  - Control amount of excess air while burning
  - Consistent maintenance for efficiency of boiler

Some precautions for the safety of operators and staff are:

- To wear dust filter mask
- To wear eye protection glasses
- To wear heat resistant clothes and gloves
- To wear safety head protection

4.6 Financial Analysis

The financial feasibility study covers analysis of alternative fuel and technologies. Net Present Value (NPV), Internal Rate of Return (IRR), and payback periods are financial tools used to measure their cost efficiency.

Source of Fund

The investment of either implementation can be funded by the studied company. This can be done using profit earned from many years of business, and no financial problems are foreseen on this for the company.

Financial Analysis

The financial analysis is divided into two cases which are CFB modification and TGS modification. The value of $\beta_{unleveraged}$ in the financial parameter is from research conducted by NYU. The gathered data are from five-year records of selected companies categorized by industry. Since this value of $\beta_{unleveraged}$ in paper products is only found rather than calculated uniquely for the case company, the value of $\beta_{unleveraged}$ in this case is assumed to be the same value. In addition, the revenue parameter in the calculation represents the cost savings of alternative fuel over the expense of utilizing fuel oil.

The calculation of NPV, IRR, and payback period of each case are illustrated as follows:

1. CFB Modification

Table 13: Financial Analysis for CFB Modification

COST ESTIMATION		
Furnace parts and accessories	1,800,000.00	Baht
Controller, transmitter and sensor	500,000.00	Baht
Economizer	800,000.00	Baht
Silica sand vibration screen	150,000.00	Baht
Induced/forced draft fans	640,000.00	Baht
Dust separators	1,400,000.00	Baht
Fuel feeding system	1,200,000.00	Baht
Civil work	4,000,000.00	Baht
Fuel and ash transportations	5,000,000.00	Baht
MISC.	1,600,000.00	Baht
Total	17,090,000.00	Baht

TECHNICAL PARAMETERS		
Type of fuel	Bituminous Coal	
Plant Life	7	yr
Efficiency of combustion sytsem	85	%
Calorific Value of fuel (Gross Heating Value, GHV)	29.93	MJ/kg
Fuel Consumption	8,064.00	tons/month

FINANCIAL PARAMETERS		
Equity	17,090,000.0	Baht
Loan:		
Loans	0	Baht
Discount rate (WACC)	10.00	% p.a
- Cost of Equity		
Risk Free Rate	4.50	%
βlevered	0.60	
βunlevered	0.60	

SAVING PARAMETER		
Fuel cost saving	67,714,560.00	Baht

COST PARAMETER		
O&M cost	9	% of equipment cost
Equipment cost for O&M	584,100.00	Baht
Fuel Expense	15,805,440	Baht/yr
- Fuel price	1,900	Baht/ton
- Ash disposal	2,000	Baht/ton
- Amount of fuel	672.00	tons/month
- Ash disposal cost	483,840	Baht/yr
Annual power bill	9,600,000	Baht/yr
Administration cost	480,000	Baht/yr
Other		
Insurance (% of plant cost)	0.75	%
Income Tax rate		
-year 1-7 (after commissioning)	30	% p.a.
Depreciation		
Depreciation of the project	2,441,429	Baht/yr
Depreciation = (Total project cost)/ plant life		

CASH INFLOW (Million Baht)	2010	2011	2012	2013	2014	2015	2016	2017
Revenue								
Total Revenue	-	67.71	67.71	67.71	67.71	67.71	67.71	67.71
Tax depreciation return	-	0.73	0.73	0.73	0.73	0.73	0.73	0.73
Loan drawdown	-	-	-	-	-	-	-	-
Total Loan	-	-	-	-	-	-	-	-
TOTAL CASH INFLOW	-	68.45	68.45	68.45	68.45	68.45	68.45	68.45
CASH OUTFLOW								
Investment cost	17.09							
Annula power bill	-	9.60	9.60	9.60	9.60	9.60	9.60	9.60
Administration cost	-	0.48	0.48	0.48	0.48	0.48	0.48	0.48
O&M expenses								
9% of equipment cost	-	0.58	0.58	0.58	0.58	0.58	0.58	0.58
Insurance expense	-	0.13	0.13	0.13	0.13	0.13	0.13	0.13
Total Cost	17.09	10.79	10.79	10.79	10.79	10.79	10.79	10.79
TOTAL CASH OUTFLOW	17.09	10.79	10.79	10.79	10.79	10.79	10.79	10.79
NET CASH FLOW on Project	(17.09)	57.65	57.65	57.65	57.65	57.65	57.65	57.65
NPV (Million Baht)	239.63							
IRR (%)	370%							
Payback Period (Month)	3							

