LIFE CYCLE COST ANALYSIS OF COAL WATER SLURRY PROCESS IN INDONESIA

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Abstract- Coal is expected to take the position of crude oil as the largest primary energy contribution in the Indonesia energy mixes in 2016 until 2050. Most of the coal resources are classified as low rank coal. Coal water slurry process with upgrading, one of government’s energy programs, is a clean coal technology that utilizes low rank coal and produce a type of slurry fuel with a higher heating value with more advantages than unprocessed coal to substitute MFO utilization. This study provides an overview of the opportunities of coal water slurry implementation projections based on its life cycle cost then make energy policy recommendations. Life cycle cost method was conducted to investigate coal water slurry commercial plant with a capacity of 1,000,000 tonnes/year based on data from JGC Coal Fuel demonstration plant in Karawang, West Java. Plant site was selected at Darmo Kasih Village, Gunung Megang, Muara Enim, South Sumatera. The total capital investment was USD 325.6 million, the production cost was USD 120.4/tonne product and the price of the product was determined at USD166/tonne to got the positive net present value. IRR was 16 % and payback period was 5.52 years of 15 years of service life. Coal water slurry product was more competitive or cheaper than MFO in terms of fuel cost in power plants. Fuel cost of coal water slurry product was USD 520.4 million/year, and MFO was USD 644.2 million/year. Based on the result of the study above, the coal water slurry process is feasible to be implemented with adequate infrastructure support and special price fixing of low rank coal feedstock as energy policy recommendations.

Keywords- Low Rank Coal; Coal Water Slurry; Life Cycle Cost; Economic Feasibility; Competitiveness; Energy Policy

1. INTRODUCTION

Based on data from Indonesia Energy Outlook 2015, BPPT, November 2015, coal will shift the position of crude oil as the largest primary energy contribution in the national energy mix in 2016 until 2050 [1]. Coal water slurry (CWS) process with upgrading, is a clean coal technology that utilizes low rank coal and produces a type of slurry fuel with a higher heating value which intends to substitute marine fuel oil utilization (MFO) as fuel oil in some industries. The government supports increase value-added of coal, coal water slurry program through government regulation No. 77 of 2014 regarding the third amendment to the government regulation No. 23 of 2010 on implementing the business activities of coal mining mineral and mandated in the explanation of Article 94 paragraph 1. Another one, National Energy Policy (KEN), set a coal policy to utilize coal as a main energy source of national energy supply used in industries.

This Technology currently developed by Japan Gasoline Company (JGC) Corps through JGC Coal Fuel demonstration plant with a capacity of 10,000 tonnes/year in Karawang Regency, West Java. Raw material used is low rank coal from several regions in Indonesia. Hot Water Treating (HWT) technology is used as an upgrading process that aims to change the hydrophilic surface properties into hydrophobic and to reduce water content. This process is carried out at a temperature of 330°C and pressure of 15 MPa [3]. Coal resulted from upgrading process, crushed and added with water and additives to obtain slurry that can flow and stable during storage, transport and combustion.

Advantages of coal water slurry product utilization are as follow:

a. The flow properties are more or less similar to marine fuel oil (MFO) fuel properties.

Fig.2. Primary Energy Mix

Most of the coal resources in Indonesia are classified as low rank coal (LRC) that low and moderate heating value and high moisture content so that its utilization is less favored in the market.

