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The Coal Bio-Solubilization Technology for Energy Security

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Abstract. The petroleum needs as primary energy in Indonesia more increasing, while the petroleum reserves were more depleting so that coal utilization as primary energy is inevitable. Therefore, needed a solution in coal utilization which is environmentally friendly (clean energy) to fulfill the national energy needs. This research is based on the analysis and study of 11 research journals related to coal bio-solubilization technology published in the period 1994 to 2019. The results show that low-rank coal has the potential as the environmentally friendly alternative energy by converting solid coal into liquid phase equivalent to gasoline and diesel which is sulfur and nitrogen-free with bio-solubilization technology. However, this bio-solubilization technology has the disadvantage of the slow coal degradation process into the liquid phase because it only relies on the microorganism's ability. The application of coal bio-solubilization technology as the alternative energy to support energy security requires genetic engineering and catalyst technology research support to improve the microorganism's ability to increase the coal degradation rate.

Keywords: coal, clean coal technology, bio-solubilization, energy security

1. Introduction

Indonesia's fuel oil needs continue increasing along with the increase of the population and economic activities. Based on the 2019 Indonesia Energy Outlook, the highest consumption is used by the transportation sector by 40%, then followed by the industrial sector by 36%, the household by 16%, the commercial sector by 6% and other sectors by 2%. Indonesia's current fuel oil needs reach about 1.6 million barrels/day, while the domestic petroleum production only reaches about 760 thousand barrels/day with the refinery capacity of 1.1 million barrels/days, that require the petroleum import about 300–400 thousand barrels/day and the fuel oil import about 500–600 thousand barrels/day to fulfill the Indonesia petroleum and fuel oil needs. To reduce the dependence on petroleum and fuel oil imports, it is necessary to find an alternative source of fuel production solution. This paper analyzes and studies coal utilization as an alternative source of fuel production using bio-solubilization technology that converts coal into the new energy which is included in the new renewable energy group.

Based on 2018 data, Indonesia coal production reached 557 million tons with the export quantities of about 357 million or around 63% total production. In this case, Indonesia becomes one of the largest coal exporters in the world aside from Australia. The situation is inversely proportional to the domestic demand which only reaches about 115 million tons or smaller than the domestic coal consumption target of 121 million tons. The low of the domestic coal consumption target realization is due to the construction and operation implementation of the coal power plant for the 35,000 MW program which not inappropriate as the plan, even more with the domestic industrial activities declining.

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The National Energy Policy (KEN) targeting coal utilization increasing by 33% and the new and renewable energy utilization by 23% in the 2025 energy mix (DEN, 2019). Although the new renewable energy technology has been promoted by the Government, the fact is that the new renewable energy mix target of 23% by 2025 will difficult to achieve due to the obstacles of new renewable energy technology especially related to the costs and selling prices of the new renewable energy that cannot compete for the fossil energy. On the other hand, the increasing coal consumption target which also programmed in the National Energy General Plan (RUEN). To achieve this coal utilization target, it is necessary to be supported by further studies so that coal utilization still concern with environmental acceptance as clean energy.

One of the coal clean energy technologies called Bio-solubilization. Bio-solubilization is a technology that utilizes microbes to convert coal into liquid phase products which are sulfur-free and nitrogen-free. So that the product utilization in the combustion process will not produce SOx and NOx gas. However, the technology development is still slight because the solubilization product's results are still low and have varied characteristics, and also requires a long conversion time (Su-dong et al., 2009 in Irawan Sugoro et al., 2010). In this research, a literature study is used to fill the gap in previous studies by providing the clean coal technology insights which can be used as the alternative energy to fulfill the petroleum and fuel oil needs and also improve the energy security in Indonesia. This study aims to provide comprehension of how the development potential of bio-solubilization technology in producing alternative energy as bio-solubilization coal products which are environmentally friendly fuel oils as a solution to achieve energy security in Indonesia.

The writing system of this paper is presented in several sections beginning with an introduction that elaborates this study necessity background. The next section presents several pieces of literature related to coal solubilization research that will be analyzed in this study. Sub-section 2.1 explains coal conversion and clean coal technology utilization. Sub-section 2.2 explains the fundamental study of microbial transformation of low-rank coal which constructs further research on the coal bio-solubilization process. Sub-section 2.3 presents some findings from a literature survey on technology solubilization. Section 3 presents several discussions and conclusions about the study results and the coal bio-solubilization technology potential to be applied in Indonesia according to the literature survey.