2. TGS Modification

Table 14: Financial Analysis for TGS Modification

COST ESTIMATION		
Furnace parts and accessories	1,265,000.00	Baht
Controller, transmitter and sensor	500,000.00	Baht
Economizer	800,000.00	Baht
Induced/forced draft fans	500,000.00	Baht
Dust separators	1,400,000.00	Baht
Fuel feeding system	1,200,000.00	Baht
Civil work	3,400,000.00	Baht
Fuel and ash transportations	5,000,000.00	Baht
MISC.	1,200,000.00	Baht
Total	15,265,000.00	Baht

TECHNICAL PARAMETERS		
Type of fuel	Bituminous Coal	
Plant Life	7	yr
Efficiency of combustion system	78	%
Calorific Value of fuel (Low Heating Value, LHV)	29.93	MJ/kg
Fuel Consumption	8,640.00	tons/month

FINANCIAL PARAMETERS		
Equity	15,265,000.0	Baht
Loan:		
Loans	0	Baht
Discount rate (WACC)	10.00	% p.a
- Cost of Equity		
Risk Free Rate	4.50	%
βlevered	0.60	
βunlevered	0.60	

SAVING PARAMETER		
Fuel cost saving	66,585,600.00	Baht

COST PARAMETER		
O&M cost	9	% of equipment cost
Equipment cost for O&M	509,850.00	Baht
Fuel Expense	16,934,400	Baht/yr
- Fuel price	1,900	Baht/ton
- Ash disposal	2,000	Baht/ton
- Amount of fuel	720.00	tons/month
- Ash disposal cost	518,400	Baht/yr
Annual power bill	10,400,000	Baht/yr
Administration cost	480,000	Baht/yr
Other		
Insurance (% of plant cost)	0.75	%
Income Tax rate		
-year 1-7 (after commissioning)	30	% p.a.
Depreciation		
Depreciation of the project	2,180,714	Baht/yr
Depreciation = (Total project cost)/ plant life		

CASH INFLOW (Million Baht)	2010	2011	2012	2013	2014	2015	2016	2017
Revenue								
Total Revenue	-	66.59	66.59	66.59	66.59	66.59	66.59	66.59
Tax depreciation return	-	0.65	0.65	0.65	0.65	0.65	0.65	0.65
Loan drawdown	-	-	-	-	-	-	-	-
Total Loan	-	-	-	-	-	-	-	-
TOTAL CASH INFLOW	-	67.24	67.24	67.24	67.24	67.24	67.24	67.24
CASH OUTFLOW								
Investment cost	15.27							
Annula power bill	-	9.60	9.60	9.60	9.60	9.60	9.60	9.60
Administration cost	-	0.48	0.48	0.48	0.48	0.48	0.48	0.48
O&M expenses								
9% of equipment cost	-	0.51	0.51	0.51	0.51	0.51	0.51	0.51
Insurance expense	-	0.11	0.11	0.11	0.11	0.11	0.11	0.11
Total Cost	15.27	10.70	10.70	10.70	10.70	10.70	10.70	10.70
TOTAL CASH OUTFLOW	15.27	10.70	10.70	10.70	10.70	10.70	10.70	10.70
NET CASH FLOW on Project	(15.27)	56.54	56.54	56.54	56.54	56.54	56.54	56.54
NPV (Million Baht)	236.34							
IRR (%)	337%							
Payback Period (Month)	3							

Result of Financial Analysis

Table 15: NPV, IRR, and Payback Period Calculations

		CFB	TGS
Bituminous Coal	IRR (%)	370%	337%
	NPV (Million Baht)	239.63	236.34
	Payback Period (Month)	3	3

The modification of the fuel oil combustion system to CFB returns a NPV value of 239.63 million baht and IRR value of 370%. For the TGS modification, it returns a NPV value of 236.34 million baht and 337% IRR value. CFB has NPV and IRR values greater than TGS which suggests in financial terms that CFB is a better option for investment than TGS.

4.7 Discussion of Results

The framework for the research includes technical, environmental, operational, and financial analysis. In technical analysis, two alternatives of technology are analysis in terms of flexibility and burning efficiency. CFB has shown more advantage over TGS in better utilized fuel and electric power consumption in CFB.