<table>
<thead>
<tr>
<th>Quality</th>
<th>Million Tonnes</th>
<th>Total (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Calorie</td>
<td>34,872.70</td>
<td>28.94</td>
</tr>
<tr>
<td>(&lt; 5,100 cal/gram)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moderate Calorie</td>
<td>74,469.00</td>
<td>61.80</td>
</tr>
<tr>
<td>(5,100-6,100 cal/gram)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>High Calorie</td>
<td>9,362.85</td>
<td>7.77</td>
</tr>
<tr>
<td>(6,100-7,100 cal/gram)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Very High Calorie</td>
<td>1,795.45</td>
<td>1.49</td>
</tr>
<tr>
<td>(&gt;7,100 cal/gram)</td>
<td>120,500.00</td>
<td>100</td>
</tr>
</tbody>
</table>

Table 1: Coal Quality and Resources [2]
b. CWS can be used as a liquid fuel directly to substitute heavy oil/MFO in refineries or other industries that use heavy oil/MFO as fuel commonly for processing products.

c. The handling is the same as heavy oil/MFO. Coal water slurry product can be delivered through pipes to various locations inside or outside plant.

d. CWS can be used at the same boilers that use heavy oil/MFO as fuel with slight modifications.

e. Coal in the form of a suspension can be handled cleaner than usually so that supporting environmentally clean program and avoid the possibility of spontaneous combustion, explosion, and dust problems normally generated by coal in powder form [4].

II. METHODOLOGY

The basic principles of this study are divided into four main part i.e. life cycle cost analysis, economic feasibility analysis, CWS fuel cost competitiveness, and energy policy recommendations.

A. Data Collection

A number of data collections that required supporting this study have been collected from various sources in Indonesia. The sources of the data collection describe as follows.

<table>
<thead>
<tr>
<th>Data</th>
<th>Description</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site Selection</td>
<td>Feedstock supplier, source of water and access road</td>
<td>Indonesian Central Bureau of Statistics (BPS)</td>
</tr>
<tr>
<td>Feedstock Price</td>
<td>Historical of low rank coal price</td>
<td>Indonesian Coal Index, PT Pendopo Energi Batabara</td>
</tr>
<tr>
<td>Technical Process data</td>
<td>Technical process data of coal water slurry</td>
<td>JGC Coal demo plant, R&amp;D Center for Mineral and Coal Technology (tokMIRA)</td>
</tr>
<tr>
<td>Plant Construction data</td>
<td>Building construction &amp; company service expense</td>
<td>JGC Coal Carbon plant, tokMIRA</td>
</tr>
</tbody>
</table>

B. Breakdown Costs

1) CWS Total Capital Investment (TCI)

\[ TCI = FCI + WC \]

FCI: Fixed Capital Investment  
WC: Working Capital

\[ A = \frac{i(1+i)^n}{(1+i)^n - 1} \]

\[ A \] is the annual payments (USD/year)  
\[ P \] is the worth of the first investment cost (USD)  
\[ i \] is the annual interest rate : 5.75 \%  
\[ n \] is service life (years)

2) CWS Plant Production Cost

\[ C_{MC} = C_F + C_T + C_{OL} + C_U + C_{CWS} \]  
\[ GE = C_A + C_{PT} + C_M + C_{RD} \]  
\[ C_{PC} = A + C_{MC} + GE \]

\[ C_{MC} \] is the manufacturing costs (USD/tonne)  
\[ C_F \] is the feed stock cost (USD/tonne)  
\[ C_{OL} \] is the operating labor cost (USD/tonne)  
\[ C_U \] is the upgrading process costs (USD/tonne)  
\[ C_{CWS} \] is the CWS process costs (USD/tonne)  
\[ GE \] is the general expenses (USD/tonne)  
\[ C_A \] is the administrative costs (USD/tonne)  
\[ C_{PT} \] is the CWS product transportation cost (USD/tonne)  
\[ C_{PM} \] is the marketing costs (USD/tonne)  
\[ C_{RD} \] is the research and development costs (USD/tonne)  
\[ A \] is the annual payments (USD/tonne)
CWS process in this study based on the CWS process in JGC Coal Fuel demonstration plant in Karawang, West Java with a capacity of 10,000 tonnes/year.

