Progress on research and development of bio-oil as a fuel in Indonesia

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Abstract. The abundance of biomass in Indonesia are potential to be utilised as a material for biofuel production. Pyrolysis can be employed to convert biomass into syngas that can be condensed into pyrolysis oil or known as bio-oil. Biomass as a material for biofuel production is available in a large quantity thus avoid the competition with materials for food source, and inexpensive. Current bio-oil research mainly studies the process of converting biomass into bio-oil from inexpensive sources, such as food crops, timber waste and agro-industrial waste. The components of bio-oil are water and organic compounds (hydrocarbons), which are traditionally produced from petroleum. Due to the depletion of petroleum reserves, bio-oil has the potential to be developed into a source of petroleum-supporting fuels. The present study reviews the status of bio-oil research and development in Indonesia, including the potential biomass sources, the latest technologies to convert and utilise bio-oil as a fuel, and government policies on the application of bio-oil in Indonesia. This review is expected to be used as a basis for the development of bio-oil policy and scientific and technological utilisation of bio-oil in Indonesia.

1. Introduction
Indonesia produces biomass in a large number that is potential to be converted into biofuel [1]. The first generation of biomass into biofuel is bioethanol from sugar cane or carbohydrate, biodiesel from palm oil, moringa, and other plant oils or animal fats. Despite the large number of sources, the first generation of biofuel production is limited due to the competition of the feedstock with materials for food source. Therefore, biomass from wastes, such as food waste, forest waste, and urban waste is economically more viable to be developed as biofuel [2].

Pyrolysis is a conversion of biomass into solid (biochar), syngas and liquid through a complex thermo-chemical reactions [3]. The liquid, also known as pyrolysis oil or bio-oil is produced by condensing syngas as a product of pyrolysis. As a liquid fuel, bio-oil has the advantages of the more practical handling/transportation and combustion, higher energy density/more calorific value, lower ignition temperature, and less pollutive when compared to solid fuel [4].

Recent research on bio-oil is limited to finding various sources of biomass for bio-oil production [5-7]. However, information on the subsequent processes to convert bio-oil into applicable fuel or chemical production in Indonesia are limited. Therefore, the present study reviewed the progress of bio-oil research and development in Indonesia, including the potential biomass sources, the latest
technologies to convert and utilise bio-oil as a fuel, and government policies on the application of bio-oil in Indonesia. This review is expected to be used as a basis for the development of bio-oil policy and scientific and technological utilisation of bio-oil in Indonesia.

2. Biomass and bio-oil

Biomass is organic material derived from plants and animals. It contains renewable source of energy, stored from the sun via photosynthesis process. The means to convert biomass to energy are direct combustion, decomposition, fermentation, and chemical conversion. Direct combustion of solid biomass produces heat and decomposition of biomass produces biogas. Production of liquid biofuels from biomass including ethanol (produced from the fermentation of corn and sugar cane), biodiesel (produced from vegetable oils and animal fats), and bio-oil [8].

In 2012, over 95% out of 52 EJ of biomass energy came from forest. In the next 20 years, the biomass energy sources is expected to increase to a total of 150 EJ, of which 43% coming from agricultural residues, by-products and energy crops, and 52% coming from wood fuel, forest residues and by-products of the forest industry [9]. The remaining 5% will be coming from waste streams [9].

Figure 1 shows that biomass can be converted into thermal energy. Three main thermochemical means of converting biomass are pyrolysis, liquefaction, and gasification [8]. Each of this technology produces different ranges of products and application. The products of pyrolysis are gas for fuel gas, liquid for liquid fuel substitution, and solid char for solid fuel or slurry fuel. The product of liquefaction is liquid which is useful for liquid fuel substitution, and the product of gasification is gas for fuel gas. These products produce heat via combustion.

![Figure 1. Conversion pathways from biomass to thermal energy](image)

Bio-oil (pyrolysis oil) is the condensed syngas from the pyrolysis. Bio-oil produced from pyrolysis ranges in chemical quality [10]. Few high value chemicals in bio-oil are levoglucosan, toluene, xylene, limonene and phenol [11, 12], depending on the feedstocks and process condition [12]. The char is called biochar and can be used for liquid fuel addition.

The components of bio-oil are water and organic compounds (hydrocarbons), which are traditionally produced from petroleum [13]. Due to the depletion of petroleum reserves, bio-oil has the potential to be developed into a source of petroleum-supporting fuels. Table 1 shows various bio-oil
conversion technologies and the energy obtained as the products. It can be seen from Table 1 that pyrolysis and gasification are suitable for large scale energy conversion due to the lower pressure requirement and higher yields. It is also noted that pyrolysis is the better means to produce liquid fuel based on the highest yield.

| Feedstock | Pyrolysis | Liquefaction | Gasification |
|-----------|-----------|--------------|--------------|
| Feed Size | any       | small        | mixed, large |
| Moisture content | low       | very low     | 50% max     |
| Parameters |           |              |              |
| Temperature °C | 400-600   | 450-900      | 250-400      |
| Pressure, bar | 0.01-1    | 1            | 100-200      |
| Maximum throughput achieved to date, dry/ th | 5         | 0.05         | 0.1          |
| Product (dry basis on dry feed) |       |              |              |
| Gas       | Yield, % wt | up to 40    | 20           | 100-250     |
|           | HHV, MJ/Nm³ | 5-10        | 10-20        | 2-6         | May-15 |
| Liquid    | Yield, % wt | up to 30    | up to 50     | up to 3     |
|           | HHV, MJ/kg  | 23          | 30           | 23          |
| Solid     | Yield, % wt | 30          | up to 25     | nil (ash)   |
|           | HHV, MJ/kg  | 30          | 30           | -           |

Bio-oil is energy efficient. Liquid fuel such as bio-oil is easy to transport with high energy density compared to biomass [15]. However, the direct use of bio-oil into a furnace or boiler is not recommended. The high oxygen content in bio-oil promotes unwanted fuel characteristics, such as high viscosity, corrosive, low heating value and instability during storage [16]. Therefore, ongoing research to increase the quality/fuel upgrading of bio-oil is necessary.

