Power And Methanol Production From Biomass Combined With Solar And Wind Energy

Introduction:

This is intended to study the feasibility of producing power and synthetic fuel from biomass power plant with the help of Carbon Capture technology and renewable energy system (solar and wind energies)

This can be achieved by combining the Carbon dioxide (CO_2) with hydrogen(H) from water electrolysis product to produce methanol fuel. The water electrolysis process uses electricity network from renewable power sources, like solar PV and wind power to ensure the sustainability of the system and to minimize the carbon footprint for the system. This integrated system is analysed both technically and economically. So that it helps to evaluate the feasibility of this proposed system. The results of this thesis includes the performance of the system in term of mass and energy balance, the effect of the uncertainty variables and locations for the integrated system.

This Integrated system is one of the way to achieve high efficiency from whole system compared to separated system. For the upcoming years the renewable energy will play the role in supplying world energy demands, in order to tackle some of the environmental issues as climate change and pollution. However, this technology still requires high cost to develop.

CO_2 emission from power plants is making more serious global warming. In order to meet the 2? target set by the Paris climate, some critical technologies have to be done. (Tan, et, al). These Biomass resources can be utilized in power plants as alternative feedstock for fossil fuel. In power generation Biomass is a carbon-neutral process because the CO_2 is captured by the plant during its growth. Capturing CO_2 from biomass power plants produces negative CO_2 emissions by combining bioenergy use with carbon capture and storage. Carbon capture technology, it has been exploited in action and the utilization of CO_2 has been studied. CO_2 can be utilized for producing methane, methanol, and other substances.

Methanol (CH_3OH) is excellent fuel for its octane number above 100 and it has many advantages,

1. In fuel as it can replace gasoline.
2. It is used in some basic chemical substance such as acetic acid, formaldehyde, polymer, paint
3. It can be used as fuel in electricity generation plant such as gas turbine engine.
4. It is also easily transported when compared to methane gas fuel and
5. It serves as energy storage media conveniently.

Hydrogen can be considered as another type of the fuel. This hydrogen fuel can be acquired from natural gas or by electrolysis of water. However, the price for producing hydrogen from electrolysis of water is about 1.5 times costly than from natural gas. The transportation of this hydrogen fuel is also challenging as it has some properties like it is small and light which cause

some problems such as leakage in storage and delivery process. One of many solutions to improve this technology is by combining hydrogen with CO2 to produce another type of fuel, that is methane gas or methanol.

Carbon capture technology can surely can give CO2 for water electrolysis system while get benefit of O2 to be utilized as oxy-fuel in thermal power plant and gasification reactors. This combination can help deliver better output and reduce emission from the power plant.

When methanol and hydrogen are derived from sustainably grown biomass, the overall energy chain can be neutral greenhouse gas. Such type of scheme would provide a major alternative for the transport sector world-wide in a greenhouse gas constrained world.

Methanol and hydrogen can be produced from biomass by the gasification. Several routes involving conventional, commercial, and advanced technologies, which are under development, are possible. Methanol or hydrogen production facilities typically consist of the following basic steps:

- Pre-treatment
- Gasification
- gas cleaning
- reforming of higher hydrocarbons
- shift to obtain appropriate H2:CO ratios
- gas separation for hydrogen production or methanol synthesis and
- purification

Many process configurations can be possible, however. Gasification can be atmospheric and pressurized, direct or indirect, resulting in very different gas compositions, different options are available for gas cleaning, processing and purification, power generation is optional. Altogether in theory there are very large number of concepts to produce methanol or hydrogen.

Improved performance of the system can be obtained by:

- · Applying improved or new non-commercial technologies. Examples:

1. Use of Autothermal Reforming instead of steam reforming,
2. improved shift processes, once through Liquid Phase MeOH process, high temperature gas cleaning,
3. improved oxygen production processes.