2. Literature Study Review

This research uses a literature study as a research foundation. The aim is to study and synthesize the results of many previous studies to obtain a more representative universal conclusion. The methodology of this research is a meta-analysis, which is an amalgamation of the experimental results of 11 selected journals related to clean coal technology for energy security (Figure 1).

There are several journals/articles related to coal bio-solubilization. In the literature, various microbes were used as coal solubilization agents. Some studies also gave various treatment to the microbes on the research to increase the bio-solubilization products. It is found that the results of each study are varied and showed the various effects of the microbes and the microbe's treatment as the coal bio-solubilization agents. Some studies even gave a result of coal bio-solubilization products equivalent to petroleum (gasoline and diesel). This is certainly interesting to learn more about the coal bio-solubilization potential, especially with coal bio-solubilization products equivalent petroleum that can convert the petroleum utilization to fulfill national petroleum necessity that keeps on increasing. Besides, the coal bio-solubilization product characteristics were found as sulfur and nitrogen free, which will not produce the SO_x and NO_x gaseous in the combustions process.

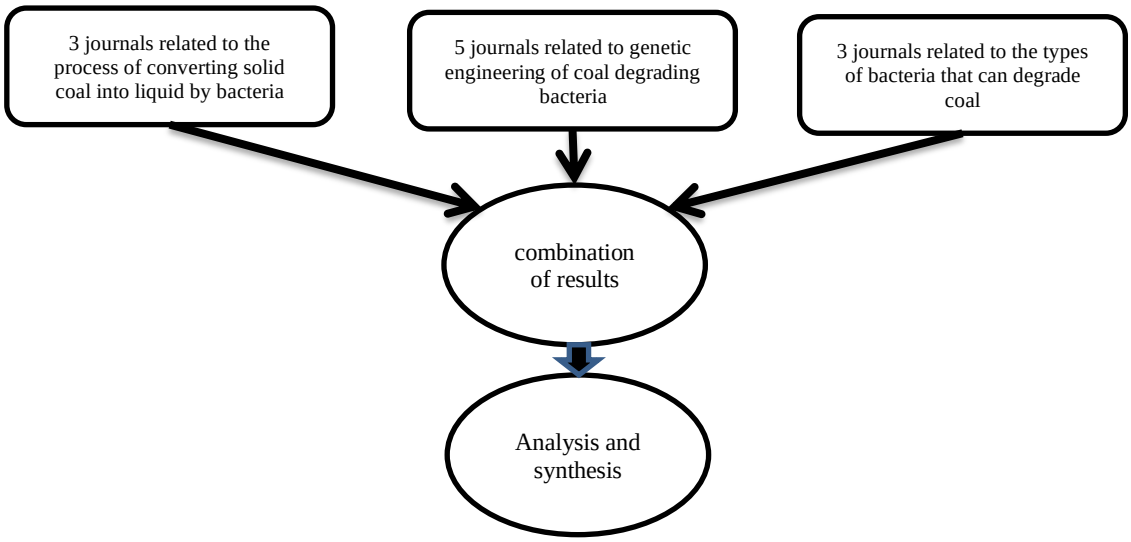

Figure 1. A meta-analysis of the coal bio-solubilization technology for energy security.

The review of literature studies related to bio-solubilization is shown in Table 1. It consists of various scientific works, research journals and thesis reports as well as research institution reports. The literature used is materials and research results related to bio-solubilization and analysis of coal bio-solubilization products which have been done by previous researchers. This paper will analyze the results of the related bio-solubilization researches published from 1994 to 2019.

Table 1. The literature study of the bio-solubilization research development.

No	Title	Authors, Year	Publisher	Research Methods	Results
1	Microbial Degradation of model compounds of coal and production of metabolites with potential commercial value	Karl-H. Engesser, 1994	Elsevier	Experimental Research	The research utilizes a special selection substrate that concerns on the new enzyme systems detection following the non-oxygenase mechanism. The aim is to synthesize organic compounds from coal-derived materials. The results showed that bacteria that are not engineered have grown the weak carbon source cells. After inducted by biphenyl, the substrate is transformed into 2,3-dihydro-2,3-dihydroxy biphenyl. Also, the initial dioxygenase of the enzyme which is insoluble in bacterial extracts, the enzyme purification technique was unsuccessful. After the cloning process, the amount of the synthesized enzyme is manipulated to increase the expression level.
2	Prospects for bio-desulfurization of coal: mechanisms and related process designs	Gregory J. Olson, 1994	Elsevier	Qualitative Research	This research analyzes coal purification from sulfur compound's development. The coal sulfur eliminated by microbiological deprioritization as sophisticated as coal desulfurization high-tech but not tested on a large scale yet. However, the coal bio-sulfurization prospect has the potential to consider the fossil fuel biodesulfurization (petroleum) to enter the moving from the laboratory to the large-scale laboratory

