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CO_2 emission abatement analysis of waste wood to hydrogen using gasification process

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ABSTRACT

This article presents an analysis on CO_2 emission abatement from introduction of a new path in producing hydrogen in Japan. The bio-hydrogen production method is using gasification system and waste woody biomass as a feedstock. The waste woody biomass is from the fast growing tree or short rotation plantation, in which the three species of *Acacia mangium*, *Acacia auriculiformis* and *Eucalyptus sp*. that used in forest industries. The gasification process used a Blue Tower technology, which the pyrolysis and reforming reactions occur during reductive atmosphere can synthesize the higher concentration of hydrogen gas efficiently. We will discuss about the potential of bio-hydrogen fuel supply chain in ASEAN-Japan region to see the necessity of bio-hydrogen fuel network system. On the environmental impact aspect, this article will focus on CO_2 emission posed in the hydrogen lifecycle production. The LCA methodology used to estimate the CO_2 emission in consideration of hydrogen form variation (liquid and gaseous). Sensitivity analyses in several policy scenarios are to seek a least emission strategy of supplying hydrogen from woody biomass. Finally, we suggest the energy paths so that the CO_2 emission abatement benefit would acquire by the promotion of hydrogen fuel network in ASEAN region in comparison to the conventional hydrogen supply system.

1. INTRODUCTION

Petroleum-based fuels became the primary source energy for transportation needs in the 20th century and continued in the beginning of the 21th century with almost all vehicles running (Ballat & Kirtay 2010). It means that the demands of petroleum-based fuel will increase on the other hand fossil fuels resources are decrease because it is non-renewable. The uncertain supply and the price of petroleum-based fuels because of the unevenly distributed in the world become threat for the sustainability economy

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development, especially for the fuel importer countries. The usage of petroleum will also create global warming problem that become concerns of all countries in the world.

This situation drives many countries to develop more sustainable energy in term of supply and environmental friendly. Many scientist, engineers, companies, governmental agencies are convinced that hydrogen's physical and chemical advantages will make it an important synthetic fuel in the future (Schlapbach & Zuttel 2001). Hydrogen is a clean fuel that can use in combustion engines and fuel cells for electricity generation without CO_2 emissions (Tock & Marechal 2010).

Automotive industry in Japan and Europe will increase the promotion fuel cell vehicle (FCV) in the roadmap of car manufacturing industries to answer the challenge of scarcity of petroleum fuel and environment problem in the near future. Although hydrogen consider as environmental friendly in the usage process but in the manufacturing process until now more than 90% hydrogen production using fossil fuel energy such as natural gas and coal. Under these circumstances, the exploration of new hydrogen energy paths that is less or zero fossil fuel would be necessary and the LCA methodology are important to see the environmental impact of the introduction of new path comprehensively.

Woody biomass is one of the potential renewable energy resources because it is carbon neutral. Biomass energy accounts for about 15% of the world's primary energy consumption and about 38% of the primary consumption in developing countries. The increasing carbon emissions, deforestation, and forest degradation reduce the availability of woody biomass. Approximately 2.5-2.7 billion people are depending for daily cooking fuel (Koopmans 2005), given this widespread dependency on wood for energy and the importance of forests to mitigate climate change, there is a strong need to assess the sustainability use biomass from forest and the biomass energy emission from whole life cycle.

ASEAN member countries located in tropical area and the role of tropical forest in this area are important as carbon capture storage and the sources of timber and other forest products of local energy for cooking. The utilization of biomass to energy is less than 2% from the total potential in ASEAN region (Lidula et al 2007).

The increasing of hydrogen demand and less utilization of biomass energy in ASEAN became the motivation of this study to elaborate the possibility of bio-hydrogen network system between Japan and ASEAN in the future. This paper focus on the comparison of lice cycle CO_2 emission of hydrogen production (well-to-tank) between conventional system and proposed scenario. The tank-to-wheel phase ignored because the usage of hydrogen will be the same.

The paper content begins with the motivation of the study in the introduction. The second part describe the conventional system of hydrogen production in Japan and its life cycle inventory, potential of waste woody biomass for energy in ASEAN countries and its life cycle inventory of CO_2 emissions ($LCCO_2$). The third part describes the $LCCO_2$ hydrogen production system that is focus on gasification process and the possibility of three-phase product.