- · Combined fuel and power production by ‘once through’ concepts. Combined fuel and power production, this may lead to lower cost and possibly higher thermal efficiencies because it has cheaper reactor capacity and reduction of internal energy consumption of the total plant.
- · Economies of scale: various system analyses have shown that as the higher conversion efficiencies and lower unit capital costs that accompanies increased scale generally outweigh increased energy use and costs for transporting larger quantity of biomass. Furthermore, it should be noted that paper mill and pulp mills, sugar mills, and other facilities operate around the world with equivalent thermal inputs is of the range of 1000-2000 MWth. Such a scale could therefore be considered for production of energy

or fuel from that is imported biomass as well.

Objectives:

The aim of this is to study the answers of the question “How biomass energy system can be integrated with solar energy and wind energy to achieve high efficiency?” The system will provide energy and power in the same time with supply of biomass. Therefore, the objectives of this are:

- Investigating the feasibility of Integrated system technically and economically
- Estimating the cost of energy from the system production
- Review the effect of location to the system
- Review the effect of uncertainties factor on the cost of energy

Economic Model:

The economic model is determined on the basis of annual cost of the system and levelized cost of the energy. Annual cost consists of annualized capital cost, maintenance and operation cost, and fuel cost. In addition, selling cost of energy is influenced by the energy produced by the system, annual cost, and from selling commodity or incentives received. By looking at these result values and comparing with other conventional system, the feasibility of this proposed integrated system can be determined.

Technical Model:

The technical model is defined by the configurations of these proposed systems. Each of these system component performance is analyzed and reviewed. Therefore the input and output of the component is interconnected to each component and affected the whole integrated system. Since they depend on one another, one fixed input variable is defined to make the comparison of the systems are clear and just. The technical model includes the calculations and simulations for each systems and sub-systems.

Sensitivity Studies:

In order to understand the relationship between input and output variables for the system, it is beneficial to do sensitivity studies. Some uncertainty factors are evaluated in this study such as effects of location for building the system, fuel price and capital cost variations. The result demonstrates the impact of the input for the performance of the integrated systems and it will help in deciding which one will benefit the most for the system.

Literature Survey:

Methanol synthesis using carbon dioxide:

A research showed that the methanol production system using captured carbon dioxide(CO_2) and hydrogen(HE) as supplying substances (Van-Dal and Bouallou 2013). The carbon dioxide is captured by chemical absorption from the flue gases of the thermal power plant while

hydrogen is produced from electrolysis of water using carbon-free electricity. The result showed 0.67 ton of methanol produced per ton of carbon dioxide (CO_2) supplied. Also with operation of 8000 hours/year, the annual methanol production of the plant is equal to 470,500 ton. Meanwhile, the oxygen that is produced from the electrolysis of water process can be sold to the market as another means of commodity beside methanol.

Solar PV and Wind power system:

Solar PV and wind power system are well-developed technologies in the renewable energy business. In 2016, solar power installed 71 GW new capacity and the wind power installed 51 GW globally according to Renewable Energy World. This means such technologies are mature enough and ready to integrate with another power system.

Combining solar and wind power with electrolysis of water is attracting new researches. According to, two demonstration projects has shown the possibility of this concept. The first one is in the Sotavento's wind farm in Spain where electrolysis of alkaline water supplied by wind farm of 17.56 MW and producing hydrogen 60 Nm3/h. Then hydrogen produced is used to generate electricity. By combustion in a 55 kW generator to generate electricity.

Fig.1 Solar PV power water electrolyzer.

The second project is named Wind2H2 developed by the U.S. NREL (National Renewable Energy Laboratory.) and Xcel Energy. It consists of some systems like hydrogen, photovoltaic, and wind systems. This project includes 1) a 10 kW photovoltaic solar array, 2) two wind turbines of 10 and 100 kW, 3) two PEM electrolyzers of 1.05 Nm3/h, 4) an alkaline electrolyzer of 5.6 Nm3/h, and 5) a 50-kW hydrogen-fueled internal combustion generator.