					testing design and factory testing stages. Such progress requires processing and economic performance estimations.
3	Microbial Degradation and Modification of Coal	Dr. Martin Hofrichter and Rene M. Fakoussa, 2004	University of Helsinki, Finland	Qualitative Research	This study analyzes the coal degradation by microorganisms based on the two decades earlier research. The results show that there are two mechanisms of coal degradation using bioconversion namely Solubilization and Depolymerization. In his research, the Solubilization process utilizes microfungi and aerobic bacteria while the depolymerization process utilizes basidiomycetous fungi.
4	Characterization of Coal Biosolubilization Products By Kap4 T4 Isolated from the Tanjung Enim Mining Land in South Sumatra	Irawan Sugoro, 2010	Journal of Valensi	Experimental Research	This research utilizes indigenous fungi in lignite type coal mining in Tanjung Enim, South Sumatra. The results obtained 8 isolates of mold from the soil and coal, 4 of which can isolate low-rank coal such as lignite with different results. The four isolates are symbolized by T1, T2, T4 and T5. The results showed that T5 fungi on the 7th day of incubation produced the largest percentage of hydrocarbon compounds with carbon composition equivalent to gasoline and diesel fuel, indicated by the detection of higher naphthalene ($C_{10}H_8$) compounds compared to control. The highest product which is equivalent to gasoline is produced by mold T5 of 74.97 with the percentage of the area followed by T1, T2 and T4. While the highest equivalent to diesel product is produced by T5 mold with a yield of 72.58% followed by T1, T2 and T4. These results indicate the potential as an alternative energy substitute for fuel oil which is equivalent to gasoline and diesel.
5	Characterization of Extracellular Enzymes and Coal Biosolubilization Products from Gamma Irradiation by *Penicillium* sp and *Trichoderma* sp.	Yelvi Erida, 2010	Scription, Islam Syarif Hidayatullah University	Experimental Research	This research utilizes 2 types of molds namely *Penicillium* sp. and *Trichoderma* sp. with an irradiation dose of 5 kGy and without irradiation. The results found that even without irradiation, *Kapang Penicillium* sp. was able to degrade coal on the 7th day of incubation, evidenced by the detection of the C_9-C_{21} compound while with a dose of 5 kGy irradiation produced C_{13}-C_{14} compound in the same period time. While the results of coal bio-solubilization with *Trichoderma* sp. which were not irradiated, detect C_9-C_{13} compounds on the 14th day of incubation, while irradiation results in the same period produced C_9-C_{16} compounds. The product of the coal bio-solubilization process using *Trichoderma* sp. without irradiation has

					the potential as an alternative energy substitute for fuel oil which is equivalent to gasoline.
6	Coal Biosolubilization Results of Gamma Irradiation in Various Doses By Kapang *Penicillium* sp.	Astri Ana, 2010	Scription, Islam Syarif Hidayatullah University	Experimental Research	This research utilizes gamma irradiation nuclear technology with gamma irradiation doses variations ranging from 0 kGy, 5 kGy, 10 kGy and 20 kGy. By utilizing microorganisms from *Penicillium* sp. The results showed that the best dose of gamma irradiation to improve the sub-bituminous coal solubilization process by *Penicillium* sp. is at 20 kGy dose, where the peak occurs on the 14th day of incubation with the results of bio-solubilization products equivalent to gasoline and diesel. However, on the 7th day, gasoline-equivalent compounds were detected with an area percentage of 73.24 and diesel fuel at 48.05. Based on these results it was found that liquid coal can be used as a petroleum alternative which is equivalent to gasoline and diesel.
7	Characterization of Lignite Biosolubilization Products by Indigenous Mold from Coal Mining Land in South Sumatra.	Irawan Sugoro, 2011	Journal of Biology Indonesia	Experimental Research	This study utilizes indigenous molds with 4 isolates with the results showing that each mold has different abilities. FTIR results showed an absorbance decrease of phenol O-H groups, C-O phenols, C-H alkanes, and C = C aromatics in all molds indicating the enzymatic oxidation reactions during the bio-solubilization process. GC-MS results showed the percentage of hydrocarbon compounds with the largest composition equivalent to gasoline and diesel fuel.
8	Coal Bio-solubilization from Gamma Irradiation by Kapang *Trichoderma* sp.	Pingkan Aditiawati et al., 2011	Scientific Journal of Isotope and Radiation Applications	Experimental Research	The bio-solubilization study of gamma-irradiated coal by *Trichoderma* sp. proved that the effectiveness of bio-solubilization by *Trichoderma* sp. mold can be increased with the help of gamma irradiation. The gamma irradiation dose which produces the highest level of coal solubilization is at 5 kGy and 20 kGy with an incubation period of about 28 and 21 days respectively with the acquisition of bio-solubilization products equivalent to diesel and gasoline.
9	Solubilization of Sub-bituminous Coal from Gamma Irradiation in Benzene Solvents.	Romdonia et al., 2013	Proceeding National Seminar on Nuclear Science and Technology PTNBR-Batan Bandung.	Experimental Research	This research utilizes gamma irradiation of sub-bituminous coal which can improve the solubilization process. The highest solubility of benzene solvent occurs at a dose of 5 kGy, about 6%. The irradiation resulted in the coal functional group change in the benzene solvent.
10	Investigation in Fungal Solubilization of Coal:	M.J. Ghani et al., 2015	Journal Biotechnology and Bioprocess Engineering	Qualitative Research	This research develops biological processes that can transform coal into liquid fuels. Biodegradation of coal by lignin-degrading fungi depends on

