

# Life Cycle Assessment (LCA) in Pulp & Paper Mills: Comparison Between MFO With Biomass in Lime Kiln

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## ABSTRACT

Pulp and paper mills keeps trying to take advantage of renewable energy as an energy source. One of utilization is used bark as renewable energy source to substitute fossil fuel. Bark from wood preparation utilized in bark gasifier to produced syngas as primary fuel in lime kiln. The aim of the study is to evaluate the effects of biomass utilization to environment using life cycle Assessment (LCA) method. The “gate to gate” approach was used to evaluate two scenarios of different fuel combination: (1) 75% biomass and (2) 100% MFO as primary fuel in the lime kiln for 1000 kg CaO. Evaluation of environment impact related to each scenario using ISO 14040 (2006) that consist of goal and scope definition, inventory analysis, life cycle impact assessment (LCIA) and interpretation. Result shown used biomass to produce syngas as fuel in lime kiln has impact to global warming 4.25E+01 kqCO<sub>2</sub> /ton CaO. Its lower than if used MFO that impact to global warming 6.91E+01 kqCO<sub>2</sub>/ ton CaO. For increased environmental quality, using 100% biomass as primary fuel in lime kiln is recommended.

**Keywords:** Biomass, bark gasifier, lime kiln, pulp and paper

## 1. INTRODUCTION

The pulp and paper industry is an industry that plays an important role in the Indonesian economy. Paper products and their derivatives are needed in large quantities and are widely used in community activities. The use of paper is widely used as a medium or a place to print, write, draw, wrap, and use tissue, usually related to food and hygiene. Industries and offices also use a lot of paper products and their derivatives that are used as print media, wrapping media, writing media, until now they are widely used for water & food cups as a substitute for plastic packaging [1].

The amount of pulp and paper production certainly requires enormous energy [2]. The use of fossil energy as the main energy source will certainly have an impact on the environment in the form of air, water and land emissions [3]–[6]. This impact certainly affects the course of the production process so that slowly the use of fossil energy sources is starting to be replaced with renewable energy sources [7]. The primary energy used

to produce pulp is 12.91 Tj/kt and produces emissions of around 0.30 kt CO<sub>2</sub>/kt of product [8].

The ratio of primary energy use in pulp & paper production in Europe is around 1.6% fuel, 3.4% coal, 32.9% BBG and 59.8% biomass. Development in the use of renewable energy continues and one that has started to be implemented is the use of gasification by utilizing biomass in the form of bark [9].

PT. OKI Pulp & Paper Mill is the biggest pulp mill in South Sumatera with 2,800,000 production capacity. This mill used renewable energy as energy resources to support production. Bark from wood preparation used to produce syngas in Bark Gasifier. Gasification is a method of thermochemical conversion of solid fuel into synthetic gas (syngas) in a gasifier container by supplying the agent [10], [11]. Gasification such as hot steam, air and others [12], [13]. Syngas is a gas capable of burning and can be used as a source of renewable energy to replace fossil energy sources. In the pulp & paper mill, syngas can be used as fuel in Lime Kiln as a

substitute for Liquid Natural Gas (LNG) and Marine Fuel Oil (MFO) [4], [5], [14]. The use of LNG to replace MFO in the pulp & paper production process has the potential to reduce about 20% of greenhouse gases [15]. Syngas produced from the gasifier unit cannot replace fossil energy as a whole in the lime kiln unit. MFO is still needed at start-up and as a backup when the gasifier unit has problems [16].