Fig.2. wind2H2 system schematic.

Biomass carbon capture utilization power plant:

Several studies demonstrated that it is feasible to combine biomass power plant with carbon capture system. There are three different ways to implement this method.1. Using oxy-fuel combustion, 2.Integrated Gasification Combined Cycle (IGCC), and 3.Utilization of syngas from gasification. Currently there are only few limited number of operational oxy-fuel power plant in Europe. This pilot plant shows the possibility of the oxy-fuel implementation in thermal power plant. Therefore this oxy-fuel biomass-based is possible because the biomass feedstock is compatible with coal.

Oxy-fuel power plant system model by Cormos is evaluated using three different feedstock; coal, lignite, and biomass. For each of these different feedstock, the carbon capture rate is set to 93%.

Material And Methodology:

The integrated system comprises of the biomass-powered power plant, electrolysis of water system, methanol synthesis. Biomass power plants as the main source of carbon and combining with hydrogen from electrolysis of water to produce methanol. The three types of

biomass power plant used as the model are oxy-fuel combustion, IGCC, and syngas gasification plant. These three type required oxygen as for their operational which provided by the electrolysis process.

Methanol can be produced by combining carbon dioxide and hydrogen through methanol synthesis process. Hydrogen is obtained from electrolysis of alkaline water, which also be powered by solar and wind energy. Meanwhile, CO_2 is captured from biomass power plant. In addition, syngas from gasification process can be processed directly into the process of methanol synthesis.

Fig.3. Integrated system.

System 1: Oxy-fuel combustion biomass power plant combined with solar and wind energy for power and methanol production:

System 1 consists subsystems as oxy-fuel combustion power plant with carbon capture, water electrolysis system, solar and wind system and methanol synthesis. This power plant is defined as the super-critical double reheat boiler oxy-combustion with flue gas treatment. The Steam turbine system generates electricity by utilizing thermal heat energy from the combustion. Carbon capture rate from the oxy-fuel power plant is assumed to be 93%. In addition, to maintain required mass flow rate and oxygen concentration,75% of captured CO_2 is circulated back to the boiler. Captured CO_2 is pumped and sent to the methanol synthesis reactor. Oxygen required for oxy-fuel combustion is provided by the electrolysis of water product which also produces hydrogen for methanol synthesis. In addition, the electricity needed for alkaline water electrolysis is supplied by the solar and wind power system. It is assigned that there is excess energy production from wind and solar power to be sold as electricity separately. All electricity is supplied to electrolysis process.

System 1 detailed configuration

System 2: IGCC combined with solar and wind energy for power and methanol production:

. System 2 consists of IGCC, water electrolysis system, solar and wind system and methanol synthesis processes takes place. This system provides carbon dioxide(CO_2) by pre-combustion carbon capture which takes place after gas conditioning of syngas from the gasification process. The capture rate is set to be 90% according to The IGCC consists of oxygen-supplied gasifier which converts biomass into syngas, WGS (Water Gas Shift) reactor which converts CO into CO_2 and H_2, and cleaning section where H_2S and CO_2 is separated from syngas as a part of pre-CCS process. Syngas after cleaning is combusted in the gas turbine system to generate the electricity. CO_2 captured is supplied to methanol synthesis process with hydrogen from electrolysis of water.

System 2 detailed configuration

System 3: Biomass gasification combined with solar and wind energy for methanol production:

Syngas (that is a mixtures of CO_2, CO, H_2, CH_4, and N_2) is produced and sent directly to methanol synthesis reactor in system 3. There will be gas cleaning or washing and drying accompanied by the gasification process to deliver syngas without tars. The gasifier is the oxygen-blown down-draught pressurized type with gas cooler, tars scrubber, and gas dryer. There is another type of gasifier can be implemented here Example Entrained Gasifier and Fluidized Bed Gasifier but downdraft gasifier is chosen due to its simplicity of the design and operations. It has the high turn-down ratio from 100% to 25% design load which brings advantage in the flexible operation. Oxygen supply from water electrolysis can be inconsistent due to fluctuated energy supply from renewable sources. This type can also reduce the char formation per carbon content percentage from the biomass. Oxygen and wood chips are fed from top side of the bed and the gasifier will be operating at the temperature above 800°C with heat provided by pyrolysis gases. All the syngas after dryer is sent to methanol synthesis with hydrogen from water electrolysis powered by solar and wind power systems.