	Mechanisms and Significance				extracellular fungal enzymes, chelators, alkaline substances and surfactants. The results explained that solubilization as a method to clean the coal, provides liquid fuel, with a simple process that does not produce toxic byproducts. However, coal bio-solubilization is less efficient as a fuel because the commercial value of coal solvent microorganisms is based on its ability to convert dissolved coal derivatives into useful products.
11	Bacteria Solubilization of Shenmu Lignite: influence of surfactants and characterization of the biosolubilization products	Hongli Kang et al., 2019	Energy Sources, Part A: Recovery, Utilization and Environmental Effects Taylor & Francis Group	Experimental Research	Shenmu Lignite bio-solubilization experiments were carried out using the types of bacteria *Ochrobactrum cystisi*, *Novospingobium naphtalenivorans*, A*lcaligene faecalis* and *Pseudomonas fluorescens*. The effects of four surfactants SDS, LAS, Tween 80 and Triton X-100 on coal bio-solubilization showed the results that the *pseudomonas fluorescens* bio-solubilization rate could reach 61.9% while the bio-solubilization time was shortened in the presence of Triton X-100. The hydrophilicity increased of the oxidized coal surface helps increase the coal solubilization.

2.1 Coal Conversion as a Clean Energy Source

Coal is one of the primary energy sources known as unclean fossil fuels because it caused environmental pollution in its utilization. As explained earlier that the coal utilization also causes environmental impacts because of its exhaust gas emissions, so it is necessary to apply technology to reduce the emissions pollutants in coal utilization. The technology is known as clean coal technologies (CCT) (Suarna, 2011). The technology can be classified based on the application of the energy production process level which includes pre-combustion, combustion and post-combustion technology and coal conversion. *Combustion technologies* is a technique that implementing pollutant emissions prevention in the furnace-boiler when the combustion process is running. *Post-combustion technologies*, exhaust gases coming out of the boiler-furnace are treated to reduce their pollutant content. Finally, *coal conversion*, which is the conversion of coal into gas or liquid that can be cleaned and utilized as fuel.

Coal conversion is a coal conversion technology that converts coal from solid to other forms such as gas or liquid (Figure 2). The developing technologies for the coal conversion process include gasification and liquefaction. The products of coal gasification and liquefaction technology are various and economically valuable gases, including phenol, LPG, hydrogen and C_1-C_4 as well as by-products in the form of oil and synthetic gas from coal (Dhebyshire, 1988 in AR, Hasnawaty et al., 2017).

