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Potential thermochemical conversion of bioenergy from *Acacia* species in Brunei Darussalam: A review

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ABSTRACT

As the demand for energy increases and fossil fuel resources are depleted, the search for clean sources of energy has intensified worldwide. This is coupled with a strong global desire to reduce CO_2 emissions to curb global warming. Brunei Darussalam is committed to reduce its CO_2 emissions but currently utilizes fossil fuels to meet almost all of its energy requirements. This situation provides good incentives to search for renewable and sustainable resources to produce energy in the country. *Acacia* species are exotic species that have invaded and spread to natural habitats in Brunei Darussalam. *Acacia* species are a sustainable source of high quality biomass feedstock to produce bioenergy in the country. Hot tropical weather of the country is highly suitable for the rapid growth of *Acacias* without requiring any major agricultural input. This study reviews the thermochemical conversion of *Acacia* species especially; *Acacia mangium* and *Acacia auriculiformis* to produce biofuels and bio-products. The prospective of using *Acacia* biomass as feedstock in pyrolysis, gasification, liquefaction and combustion is also discussed. *Acacia* biomass is a sustainable and renewable energy resource for Brunei Darussalam to be exploited for energy requirements and can be beneficial for the economy of the country by providing new investment and employment opportunities.

1. Introduction

The threat of diminishing of fossil fuel resources and the impact of their burning on environmental pollution is well-known problem and has motivated researchers to look for alternative sustainable and renewable fuel resources. There has been a significant increase in the efforts to search for clean, socially acceptable methods of producing energy [1]. The demand of energy is continuously increasing due to economic development and rapid increase of population of the world. The world's demand for energy is predicted to be doubled within upcoming few decades [2–4].

On 12 December 2015, the United Nations Framework Convention on Climate Change (UNFCCC) adopted the Paris Agreement on climate change in which 195 participating countries committed to keeping the global temperature rise limit well below 2 °C above pre-industrial levels [5].

Energy is considered to be one of the most important commodities of life. Secure and sustainable supply of energy is mandatory for the socio-economic development of any country. Rapid human population rise along with increasing urbanization and industrialization trends are putting worldwide challenges in terms of energy resource development and management. Existing fossil energy resources based technologies cannot meet the ever rising demand of energy [6]. Utilization of fossil fuels has contributed substantially to increasing environmental pollution causing serious problems such as acid rain, ozone depletion, and global warming which results from the emission of harmful gases like SO_X, NO_X and CO_2 [7,8]. Encouraging reports have been published recently to show the expanding usage of low-carbon energy resources [9]. It is believed that the global economy growth and energy-related emissions might have started to decouple. Thus, non-renewable fossil resources are not the reliable option in long term future basis [10].

Many renewable and sustainable energy resources of energy are available to replace fossil resources such as biomass, sunlight, tidal and geo thermal energy [11,12]. Biomass is an abundant and renewable source of energy derived from organic materials originating from living organisms [13]. Worldwide biomass ranks fourth as energy resource

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providing approximately 14% of the energy requirements [14]. Plant biomass results from photosynthesis processes in plants, and is sometimes referred to as lignocellulosic biomass and its constituting components include carbohydrate polymers and aromatic polymers. Carbohydrate polymers in plant biomass are called as cellulose and hemicellulose; while the aromatic polymers are called as lignin [15]. Energy in the biomass is basically the solar energy stored as chemical energy, This chemical energy can be released by breaking the chemical bonds between adjacent oxygen, carbon, and hydrogen molecules using biological or thermochemical processes [16]. Non-renewable resources are also believed to be derived from biomass through microbial anaerobic degradation and metamorphic geological conversions over millions of years [17]. This review paper deals with plant biomass and will refer to it as biomass. Despite the fact that biomass conversion to energy has various environmental and social benefits over the use of petroleum fuels; many challenges are there in terms of commercialization of technologies which are much expensive than the traditional ones. Also, for sustainable development, biomass conversion processes are needed to improve their efficiencies [18].

Lignocellulosic biomass is the most abundantly available raw material on earth to produce biofuels and chemical feedstock for industry. Various studies are reported in literature on the viability of bio-energy production from forest-based biomass with financial feasibility and sustainability [19–22]. Thus, biomass is a logical choice which can contribute for energy requirements of the world to minimize dependency on fossil resources [23,24].

Acacia is a large genus of 1350 species of shrubs and trees that are found in Australia, Africa, Madagascar, throughout the Asia-Pacific region and in the Americas. They are most diverse in Australia, with close to 1000 species recorded, and is the largest genus of vascular plants in Australia [25].

This study is aimed to review the potential of thermochemical conversion of *Acacia* biomass to produce value added materials such as biofuels and other bio-products in Brunei Darussalam. Studies reported in literature on the pyrolysis, gasification, liquefaction and combustion of different *Acacia* species are discussed and summarized. Brunei Darussalam is located between 4° N and 5.8° N latitude and 114.6° E and 115.4°E longitudes on the north-west coast of Borneo island; map is shown in Fig. 1 [26]. Brunei Darussalam's tropical climate is aseasonal with high temperatures and rainfall year round [27] and this climate appears to be highly suitable for the growth of different *Acacia* species.