For operational analysis, both CFB and TGS obtain similar working process. The mainly difference is the combustion chamber. Automatic functions and central control enhance effectiveness of working process which might lead to the reduction of human resource. However, since coal is solid and required larger amount input into combustion chamber in order to produce the same output as fuel oil combustion system, more fuel feeding system is required including operator to manage the flow. Instead of two operators in fuel oil boiler, these systems are required approximately three operators to control the steam production process.

For environment concern, both technologies have toxic elimination components installed. Before flue gas is released into atmosphere, it is cleaned up by multi-cyclones and ESP. Regarding to the regulation of Ministry of Natural Resources and Environment, Thailand, CFB and TGS show significant numbers of emission of NO_x and SO_2 comparing to the regulation. However, SO_2 emission in CFB is lower than TGS, as it allows to capture SO_2 in combustion chamber which helps eliminate SO_2 before releasing through atmosphere.

In financial analysis, bituminous coal with implementation of CFB shows the highest result of NPV and IRR which are 239.63 million baht and IRR value of 370%, respectively. Comparing to TGS values, the NPV value is 236.34 million baht, and IRR value is 337%. The payback period of both is the same which is at 3-month period. The result of analysis shows that by using bituminous coal as a fuel, the cost of production can be reduced to 8.5% of the original cost.

Chapter V

Conclusion and Recommendation

This chapter is the conclusion and recommendation of the research. The result is obtained from the steps of gathering data on alternative fuels and technology, proposing alternative fuels and technology options, and conducting feasibility study in technical, operational, environmental, and financial areas. Also, a recommendation on future study is provided at the end of the chapter.

5.1 Research Conclusion

The alternative fuels to replace fuel oil have been sought as fuel oil price rises steeply. As a result, it is essential to conduct feasibility study on alternative fuels in order to reliably lower production cost. The most promising alternative fuels to analyze are biomass and coal. Since biomass and coal use different combustion compared to fuel oil, the technical alternatives of new machine replacement are also studied and justified. The framework for the research is the analysis of the current boiler in terms of processes, components, and requirements. Next, the analysis of available alternatives of technologies and alternative fuels is conducted. And potential alternatives are proposed for further analysis in technical, environmental, operational, and financial areas.

Current Boiler

The requirements of steam for feeding the paper production are 180C temperature water to produce 22 tons of steam, and a pressure of steam of 8 bar. In addition, the age of the boiler is approximately 18 years already, and the normal life of a boiler is about 20-25 years. The condition of the boiler is still good, and so in this research the boiler life is assumed to be 7 years.

Available alternatives

From analysis of locally available biomass, rice husks and rice straw are two products that are available. In 2006-2007, the biomass residue was around 33.68 tons, which consists of 10,102.68 tons of rick husks and 23,572.92 tons of rice straw. However, this residue has already been utilized as fuel. Another type of alternative fuel analyzed is coal. There are three formations – gasification, liquefaction, and solidity.

Since the discovery of natural gas, coal gasification had been neglected in industries and in household use due to the cleaner energy and higher heating value of natural gas. However, for the future the return of coal gasification in industry and household is possible since it is more environmentally friendly than direct coal burning. Liquid coal is not yet available as a commercial fuel as it is still under research. Next, the types of solid coal are divided into peat, lignite, sub-bituminous, bituminous, anthracite, and graphite. Even though anthracite and graphite obtain high carbon and low volatile matter, they are hard to ignite. Compared to peat and lignite coals, they are easy to ignite but contain high quantities of moisture, volatile matter, and low carbon. With sub-bituminous and bituminous coal, since sub-bituminous coal has more volatile matter and moisture, bituminous coal is more commonly used for steam production.

According to DEDE, coal fire boilers commonly include three technologies - the traveling-grate stoker (TGS), pulverized, and the circulating fluidized bed (CFB) technologies. The pulverized combustion system is first to be eliminated from consideration since it is applicable only for high pressurized boilers. As a result, only bituminous coal is proposed as an alternative fuel in this research along with CFB and TGS technologies.