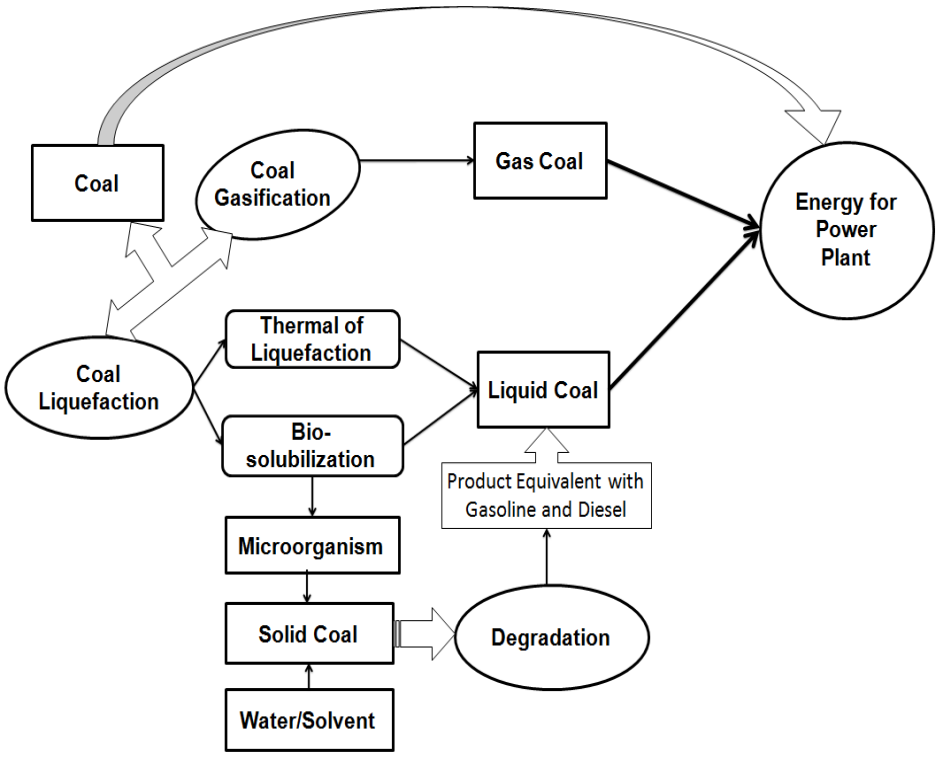

Figure 2. Coal conversion as a clean energy source.

2.2 Low-Quality Coal Microbial Transformation

Low-quality coal can be upgraded with a variety of technologies. According to Crawford (1992), low-quality coal contains volatile compounds which are organic compounds with light molecules that can be distilled or even ready for the microbial metabolism process. Besides, it also contains toxic compounds such as metals. Low-quality coal is also enriched by the macromolecular components in the form of poly-aromatic residue condensate in the form of rings condensate such as phenol, quinone and benzyl carboxylate which are easily degraded by microbes. Microbial growth is better in the low-quality coal conditions in the form of lignite which has a high humidity level, where microbes can grow on the surface layer of water. Low-quality coal also has more pores with a larger diameter which easier for bacteria to enter it. These characteristics then contribute to lignite vulnerability to microbial invasion and subsequent changes.

Then, in the microbial degradation process, there is a washing process of the inorganic components of the polymer bulk in coal. Where the biogenic acid, alkalis or chelating are easily entering the pore structure of low-quality coal and interact with ion-replacement cations or other minerals. As mentioned earlier that low-quality coal has a high humidity level and also contains metals that are bound to carboxylic acids so that this coal is ready to be washed through microbial metabolism. Washing by microbes itself does not reduce the metal content, but the process will increase the solubility of the polymer by forming an ion bridge, also, the washing agent reacts with organic components. Where biogenic acid can hydrolyze the ester and ether bonds. Then the washing agent can also remove sulfur and organic nitrogen contents from the polymer. Where the breaking of carbon-sulfur or carbon-nitrogen bonds in organic heteroatom compounds occurs with the help of the microbe enzymes. These enzymes are very important for breaking carbon bonds with other metals, so it can increase the chances of the coal polymer significantly. Based on this knowledge, further studies will emerge regarding the process and production of coal solubilization in improving the quality of coal by utilizing microorganisms, hereinafter referred to as bio-solubilization.

2.3 Bio-solubilization

Bio-solubilization is one of the clean coal technologies included in the coal conversion category. Bio-solubilization is the process of dissolving in a medium with the help of microorganisms (Faison et al., 1989 in Erida, 2010). The liquid coal production process is carried out by utilizing the enzymes produced by the metabolism of microorganisms. Bio-solubilization utilizes microbes to dissolve or melt coal solids and produce a lump of liquid phase coal which has potential as cleaner energy because of its sulfur and nitrogen compounds free. Figure 3 shows the schematic interaction representation involved in dissolving coal by fungi. Solubilization and cultivation of animal feed are developed by nutrition. Nutrient-rich media will be a factor in the efficiency of the solubilization process.