### III. RESULT AND DISCUSSION

#### A. Initial Considerations

Based on data of Geology of Ministry of Energy and Mineral Resources of Indonesia (MEMR) in 2013, the total of coal resources in Indonesia was 120 billion tonnes and 31 billion tonnes of reserves and mainly distributed in South Sumatera and East Kalimantan [2]. South Sumatera had potential coal reserves of about 22.24 billion or amounted to 48.45% of the total national coal reserves in 2008. The coal reserves are spread in the Muara Enim Regency 13.6 billion tonnes. Coal quality is generally low, kind of low rank coal ( lignite-sub-bituminous) [5]. Because Muara Enim Regency is the biggest of LRC mining location then it made one of the considerations for selecting the location of a coal water slurry plant.

Plant site was selected at Darmo Kasih Village, Gunung Megang Sub District, Muara Enim Regency, South Sumatera Province, based on considerations as follows:

a) Gunung Megang Sub District included industrial zone area as listed in The Local Regulation of Muara Enim Regency number 13 in 2012 regarding Spatial Plan of Muara Enim Regency year 2012-2032, article 45, paragraph 2 [6].

b) Darmo Kasih is village and a part of Gunung Megang Sub District which is appropriate as coal water slurry plant site because the land is suitable and supporting, close to PT. Pendopo Energi Batubara’s coal mining concession as LRC feed stock supplier, close to Lematang River as water sources, close to access main road, Lampung Province as a market location can be reached.

#### B. Life Cycle Costing

1). Total Capital Investment Cost (C_{TCI})

The total capital investment of CWS process was calculated by IDR 3.05 trillion or USD 325.57 million with breakdown costs as follows:

#### Table 3: Total Capital Investment

<table>
<thead>
<tr>
<th>No</th>
<th>Elements</th>
<th>Cost (IDR)</th>
<th>Cost (USD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>FixedCapital Investment (FCI)</td>
<td>2,745,506,473,760</td>
<td>293,010,296</td>
</tr>
<tr>
<td>a.</td>
<td>Land Cost</td>
<td>668,687,500</td>
<td>71,365</td>
</tr>
<tr>
<td>b.</td>
<td>Plant Cost</td>
<td>2,744,837,786,260</td>
<td>292,938,931</td>
</tr>
<tr>
<td>1</td>
<td>Engineering Costs</td>
<td>109,793,511,450</td>
<td>11,717,557</td>
</tr>
<tr>
<td>2</td>
<td>Project Management Costs</td>
<td>109,793,511,450</td>
<td>11,717,557</td>
</tr>
<tr>
<td>3</td>
<td>Procurement Equipment Costs</td>
<td>1,646,902,671,756</td>
<td>175,783,559</td>
</tr>
<tr>
<td>4</td>
<td>Electrical Instrument Cost (20%)</td>
<td>32,938,053,435</td>
<td>35,152,672</td>
</tr>
<tr>
<td>5</td>
<td>Building &amp; Construction Costs</td>
<td>823,451,335,878</td>
<td>87,881,679</td>
</tr>
<tr>
<td>6</td>
<td>Commissioning Costs</td>
<td>54,896,755,725</td>
<td>5,858,779</td>
</tr>
<tr>
<td>2</td>
<td>Working Capital (WC)</td>
<td>305,056,274,862</td>
<td>32,556,700</td>
</tr>
<tr>
<td>2</td>
<td>Total Capital Investment (TCI)</td>
<td>3,050,562,748,622</td>
<td>325,556,995</td>
</tr>
</tbody>
</table>

The final calculation for the investment cost per tonne of product for CWS commercial plant with a capacity of 1,000,000 tonnes/year was IDR 308,983,907/tonne or USD 32,975,871/tonne or IDR 308,983.91/tonne CWS product or USD 32.98/tonne CWS product.