By utilizing biomass as an energy source, of course it will reduce the impact on the environment, but this needs to be re-examined using the Life Cycle Assessment (LCA) [17]. LCA is a compilation and evaluation of inputs, outputs and potential environmental impacts of all stages of the product life cycle, starting from the raw materials obtained until the product is used or disposed of [18]. LCA is not only used to increase efficiency and reduce environmental impacts but can also be used to analyze the use of biomass as an energy source to replace fossil energy [19], [20]

The potential environmental impacts that can be caused at each phase of energy supply in the pulp & paper industry can be analyzed using LCA by calculating the environmental load based on an inventory analysis of the use of the resources used [21]–[23]. This allows LCA to be used to analyze the effectiveness of Bark Gasifier utilization in pulp production. One of the results of the LCA study of pulp & paper products in Portugal shows that reducing the environmental impact can be done by replacing fossil energy sources with renewable energy source [24]. Based on this research, it is concluded that the results obtained from the LCA can be used as a source of information to minimize pollution and energy efficiency in order to support the sustainability of the company and fulfill the reduction of greenhouse gas emissions set by the government.

## 2. RESEARCH METHODS

Life Cycle Assessment (LCA) method implemented based on principles and framework in ISO 14010:2006 that consist of goal and scope definition, inventory analysis, life cycle impact assessment (LCIA) and interpretation. The goal of this assessment is to compare the environment impacts of lime kiln using syngas from bark gasifier with lime kiln using MFO as fuel. In this paper, study is done in two alternatives, the first which is interested in the production of CaO from lime kiln with syngas of bark gasifier, and the second alternative is interested to the production of CaO from conventional lime kiln. The functional unit is 1 ton of CaO production in lime kiln unit process.

Assessment used SIMAPRO v.9 software with ecoinvent 3.5 database. This database is used as an approach reference for the data to be assumed.

Production data that has been processed for one year of production has used as primary data and supporting data are used from some of the closest and most relevant references.

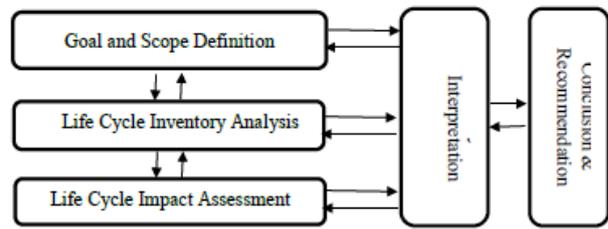


Figure 1 Research Method

This research was conducted in one of the pulp & paper manufacture that have used syngas produced from the bark gasifier as an energy source in lime kiln. This gasifier uses bark, fines and pins which are a by-product of the chipping process in the Wood Preparation unit. The scope is limited by the gate to gate system of the utilization syngas from gasifier unit to produce CaO in lime kiln.

## 3. RESULT AND DISCUSSION

### 3.1. Life Cycle Inventory

Inventory is carried out based on material input and output in the system. Input data consists of raw material requirements, energy / electricity, and water. The output is syngas production and ash that out from cyclone unit. Table 1 shows an inventory of 1 MJ syngas production.

Table 1. Life cycle inventory for 1 MJ syngas

|                     | Value    | Unit |
|---------------------|----------|------|
| <b>Input</b>        |          |      |
| Bark, fines and pin | 1.81E-04 | ton  |
| Water               | 7.19E-05 | m3   |
| Lime Stone          | 7.79E-06 | ton  |
| Electric Power      | 7.17E-08 | MW   |
| LP Steam            | 1.99E-04 | ton  |
| Diesel Oil          | 2.68E-04 | L    |
| <b>Output</b>       |          |      |
| Ash                 | 5.42E-06 | ton  |

No mention emission released to environment due to all gasifier product direct flow lime kiln to burn lime stone. In lime kiln syngas mixed with methanol, H2 and MFO. Methanol is recycled product from VE unit. This unit evaporated black liquor from pulp making unit and recovered weak black liquor to be heavy black liquor (HBL), its will be used in fuel in recovery boiler unit.

H<sub>2</sub> produced in Alkaline Chlorine Plan unit which is the main product is O<sub>2</sub> to support process in pulp making unit. MFO and diesel oil used for start-up and backup due to if bark gasifier not stable and low performance.