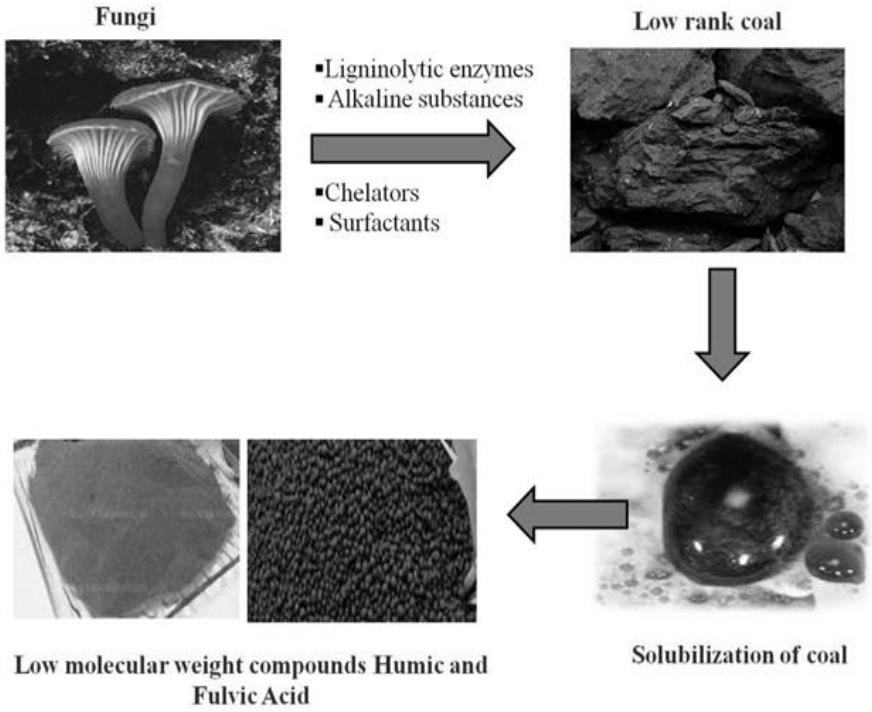

Figure 3. Coal bio-solubilization mechanism schematic (Ghani, 2015).

The presence of microbial populations in coal was discovered as early as 1962. But evidence of the microorganism's potential utility in coal conversion was not reported until 20 years later. Coal bioconversion was first recognized as the transformation of low-rank coal into a water-soluble liquid product by axenic microbial culture, at room temperature and atmospheric pressure. Filamentous fungi and ***actinomycetes*** are the organisms most frequently associated with this solubilization activity, which correlates the hyphal branching culture through both the coal surface and the organism, which then occurs coal transformation by microbes and produces new compounds with more simple molecular weights.

3. Discussions

The research has proven the potential for clean coal technology development by converting coal into a liquid phase method utilizing appropriate microorganisms to degrade coal compounds into other compounds in the liquid phase which are equivalent to gasoline and diesel fuel. The related research of coal bio-solubilization is mostly done on low-rank coal from lignite and sub-bituminous types. It is known that the lignite direct burning harms the environment. With bio-solubilization technology, it is proven that coal bio-solubilization produced sulfur and nitrogen compound free products. So that the coal bio-solubilization product will not produce SO_x and NO_x gas when going through a direct combustion process which makes it a clean energy source (Fakoussa, 1999 in Aditiawati, 2011).

Besides, based on the study also found that low-rank coal has a greater potential to be processed as environmentally friendly alternative energy by applying bio-solubilization technology.

The coal bio-solubilization products are water-soluble compounds, that are polar compounds with relatively higher molecular solubility (Erida, 2010). This bio-solubilization product is obtained through the contributions of the enzymes from the metabolism of microorganisms. This dissolved product has a high energy content equivalent to gasoline and diesel. On the other hand, gasoline and diesel are the main fuels that are widely used in the transportation sector that comes from petroleum. Therefore, the coal bio-solubilization product's alternative energy has the potential to replace the petroleum role as primary energy so that the petroleum scarcity can be solved.