2. $LCCO_2$ EMISSION OF CONVENTIONAL HYDROGEN PRODUCTION

The conventional production of hydrogen fuel in Japan is using steam methane reforming method from natural gas. Fig. 1 shows the flow of hydrogen production in conventional system or the system boundary. Japan natural gas mainly imported from overseas such as Indonesia, Malaysia, Australia, Qatar, Brunei, Abu Dhabi, Alaska, and Oman. The study of life cycle CO_2 emission of the Japan natural gas has already done by Okamura et al, 2005 that is the update version from Tamura et al study in year 2001.

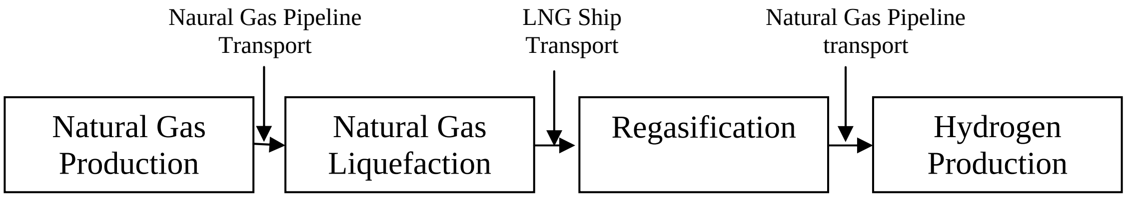


Fig. 1 shows the basic process flow diagram of steam reforming process.

The steam methane reforming flow of process shows in Fig. 2. The fossil energy and emission from steam reforming will also produced, Table 1 give the emissions in the whole life cycle in conventional hydrogen production system.

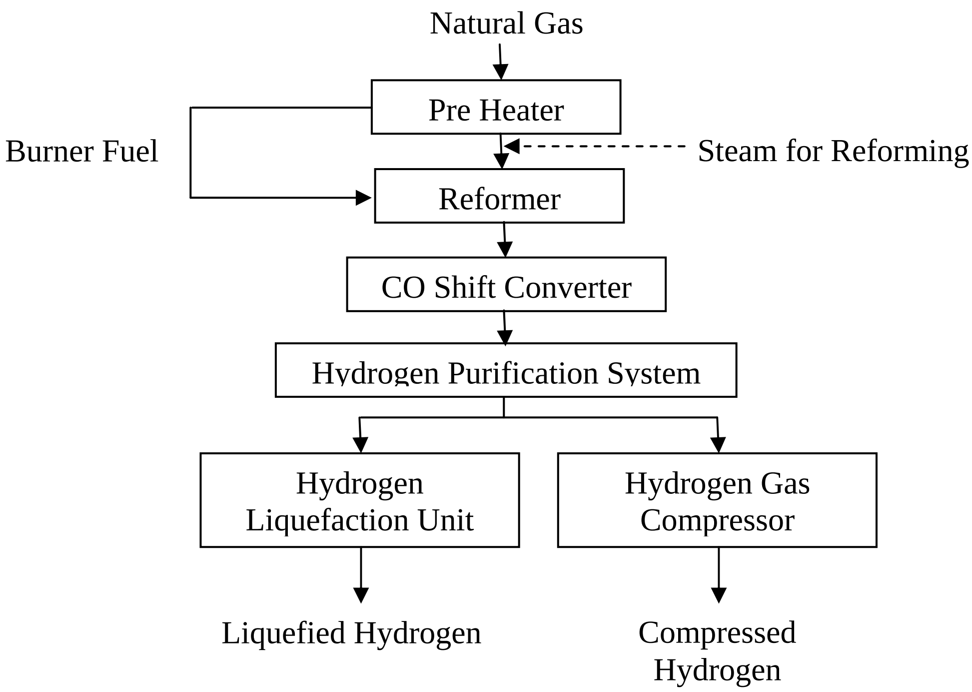


Fig. 2 Flow diagram of steam reforming

From the results, we can see that the highest contributor of CO_2 emission is steam methane reforming process. It produces more than 80% of CO_2 emission, on the other hand the natural gas production and transportation contributes less than 20% from the total life cycle. The energy demand of carbon conversion stage in steam methane reforming process give the more than 78% of CO_2 emission.