2). Total Production Cost (C_{PC})

Total production cost include investment cost, manufacturing costs and general expenses
Table 3: Total Production Cost

<table>
<thead>
<tr>
<th>No Production Costs</th>
<th>Per year</th>
<th>Per tonne CWS Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>IDR</td>
<td>USD</td>
</tr>
<tr>
<td>1. Investment Cost</td>
<td>308,983,907,387</td>
<td>32,975,871</td>
</tr>
<tr>
<td>2. Manufacturing Costs</td>
<td>308,984,33</td>
<td></td>
</tr>
<tr>
<td>Raw material costs</td>
<td>227,901,825,000</td>
<td>24,322,500</td>
</tr>
<tr>
<td>a. Feedstock costs</td>
<td>1,220,400,000</td>
<td>130,245</td>
</tr>
<tr>
<td>b. Transportation Costs</td>
<td>1,220</td>
<td>0.1</td>
</tr>
<tr>
<td>Operating Labor Cost</td>
<td>12,998,700,000</td>
<td>1,387,268</td>
</tr>
<tr>
<td>Upgrading Process Cost</td>
<td>187,400,000,000</td>
<td>20,000,000</td>
</tr>
<tr>
<td>CWS process Cost</td>
<td>281,100,000,000</td>
<td>30,000,000</td>
</tr>
<tr>
<td>General Expenses</td>
<td>2,599,740,000</td>
<td>277,454</td>
</tr>
<tr>
<td>Administrative Costs</td>
<td>5,666,000,000</td>
<td>6,047,385</td>
</tr>
<tr>
<td>CWS Product Transportation Cost</td>
<td>56,664</td>
<td>6</td>
</tr>
<tr>
<td>Cost</td>
<td>8,190,262,394</td>
<td>874,094</td>
</tr>
<tr>
<td>Marketing Costs</td>
<td>40,951,311,968</td>
<td>4,370,471</td>
</tr>
<tr>
<td>Research and Development Costs</td>
<td>40,951</td>
<td>4.4</td>
</tr>
<tr>
<td>Total</td>
<td>1,128,010,146,749</td>
<td>120,385,288</td>
</tr>
</tbody>
</table>

Net CWS Plant Production Cost (TPC) was IDR 1.13 trillion or USD 120.39 million per year. Considering the total of CWS plant capacity, its value was equal to IDR 1,128,010 per tonne or USD 120.4 per tonne.

3). Product Cost Suggested Strategy

Based on result of the calculation, there are 4 parts of the product cost which have large percentage and affect to total product cost i.e.:

a). Manufacturing Cost
(1). Raw Material (Feedstock Cost + Transportation Cost) = 27.83% + 0.15% = 27.98%
(2). Upgrading Costs = 22.88%
(3). CWS process Costs = 34.32%

b). General Expenses

CWS Product Transportation Cost = 6.92%

Fig.4. Percent Share of Net Product Cost

(1). Raw Material Suggested Strategy

Raw material costs consist of feedstock cost and transportation cost. Feed stock cost depends on market prices, the more expensive of coal price per tonne, the more expensive of total feedstock incurred. As comparison, LRC feedstock from PT. Pendopo Energi Batubara, the minimum of LRC price, was USD 33.15/tonne on May 2010 and the maximum of price was USD 45.70/tonne on February 2011 whereas in this study, the LRC price used to calculation was the average of LRC price in years 2010-2012, USD 38.61/tonne.

PT. Pendopo Energi Batubara selected to became LRC feedstock supplier because its mining concession, Teluk Lubuk, Benuang etc. is close to Darno Kasih Village, CWS plant site selected. PT. Pendopo Energi Batubara (PEB) has a concession area of 17,840 hectares with 30 year permit, from 5 May 2009 to 4 May 2039. PEB owns potential coal reserves of 2.3 billion tonnes and 1.3 billion tonnes coal reserves. Pendopo’s coal resources is classified as LRC, with a moisture content (IM) of 16.4% - 27% and total moisture (TM) between 55% - 60%, with 4% - 8% ash, low sulfur of (< 0.2%) and calorie content of 2,400 kcal/kg (GAR).