3. Biomass and bio-oil in Indonesia

3.1. Biomass production in Indonesia

Biomass source in Indonesia can be derived from a few main sources, such as forest, crops and rural resources. However, logs could not be considered as biomass from forest due to the potential of illegal logging, but the waste from sawmill and plywood industry could. Biomass from agricultural waste is limited to estate crops, such as palm oil, rubber, coconut, and sugarcane [17].

In 2017, biomass production in Indonesia reached over 147 million tons which equivalent to 470 GJ/year [18]. Figure 2 shows the supply of renewable energy sources and their contribution ratio to overall energy [19]. Biomass, sits second after hydropower, is projected to steadily increase. However, overall the contribution ratio of renewable energy only increases 1-2% of the total energy supply [19].
Figure 2. New and renewable energy supply and their contribution ratio [19]

Figure 3 shows the schematic diagram of potential biomass utilisation as energy in Indonesia. Sumatera and Kalimantan are two high producers of biomass due to large forests and plantation across the islands. Ply mills, sawmills, sugar mills, palm oil mills and rice mills are the major contributors for biomass production, excluding prime source of biomass such as logs.

Table 2 shows the various biomass sources and their potential for power generation. Sawmills and rice mills are likely to be the most potential materials to be developed into an energy source. However,
both biomasses are used for plywood industry and animal feed, respectively. Therefore, the waste of sugar mills and palm oil-based biomass has more potential to be converted as energy [14].

Table 2. The potential for biomass sources for power generation [14]

| Biomass          | Mill size | Capacity of CHP | Potential of power                          |
|------------------|-----------|-----------------|---------------------------------------------|
| Sawmills         | 1000-3000 m³/y | 40-100 kWe      | 0.6 m³ wood waste/m³ sawn timber ~ 130 kWh/m³  |
| Plywood mills    | 40 000-120 m³/y | 0.8 m³ wood waste/m³ plywood ~ 200kWh/m³  |
| Sugar mills      | 1000- 4000 TCD | 1.5 – 3 MWe     | 0.3 t bagasse/t sugarcane ~ 100 kWh/t sugar cane |
| Rice mills       | < 0.7 t/h >0.7 t/h | 30-70 kWe       | 280 kg husk/t paddy ~ 120 kWh/t paddy        |
| Palm oil mills   | 20- 60 t FFB/h | 2-6 MWe         | 0.2 t EFB/t, FFB 0.2 t fibre/t, FFB 70 kg shells/t FFB ~160 kWh/t FFB |

Figure 4 illustrates the potential biomass sources for bio-oil production, such as agroindustrial waste (empty palm oil fruit branch) [21], wood chips [22], poultry waste [23, 24], and urban waste [25] for bio-oil production using pyrolysis method. In the pyrolysis reactor, incomplete combustion of biomass produces syngas and char. The syngas is condensed in a cooling chamber to change the gas phase into a liquid phase to produce bio-oil, while some un-condensable gases are released to the environment [26].

Figure 4. The potential of biomass sources for bio-oil production in Indonesia

3.2. Bio-oil development in Indonesia
In Indonesia, bio-oil has been produced from various feedstocks. Palm oil empty fruit brunch has been widely studied as bio-oil feedstock [21]. Pyrolysis as a solution for overcoming problems caused by plastic waste by converting it as biofuel has also been investigated [27]. The means to convert biomass to energy has also been a subject of research [17, 26, 28-31]. Investigation on the bio-oil conversion as a new product has also of interest [32, 33]. The aforementioned studies generally working on the conversion of biomass to bio-oil. However, the gap that needs to be filled is the study of the bio-oil as fuel and its upgrading.

3.3. Challenge and policy of biomass utilisation in Indonesia
The utilisation of biomass as an energy source is only 3.25% of the total energy [17]. Bio-oil, which is technically part of biomass energy conversion has only a small contribution [19]. The challenges of
biodiesel research and development in Indonesia are the focus of research and development in Indonesia, including the potential biomass sources, the latest technologies to convert and utilise bio-oil as a fuel, the challenges and government policies on the application of bio-oil in Indonesia. It is clear that Indonesia has the number of biomass sources which can be converted to bio-oil. However, the development of biomass in Indonesia is stagnant due to geographical issue and investment. Despite the government support with increasing proportion of renewable energy in the future, the development of bio-oil as a fuel in Indonesia is on-going. The bio-oil development in Indonesia is still on research stage and technological development, resulting in the bio-oil is not ready to be established in a commercial scale.

4. Conclusions
The present study reviewed the status of bio-oil research and development in Indonesia, including the potential biomass sources, the latest technologies to convert and utilise bio-oil as a fuel, the challenges and government policies on the application of bio-oil in Indonesia. It is clear that Indonesia has the number of biomass sources which can be converted to bio-oil. However, the development of biomass in Indonesia is stagnant due to geographical issue and investment. Despite the government support with increasing proportion of renewable energy in the future, the development of bio-oil as a fuel in Indonesia is on-going. The bio-oil development in Indonesia is still on research stage and technological development, resulting in the bio-oil is not ready to be established in a commercial scale.

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