Table 1. $LCCO_2$ emission of Conventional Hydrogen

Item	g-CO_2/MJ	Percentage
Production		
Fuel consumption CO_2	0.59	0.93
Flare combustion CO_2	0.15	0.24
CH_4 from vent	0.2	0.32
Subtotal Production	0.94	1.49
Liquefaction		
Fuel consumption CO_2	5.27	8.33
Flare combustion CO_2	0.44	0.70
CH_4 from vent	0.31	0.49
CO_2 in raw gas	1.65	2.61
Subtotal Liquifaction	7.67	12.12
Overseas transportation		
Operation	1.83	2.89
Subtotal Overseas transportation	1.83	2.89
Regasification		
Manufacture/construction of facilities	0.002	0.00
Fuel consumption	1.60	2.53
Subtotal Regasification	1.602	2.53
Pipeline transport of natural gas		
Metane loss	0.1	0.16
Subtotal Pipeline transport of natural gas	0.1	0.16
Steam methane reforming		
Manufacture/construction of facilities	0.19	0.3
Fuel combustion/carbon conversion	49.4	78.09
Electric power consumption	1.53	2.42
Subtotal	51.12	80.81
Total	63.262	100

3. $LCCO_2$ EMISSION OF BIO-HYDROGEN PRODUCTION

3.1 Waste Woody Biomass for Energy

The usage of woody biomass as energy source will related to the land use change and forest management policy so that the other forest products that also useful for human living will not compete with the biomass for energy. Sasaki et al 2009 provided an assessment of the availability of woody biomass and bio-energy specifically in ASEAN countries considering the forestland use change, harvesting time, deforestation rate, and reforestation rate.

The conceptual for biomass allocation shows in Fig. 3 where the biomass for energy is by product from the furniture and pulp-paper industries. The idea is to recycle the wood waste to more useful product, which is waste to energy. The synergy between forest management, forest product, forest for energy and waste management are fundamental to built sustainability. Based on this concept, the annually biomass for energy potential shows in table 2.

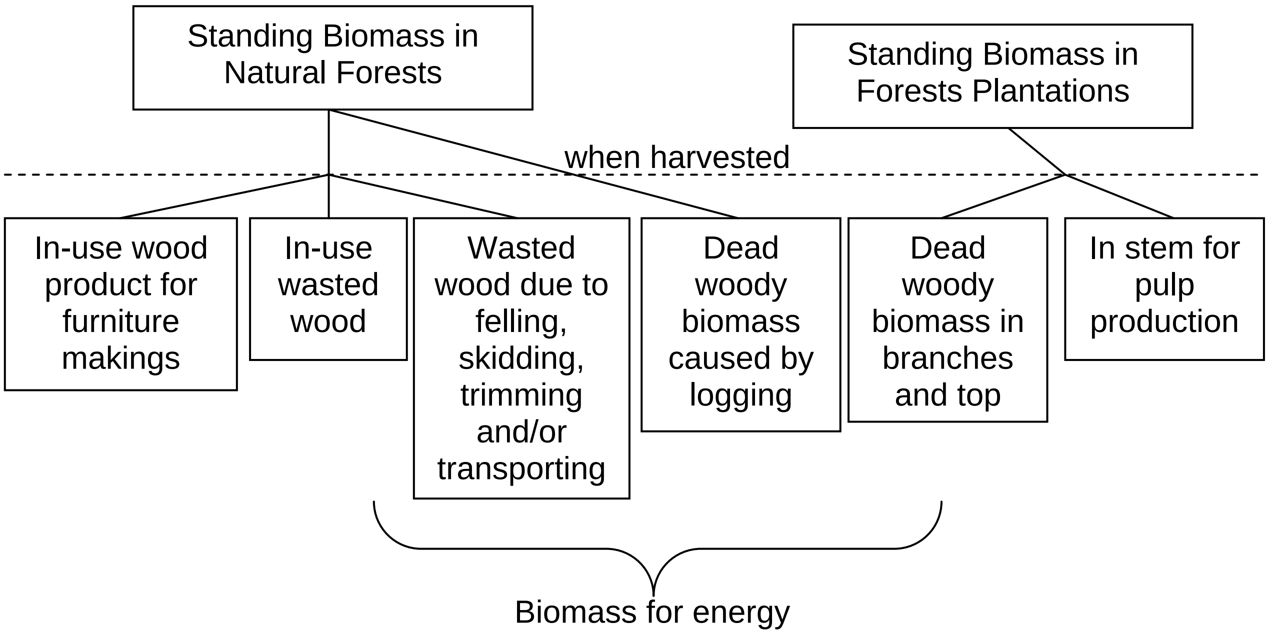


Fig. 3 Biomass allocation

There are some systems in bio-hydrogen fuel production system in use of the biomass material. In this study, the waste wood became the feedstock in producing bio-hydrogen and the hydrogen purification system through the gasification for the processing system. In Japan, the research and development on this system has implemented since the beginning of year 2000. The Blue Tower (BT) gasification system in which the pyrolysis and reforming reactions occur under reductive atmosphere can synthesize the higher concentration of hydrogen gas efficiently.