Darno Kasih Village as a CWS plant site selected is close to PEB mining concession, Teluk Lubuk. The distance of them is ± 1.2 km. The plant site selection takes effect to transportation cost. The farther the distance between the sites plant with feedstock supplier, the more expensive the costs that have to be paid.

Plant site selection affects to transportation cost and cooperation between CWS plant with feedstock supplier could be a means guarantor feedstock availability and price stability.

(2). Upgrading and CWS process Suggested Strategy

Upgrading process costs for the CWS Plant was USD 20/tonne CWS product or 22.88% of total product cost. CWS process cost was USD 30/tonne CWS product or 34.32% of total product cost. Upgrading process and CWS process include utilities. As rough approximation, utility costs for ordinary chemical processes amounted to 10-20 percent of the total product cost [7]. Exergy study is required to maximize utilities output and minimize the cost need. Exergy is a thermodynamic standard of the quality of energy which is useful to identify and quantify the inefficiencies of the energy conversion processes that cause the reduction in the value of the energy [8].

CWS process cost was the biggest percentage of total product cost. It included additives price and became to the biggest contributor of the total CWS process cost. There is no data of the price of additives that obtained in this study.

Additives used to prevent coal to sediment after the addition of water or coal remains dispersed well to form a suspension is homogeneous and stable. Additives used in general are chemicals that have an influence on a decrease in surface tension commonly called surfactants [9].

Study of suitable and cheap additives is required to minimize cost of additive purchase so that it will influence directly to total product cost that smaller
than in advance and price fixing of CWS product indirectly in the market to make more competitive.

(3). CWS Product Transportation Suggested Strategy
CWS product market location was Lampung province because there were 302 potential industries which mostly consisted of food and beverage/tobacco/textiles/garment in 2012 [10]. CWS product transportation cost in this study was 6.92% of total product cost and included the third largest expenditure after upgrading process cost. This condition due to the distance between site plants, Darmo Kasih Village with farthest market location in Lampung, South Lampung i.e. 405 km by truck as mode of transportation.

Pipeline transportation is the best alternative modes of transportation for CWS product that have the liquid formed. Pipelines are preferable to transportation by truck for a number of reasons. Employment on completed pipelines represents only "1% of that of the trucking industry so that become to the cheapest mode of transportation [11]. The strategy to minimize transportation cost to distribute of CWS product is pipeline transportation utilization.

B. Economic Feasibility Analysis
1). Annual Cash Flow (ACF)
The annual cash flow of CWS commercial plant was calculated to be IDR 552.3 billion or equal to USD 58.9 million with USD 166 million/tonne as CWS price selected. CWS price selection under consideration competitiveness with MFO in terms of fuel cost. MFO price in 2012 was IDR 6,800/liter or USD 732.1/tonne. 1 kg MFO is equal to 2.49 kg CWS product.

CWS price selected was USD 166 million/tonne, 43.4% lower than the maximum of CWS price to attracted user. Since the net annual cash flow (ACF) has positive value, then this CWS commercial plant was considered to be economically feasible.

2). Net Present Value (NPV)
\[
NPV = \sum_{t=0}^{n} \frac{CF_n}{(1+i)^t} = I_0 - I_0
\]  
\[
NPV = \frac{CF_1}{1+i} + \frac{CF_2}{(1+i)^2} + \frac{CF_3}{(1+i)^3} + \ldots + \frac{CF_n}{(1+i)^n} - I_0
\]  
CF_n = Cash flow in year n  
n = Service life  
I_0 = The initial investment outlay  
i = Discount rate is 16% for cost of equity).

The net present value (NPV) of the company was calculated using the assumed discount rate 16% /annum for cost of equity and found to be IDR 28.74 billion or USD 3.07 million. Since the net present value has positive value, this company is considered to be economically feasible.