Syngas burned in lime kiln to produce CaO. Lime kiln designed can used 3 kinds of fuel such as MFO, LNG and syngas. Each fuel can be used 100% or mixed depend on demand. In this study used 2 scenarios to do the life cycle assessment. First scenario used actual operational that used syngas as primary fuel. This scenario used operational data a in a year. Second scenario used MFO as primary fuel without syngas and still support by methanol and H<sub>2</sub>. In this scenario substitute syngas with MFO based on calorific value. The output data CaO products and emissions released to the environment in process. Table 2 shows an inventory of 1000 kg of CaO.

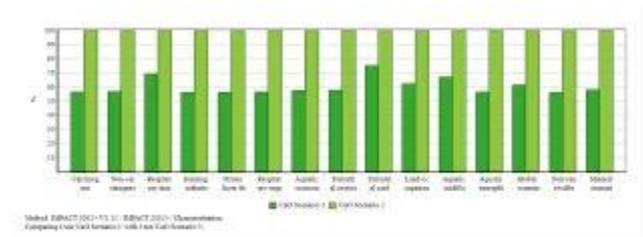
**Table 2.** Life cycle inventory for 1 ton CaO production

| Styles           | Scenario 1 | Scenario 2 | Unit |
|------------------|------------|------------|------|
| Input            |            |            |      |
| Syngas (Biomass) | 4.12       | -          | MJ   |
| MFO              | 34.77      | 134.98     | L    |
| Lime Mud         | 1.58       | 1.58       | ton  |
| Lime Stone       | 0.13       | 0.13       | ton  |
| Methanol         | 0.05       | 0.05       | ton  |
| H <sub>2</sub>   | 1.46       | 1.46       | ton  |
| Electric Power   | 0.75       | 0.75       | kw   |
| MP Steam         | 0.01       | 0.01       | ton  |
| Output           |            |            |      |
| Particulate      | 0.03       | 0.03       | kg   |
| NOx              | 0.27       | 0.27       | kg   |
| TRS              | 0.0037     | 0.0037     | kg   |
| SO <sub>2</sub>  | 0.01       | 0.01       | kg   |

### 3.2. Life Cycle Inventory

Data for scenario 1 and 2 processed in SIMAPRO v.9 and for database used similar with characteristic in ecoinvent database. Analysis impact in this research used Impact 2002+ method [25]. Result of this LCIA can be seen in Table 3.

This method included characterization and damage impact assessment in one calculating. In Table 3 shown characterization impact assessment, damage impact assessment and single score impact assessment. Characterization impact assessment is an assessment of the amount of substances that contribute to the impact category in CaO production based on its characterization factors as shown in Table 3. Damage impact assessment analysis is used to evaluate the impact of the resulting damage based on the impact of its characterization. Table 4 shown the categories of damage caused by CaO production activities in various scenarios.



**Figure 2.** Characterization of comparison used biomass and MFO for 1000 kg CaO production

**Table 3.** Characterization of comparison used biomass and MFO for 1000 kg CaO production

| Impact category         | Unit                                   | Scenario 1 | Scenario 2 |
|-------------------------|--|------------|------------|
| Carcinogens             | kg C <sub>2</sub> H <sub>3</sub> Cl eq | 7.22E-01   | 1.27E+00   |
| Non-carcinogens         | kg C <sub>2</sub> H <sub>3</sub> Cl eq | 8.79E-01   | 1.55E+00   |
| Respiratory inorganics  | kg PM <sub>2.5</sub> eq                | 1.07E-01   | 1.54E-01   |
| Ionizing radiation      | Bq C-14 eq                             | 2.78E+03   | 4.95E+03   |
| Ozone layer depletion   | kg CFC-11 eq                           | 7.64E-05   | 1.36E-04   |
| Respiratory organics    | kg C <sub>2</sub> H <sub>4</sub> eq    | 7.58E-02   | 1.34E-01   |
| Aquatic ecotoxicity     | kg TEG water                           | 1.59E+04   | 2.77E+04   |
| Terrestrial ecotoxicity | kg TEG soil                            | 3.46E+03   | 5.96E+03   |
| Terrestrial acid/nutri  | kg SO <sub>2</sub> eq                  | 2.79E+00   | 3.70E+00   |
| Land occupation         | m <sup>2</sup> org.arable              | 5.72E-01   | 9.14E-01   |