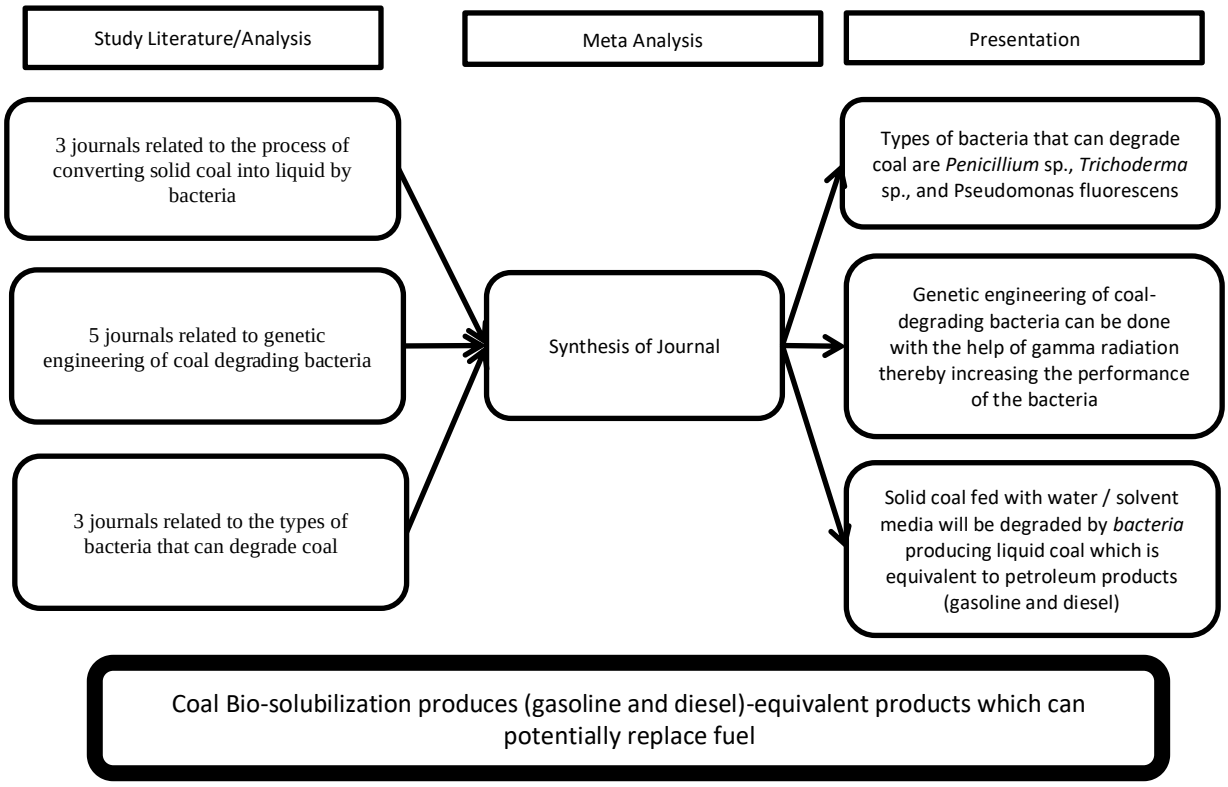

Figure 4. Data analysis framework.

The bio-solubilization development in Indonesia can utilize the low-rank coal such as lignite and sub-bituminous, as known that the Indonesian coal rank type is at low-rank on average. However, from the results of literature studies, found that the process of sub-bituminous and lignite bio-solubilization with the same type of microbes utilizes produce different bio-solubilization products. Lignite bio-solubilization can produce a liquid product in an incubation period of 7 days with product characteristics equivalent to gasoline and diesel compounds. Whereas sub-bituminous bio-solubilization cannot be degraded within a 7-day incubation period because the sub-bituminous structure is harder and the porosity is denser than lignite. Therefore, the performance of the microorganism is more limited to the sub-bituminous coal types structure. Other studies were carried out on sub-bituminous bio-solubilization but with different treatments by gamma irradiation utilization. The results showed that the products were equivalent to gasoline and diesel fuel. The gamma irradiation process proves that microorganisms treated with gamma irradiation can increase their ability to degrade coal. That is because the microbes get higher nutrition and enzyme cloning which help the microbes to degrade the coal.

On the other hand, the coal conversion method which is developing in Indonesia today is thermal coal liquefaction. If compared with thermal coal liquefaction, bio-solubilization has several advantages,

which the process is carried out under the room temperature and atmospheric pressure conditions, then microbes can use the hydrogen from water and do not need external hydrogen energy to form dissolved coal. Therefore, the coal bio-solubilization process is considered more economical because it does not require high operating costs such as coal thermal liquefaction which requires high temperatures and pressures. Although it has several advantages than the coal thermal liquefaction technology, bio-solubilization technology also has several obstacles, which the coal bio-solubilization method requires water/solvent media, which without water or solvent that suit to the coal characteristics, the bio-solubilization process will not succeed, and the product still as a solid phase compound. As stated by Liu et al. (1989) in Erida (2010) that most microorganisms need sugar and growth media like water or solvents to subsequently experience an incubation and metabolic period of more than two weeks. Therefore, the presence of water or a suitable solvent has an important role in the coal bio-solubilization process because it is a living medium for coal-degrading microorganisms. Besides, this coal bio-solubilization method is a conventional method that requires long processing time, especially in the coal degradation process.