3). Internal Rate of Return (IRR)
\[
\sum_{t=0}^{n} \frac{CF_n}{(1+i)^t} = 0
\]  
CF_n = Cash flow in year n  
n = Service life  
i' = Discount cash flow rate of return Internal Rate of Return (IRR) of CWS commercial plant was calculated at 15 years of service life. The IRR was found to be 16%. Based on data from Asian Bonds online (Asian Development Bank), the 20 years Indonesian-local currency bonds yield is 7.046% that means, with the similar amount of payback period with the Indonesian Government Bonds, the investor may increase their rate of return by 8.954% by investing this project. Hence, it is considerably feasible to make invest the CWS plant.

4). Payback Period (PBP)
\[
\sum_{t=0}^{n} CF_t \geq 0
\]  
The Payback Period (PBP) of the CWS commercial plant in this study was calculated and found to be 5.52 years. The payback period was most likely to be less than half of the service life (15 years). Therefore, CWS commercial plant was considered to be economically feasible.

C. CWS Product Competitiveness
Based on data from tekMIRA and the price of CWS product selected then was calculated the competitiveness between CWS product with MFO in terms of fuel cost as a competitor through a power plant with a capacity of 600 MW in assumption.

Table 4: Calculation of Fuel Cost in Power Plants

<table>
<thead>
<tr>
<th>Capacity of power plant</th>
<th>Fuel</th>
<th>MFO</th>
<th>CWS</th>
</tr>
</thead>
<tbody>
<tr>
<td>600 MW</td>
<td>1.200</td>
<td>1.714</td>
<td></td>
</tr>
<tr>
<td>600 MW</td>
<td>1,032</td>
<td>1,474</td>
<td></td>
</tr>
<tr>
<td>600 MW</td>
<td>9.855</td>
<td>3.950</td>
<td></td>
</tr>
<tr>
<td>600 MW</td>
<td>105</td>
<td>373</td>
<td></td>
</tr>
<tr>
<td>600 MW</td>
<td>879.662</td>
<td>3,155.190</td>
<td></td>
</tr>
<tr>
<td>600 MW</td>
<td>732.31</td>
<td>166</td>
<td></td>
</tr>
<tr>
<td>600 MW</td>
<td>644,186.450</td>
<td>520,441.519</td>
<td></td>
</tr>
</tbody>
</table>

Fuel cost for power plant with MFO and CWS product as fuel was USD 644,186,450/year and USD 520,441,519/year respectively. This shows that CWS product is more competitive or cheaper than MFO in terms of fuel cost.
CONCLUSION

The Total Capital Investment and Production Cost from Coal Water Slurry commercial plant with a capacity of 1,000,000 tonnes/year were found to be USD 325,566,996 and USD 120.4/tonne respectively.

Net Present Value (NPV) showed the positive value, Internal Rate of Return (IRR) was 16% and Payback Period (PBP) was 5.52 years of 15 years of service life.

Raw material cost, upgrading cost, CWS process costs and CWS product transportation costs became most important cost elements in economic feasibility analysis.

Coal water slurry (CWS) product was more competitive or cheaper than marine fuel oil (MFO) in terms of fuel cost for power plants. Fuel cost for power plants with MFO and CWS product as fuel were USD 644,186,450/year and USD 520,441,519/year respectively.

CWS commercial plant was considered to be economically feasible.

ENERGY POLICY RECOMMENDATIONS

Based on utilization of low rank coal to produce coal water slurry to substitute marine fuel oil as fuel with some advantages, and economically feasible to build in this study, then coal water slurry process can support the Indonesian government’s energy program.

Exploiting local energy potentials as much as possible, the development of adequate infrastructure and the establishment of a special coal prices for the feedstock are essential measures to support to coal water slurry process in Indonesia.

Government regulations and national energy policy that regulate coal is expected to become the national coal policy instrument that must be guided so that the investment climate for coal water slurry plant can take place to conducive, to maintain the feedstock supply and to the make stability of its price.

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