**Table 4.** Life cycle inventory for 1 ton CaO production

| Damage Category   | Unit       | Scenario 1 | Scenario 2 |
|-------------------|------------|------------|------------|
| Human Health      | DALY       | 8.02E-05   | 1.17E-04   |
| Ecosystem Quality | PDF*m2*yr  | 3.17E+01   | 5.34E+01   |
| Climate Change    | kg CO2 eq  | 4.25E+01   | 6.91E+01   |
| Resources         | MJ primary | 6.32E+03   | 1.12E+04   |

Based on Table 4, there are several units to determine the magnitude caused by impact damage, namely DALY, PDF \* m2 \* yr, primary MJ and kg CO2eq. DALY is a measure that a person receives from the total burden of disease, expressed as the number of years lost due to disability health problems, or premature death. One DALY is the same as one year of healthy life lost. There are 6 categories of impact characterization based on the damage factors that are grouped into the human health category, namely carcinogenic, non-carcinogenic, respiratory inorganic, ionizing radiation, ozone layer depletion, and respiratory organic.

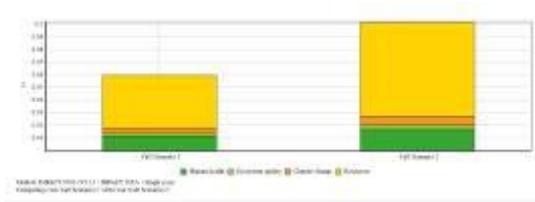
PDF \* m2 \* yr is the part of a species / ecosystem that has the potential to be lost per m2 per year, is a unit used to measure the impact on an ecosystem. One PDF \* m2 \* yr is the same as the destruction of 1 m2 of species or ecosystems on the earth's surface in 1 year. The impact characterization categories grouped under the ecosystem quality category are: aquatic ecotoxicity, terrestrial ecotoxicity, terrestrial acid / nutrient, and land occupation.

Kg CO2eq is used as a unit of the category of characterization of the impact of global warming, and the resulting effect is global climate change. Used biomass as primary fuel is better than used MFO. Characterization from biomass got low impact to environmental in Global Warming, the result is 4.25E+01 kqCO2 eq per Ton CaO and MFO is 6.91E+01 kgCO2 eq per Ton CaO

Primary MJ is the basic amount of energy needed to extract a natural resource. The impact characterization category that has primary MJ units is non-renewable energy and mineral extraction.

**3.3. Interpretation**

Interpretation is last step in LCA before make decision and take continual improvement. Figure 2 shown used MFO make negative impact to environment, it's mean optimization of bark gasifier is better to reduce MFO Consumption. Table 2 shown in the normal condition MFO still used 34.77 litres for backup when bark gasifier not stable for 1 Ton CaO production.



**Figure 3.** Single score of comparison used biomass and MFO for 1000 kg CaO production

Figure 3 shown score of scenario 1 is 1.01x10-1 Pt and scenario 2 is 5.95x 10-02. High contribution to environment from scenario when used 100% MFO. For increased environmental quality, using 100% biomass as primary fuel in lime kiln is recommended. MFO better use only if emergency case to back up production, beside that using biomass will get financial benefit.

**4. CONCLUSION**

This research shows that used biomass as primary fuel is has low impact to environmental. Used biomass to produce syngas as fuel in lime kiln has impact to global warming 4.25E+01 kqCO2 /ton CaO. Its lower than if used MFO that impact to global warming 6.91E+01 kqCO2/ CaO.

**AUTHORS' CONTRIBUTIONS**

All of the authors are involved in the process of collecting data. The first author contribution is responsible for data processing. The second author and corresponding author is responsible for manuscript writing. The third author is responsible for analysis data and for funding arrangement.

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