Generally, the coal rank owned by Indonesia is of average low rank, so the bio-solubilization technology concept is very promising to be applied in Indonesia. Also, this bio-solubilization-related research supports the Government's program through RUEN and Presidential Regulation No. 5 of 2006 concerning the National Energy Policy which explains that the coal utilization will be increased to 33% and coal liquefied by 2% at 2025 to reduce the dependence on domestic petroleum needs. Besides, coal bio-solubilization technology can also produce clean energy that is environmentally friendly and support the increase of new renewable energy utilization because bio-solubilization technology is one of the new energy technology categories. Therefore, the Government is expected to divert the use of 63% of coal as an export commodity to be more utilized in fulfilling the domestic energy needs by the coal bio-solubilization technology application, which can increase the national energy security.

Energy security was defined as the low vulnerability of energy systems. There are several categories to define energy security and conclude the aspect to comprise the energy security which are availability, accessibility, environmental acceptability and affordability (APERC, 2007). Energy security is a concern to many governments in the face of worldwide increasing energy demand and uncertainty about the stability of prices, the availability of resources and delivery conditions. In this era, all countries in the world are competing with one another to tackle climate change and global warming. This means that the acceptability of low-carbon policies and international climate regimes will in part depend on their impacts on national energy security—particularly of the major emitters (Jewell et al., 2013). Thus, every activity related to the use of natural resources emphasizes more on the aspect of environmental acceptance. In terms of energy, currently, the countries in the world are campaigning for environmentally friendly green energy. The current energy security of a country is not only judged by the availability of its supply, but also in terms of the impact of its utilization on the environment. The use of fossil oil for daily activities is still in the highest consumption category compared to other types of fuel. On the other hand, the use of coal in electricity is also still the majority. Regarding the energy security aspects mentioned by APERC, then the depletion of fossil oil and on the other hand the use of coal also adversely affects the utilization of coal bio-solubilization that can produce equivalent fossil oil products that are free of sulfur and nitrogen have better potential as energy diversification in improving energy security.

According to Chuang et al. (2013) global climate change has a significant impact on global energy sources, sufficient energy and greater energy as well as its effect on task shifting policies. Energy use has begun to shift, especially the use of renewable energy, such as solar power, wind power and others. This shows the link between energy security and economic development, technological innovation, society, culture, environmental protection and international politics. Bio-solubilization is an innovative technology that has the potential to meet the high demand for fossil oil while taking into account environmental sustainability and reducing greenhouse emissions that have an impact on global climate change from the use of fossil oil or coal directly.

Bio-solubilization products are equivalent to gasoline and diesel which are widely used in the transportation sector. The product has the potential to become fuel oils alternative sources that can decrease the import of fuel oils dependence. Although coal is fossil energy which is identical to the environmental pollution, it is proven that the coal bio-solubilization product is sulfur and nitrogen compounds free, so that it doesn't produce SO_x and NO_x compounds in it combustion process which has a negative impact to the environment. From the energy security aspect, besides fulfilling the *availability* criteria by coal utilizing as a new fuel oil alternative energy, it also fulfills the environmental acceptance (*acceptability*) criteria although it still contributes to CO_2 emissions.

However, given the slow process of coal degradation in this solubilization technology, further research and development related to genetic engineering and catalyst technology that can increase the rate of coal degradation are definitely needed. As the decomposition process of biomass using microbes and assisted by catalyst technology which then can accelerate the process of these organic compounds decay. Therefore, the genetic engineering and the application of the catalyst in the coal bio-solubilization process are thought to improve the microbe's ability, so the coal degradation process can be done in a shorter time and facilitate the coal dissolution in the water/solvent media. Therefore, it can increase the coal bio-solubilization technology's potential to fulfill the fuel oils necessity and save the foreign exchange needed to import the fuel oils.

4. Conclusion

Bio-solubilization products are equivalent to gasoline and diesel which are widely used in the transportation sector. The product has the potential to become fuel oil alternative sources that can decrease the import of fuel oils dependence. Generally, the coal rank owned by Indonesia is of average low rank, so the bio-solubilization technology concept is very promising to be applied in Indonesia. From the energy security aspect, besides fulfilling the *availability* criteria by the coal utilizing as a new fuel oil alternative energy, the used of coal bio-solubilization also fulfill the environmental acceptance (*acceptability*) criteria although it still contributes to CO_2 emissions, it does not produce SO_x and NO_x compounds that have a negative impact to the environment. Besides, to increase the decomposition rate of the biodegradation process, it can use catalyst technology which can accelerate the process of these organic compounds decay.

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