Feasibility studies

There are three cases of alternatives for the feasibility study, which are:

Option 1: Continue using existing boiler

Option 2: Convert current fuel oil combustion system to Circulating Fluidized Bed (CFB) and use bituminous coal as a fuel

Option 3: Convert current combustion sytem to Traveling Grate Spreader Stoker (TGS) and use bituminous coal as a fuel

The result from the feasibility study shows that using bituminous coal with CFB technology is the best alternative for the case study company. In technical analysis, CFB shows more advantages than TGS in terms of burning efficiency, flexibility in the content of fuel, a lower percentage of heat lost along with the flue gas and fly ash, power consumption efficiency, etc.

For operational analysis, the two technologies are mainly different in the process of the combustion chamber. Fuel handling and ash removal are processes that are required attention. The dimensions of the modified CFB can fit into the current space of the boiler, but the height of the roof needs to increase. Compared to TGS, the required length of the space is longer than the current usage space. However, the extra space can come from the oil task area which will not be utilized the same way for both combustion technologies. For coal storage, by intended to eliminate dust pollution from coal transportation in the plant area, it is recommended to replace spare part storage next to the oil tank area and turn it into coal storage. With some organization, those parts can possible be fit into other storage areas in the plant.

In environmental analysis, the benefit of having high burning efficiency in CFB is less use of fuel, and fewer emissions. In addition, CFB allows reduction of SO_2 in two stages. First, limestone can be inserted with fuel in the combustion chamber, and a second stage involves spraying limestone in the wet scrubber. In comparison to TGS, SO_2 can only be captured in the wet scrubber. For NO_x emission concerns, as the temperature inside the combustion chamber in CFB is lower than TGS, the chance of NO_x emission is lower.

The financial analysis shows that CFB's NPV and IRR values are greater than TGS' values. CFB returns a NPV value of 239.63 million baht and IRR value of 370%. For TGS, the NPV value is 236.34 million baht, and IRR is 337%. As a result, CFB has a better economic and financial efficiency.

In conclusion, CFB is more efficient than TGS in areas of technology, environment, and finance. By utilizing bituminous coal and CFB combustion system, production cost is reduced to 8.5% of current production cost.

5.2 Recommendation on Selection of Alternative

The result from feasibility study shows that the company should convert the current combustion system and use bituminous coal as a fuel. Both combustion types, Circulating Fluidized Bed (CFB) and Traveling Grate Spreader Stoker (TGS) are efficient, but CFB has higher technical performance, more environmental friendly, and more financial efficiency than TGS. Therefore, it is recommended that the company use CFB with bituminous coal as a fuel.

5.3 Recommendation on Project Implementation

Some critical guidelines and concerns for transition are:

- The reliability of supplier by focusing on their reputation, references on their clients, etc.
- Project timelines
- Material and functions of boilers including safeguard controls

  For example, the alarm is expected to be set off when water cannot feed into the steam drum including the automatic blow down steam when the pressure of steam reached is higher than required
- Monitor closely a set of tests on boiler functionality in order to eliminate errors that might impact the project timelines

  For example, after finishing installing water pipes, normally the supplier will conduct a test on the air tightness of the water pipes – a hydrostatic test which is to drain the pipes with water under a pressure of 25 kg/cm^2 and close it for 1 hour. The pipes with perfect seals will have pressure constant at 25 kg/cm^2. If the company is not working closely with the supplier, the result of the test might be ignored and work may continue on to the next process, which is to build a wall to cover the pipes. If the problem with air tightness is detected later, the wall will need to be demolished and the test performed again
- Warranty period

5.4 Future Study

Since the boiler system has only seven years of its useful life remaining, the company will have to re-evaluate the whole system soon. By that time, due to continuous research effort to search for alternative energy source there may be other fuel types that should be included for consideration. For example, Coal-Water Slurry/Mixture (CWM) technology that seems to be another cost efficient fuel if it becomes commercially available.

CWM is composed of 70% powder coal, 30% water, and 1% additives. By mixing coal with water, the outcome is slurry, which is a similar formation to liquid fuel. The coal utilization in CWM can be low-grade coals such as lignite and sub-bituminous, resulting in lower fuel cost compared to bituminous coal's price. The other advantages of CWM besides cost savings are easy handling in transportation, reduction in the risk of self-explosion or self-ignition, stability, and required smaller storage area. CWM has also been studied in many countries such as China, Japan, Italy, and Australia.

According to the Department of Industrial Works, Ministry of Industry, Thailand, CWM has currently undergone research and development by Siam Cement Group. If the research is successful, CWM will be widely available commercial fuel for industries in Thailand.

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Biography

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