So far, we executed the studies in order to confirm the absolute proof of the chemical equilibrium reactions, and/or the demo-plant (1t/d scale) at Izumo, Japan. We also developed simulator of BT process in order to estimate the operational performance. This simulation program uses the parameters estimated by the experimental results in a room condition. Kameyama et al. 2010 compared the operational result of the demo-plant to the result of the simulator, and according to this study, the simulated data were corresponding with practice data to some extent. Moreover, the bio-hydrogen plant, which is a commercial 15 t-dry/d scale, constructed at Fukuoka, Japan.

As the initial stage of the feasibility study on the import of renewable energy to Japan, we designed the bio-hydrogen energy path on basis of BT plant operation. ASEAN countries network is the supplier of biomass and/or the bio-hydrogen in this model.

Table 2. Annual Woody Biomass for Energy

Country	Biomass for Energy (ton/year)
Brunei	745,971
Cambodia	33,248,584
Indonesia	537,936,636
Lao	63,116,357
Malaysia	195,109,315
Myanmar	161,514,989
Philippines	74,026,521
Singapore	5,367
Thailand	312,915,704
Vietnam	272,938,018
Total	1,651,557,461

3.2 LCCO$_2$ Bio-Hydrogen

The scope of life cycle inventory (LCI) of bio-hydrogen shows in fig.4, this study only consider and compare the well-to-tank process because the tank-to-wheel process assumed only one path, that is Japan market in transportation sector.

From the fig.5 we can see that the gasification process is the highest contributor of CO_2 emission because the process consumed a lot of electricity. Fig. 6 shows the CO_2 emission for the conversion of hydrogen to liquid and compressed gas.