Biomass from *Acacia* species and waste biomass could be important renewable resources to meet the future needs of the country. As assessed by Malik et al., Brunei Darussalam has a potential to produce 13 $\times 10^5$ kWh/year electricity from its solid waste biomass resources [28]. *Acacia* species along with their potential to produce biofuels and bioenergy have been researched for various scientific applications and to produce many valuable products [29–42]. The current situation is challenging and demanding for the utilization of biomass from *Acacia* species which are sustainable and renewable energy resources to produce biofuels via thermochemical conversion route which will contribute to future energy requirements and to reduce the green houses gases in the country. There is also an urgent need for Brunei Darussalam to maintain its bio-resources inventory so that proper planning can be made in terms of utilization of its green resources to produce energy. Research activities should be carried out to determine the individual biofuel potential of different tree parts of *Acacia* species such as trunk, phyllodes, bark and branches because *Acacia* trees are bigger in size and produce large quantities of biomass from their different parts. Utilization to *Acacia* species to produce biofuels will impart positive effects on the economy of country by generating new investment and employment opportunities in engineering, agriculture, transportation and services sectors.

2. Energy scenario in Brunei Darussalam

Brunei Darussalam is well known for its vast fossil hydrocarbon reserves. Situation is alarming as studies have revealed that oil and gas reserves of Brunei Darussalam will be finishing within 17 and 30 years respectively if their exploration will be continued at the current rate [43]. As per World Bank country indicators data, Brunei Darussalam is the largest emitter of carbon dioxide per capita in ASEAN region as shown in Table 1 [44]. This is because of almost all the energy requirements of Brunei Darussalam are being generated from fossil fuels. Research reports show that major portion of greenhouse gases (GHG) in the world are coming from the burning of fossil fuels, producing CO_2 and other gas emissions [45]. In Brunei Darussalam major contributors to CO_2 emissions are power generation and transportation sectors as shown in Fig. 2. Brunei Darussalam is also the highest consumer of electricity per capita in Asia, with maximum of its consumption in domestic households which is may be due to high government subsidy on electricity tariffs [46,47]. The primary energy demand of the country is expected to rise at an average rate of 3.9% annually over the forecast period to reach 6.8 MTOE in 2030 [48]. Consequently, CO_2 emission rates are also expected to rise with the energy demand of the country if green energy resources are not exploited to contribute in the energy mix of the country. Being a signatory of the Paris Agreement on global warming, Brunei Darussalam is committed to reduce its CO_2

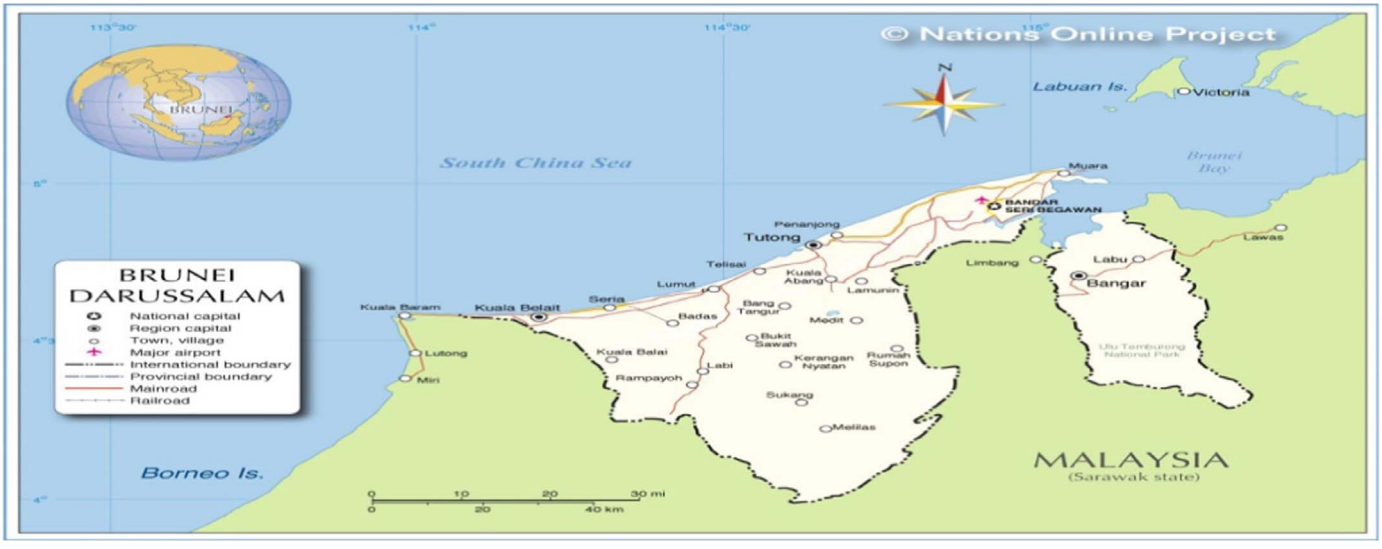

Fig. 1. Political map of Brunei Darussalam (photo credit: www.nationsonline.org) [26].