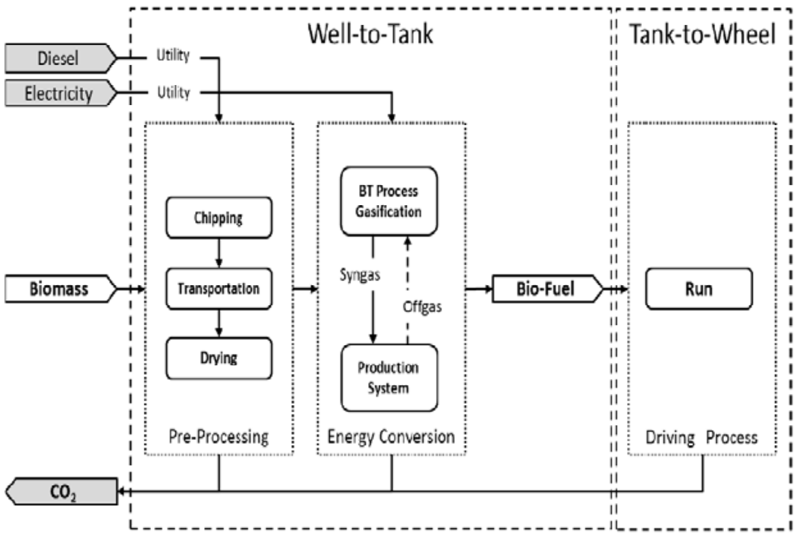


Fig. 4 Well-to-tank Bio-hydrogen production

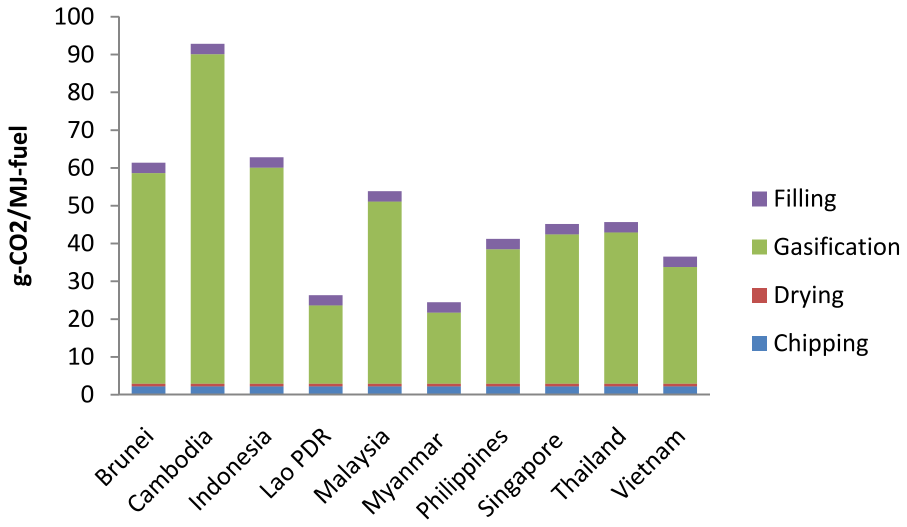


Fig. 5 CO_2 emission of Hydrogen Production

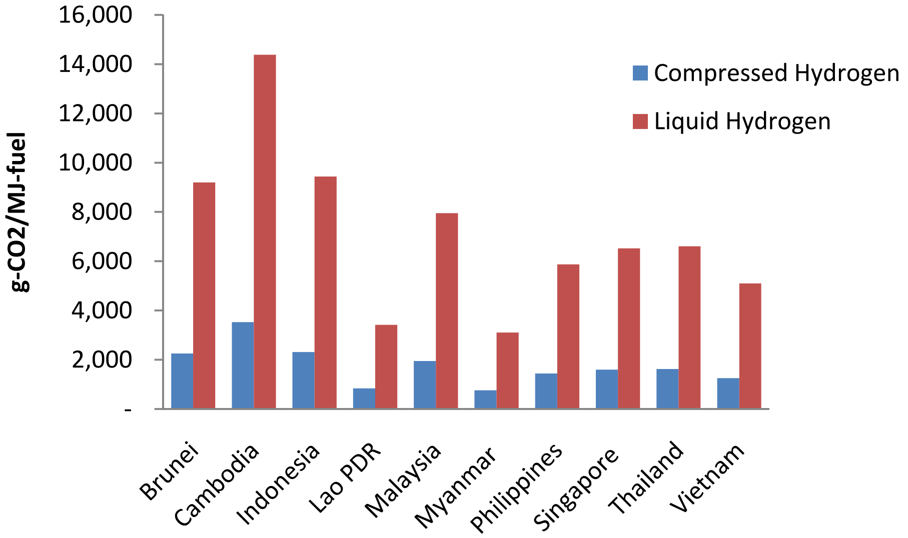
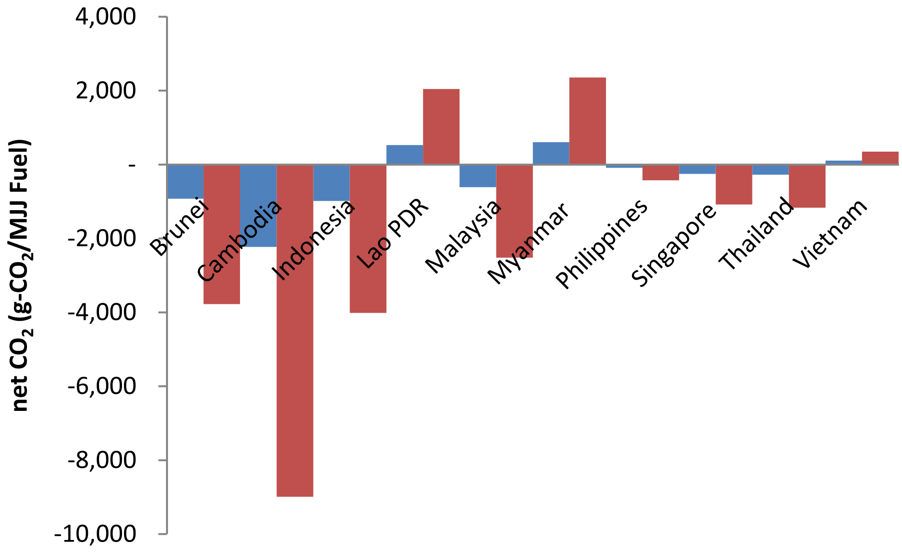


Fig. 6 CO_2 emission of Hydrogen Conversion

3.3 CO_2 emission abatement

From the result of conventional hydrogen production and the bio-hydrogen from gasification process, we can found the net CO_2 emission from the production process. The fig. 7 shows that only Myanmar and Lao who will give the CO_2 benefit due to the low CO_2 emission of electricity in comparison to other countries.



4. CONCLUSIONS

The total results show that the emission of electricity grid in each country is the most important role to get CO_2 emission benefit from the usage of hydrogen. For further research, it is fundamental to see the effect dynamic policy of electricity grid to the development of hydrogen fuel.

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