System 3 detailed configuration

Methanol synthesis:

Production of methanol requires carbon dioxide (CO_2) and hydrogen(H_2) as feed stocks. The process of synthesis of methanol can be described by the following reaction

$CO_2 + 3H_2$? $CH_3OH + H_2O$ (1)

It can be simplified by 1.375 kg of CO_2 and 0.1875 kg of H_2 will produce 1 kg of methanol for all three systems. (System 1,2,3) In addition, for the system 3 can be simplified further as the syngas production is one closed system with the methanol synthesis. Therefore, for 1 kg of wood chip supply into the gasifier requires 0.127 kg of hydrogen to produce 1.14 kg output of the methanol fuel.

Solar and wind power system:

Wind and solar energy resources are considered in the integrated system because both technologies are mature enough and growing especially in the Europe. For purpose of simplicity in determining how big the power plant should be built to accommodate the electricity needed, the capacity factor is used. CF(Capacity factor) is defined by the average power output for specific technology or device and geographical locations and divided by its rated maximum output.

Electrolysis of water:

This Water electrolysis system supplies oxygen for oxy-fuel combustion and hydrogen for methanol synthesis. The water electrolysis system can be described as the following reaction

H_2O + electricity ? $H_2 + O_2$ (2)

1 kg of electrolyzed water provides 0.111 kg of hydrogen and 0.888 kg of oxygen, and water electrolysis product from NEL Hydrogen Norway is chosen. The alkaline-based electrolysis technology is already mature and has been used in many industrial scale and it operates in the

atmospheric condition. The power demand for the electrolysis is set on 4.3 kWh/Nm3 hydrogen produced. electrolysis of water will supply oxygen and hydrogen to the system in order to produce methanol (fuel). It can provide specific quantity of hydrogen to accommodate CO_2:H_2 proportion to produce methanol according to stoichiometric condition. Meanwhile, oxygen produced is delivered into biomass power plant as it is needed and the rest is released to the atmosphere or that can be sold as another commodity. In case when the oxygen supply is not enough for the biomass power plant, the deficit of oxygen is bought from outside the system.

Economic model:

Capital and maintenance cost of several systems

Results And Discussion:

The result from simulations and calculations is demonstrated in this part. For the base case that is determined to be in Gotland Sweden, the technical performance is explained in term of the mass and energy balance for those three systems. Economic analysis is done on the basis of capital cost and LCOE to investigate the feasibility of each proposed system configurations. The sensitivity study and effect of location are performed to gain better understanding of the system.

Base Case Model Study:

For the base case, the location is set in the Gotland that is Sweden with solar energy only, wind energy only, and 50%-50% wind and solar energy. The table shows the results of three systems. By comparing with energy market cost of electricity and methanol, the three systems are not competitive. When green incentive is considered, the electricity cost is only reduced by the 0.02 €/kWh. The studied systems cannot compete with conventional power plants. According to US Energy Information Administration (EIA), typical coal-fired power plant costs 1200 €/kW while natural gas and nuclear cost 700 €/kW and 1600 €/kW. The cost of proposed systems are 2000-8000 €/kW. However, the LCOE of system 1 is much lower than that of the system 2. The capital cost depends on solar and wind systems. The more CO_2 used for methanol synthesis, the bigger solar or wind power capacity is needed for water electrolysis. Therefore, reducing the cost of solar and wind systems can dramatically decrease the capital cost of the whole system.

Table 1: Base case model analysis.

Sensitivity Study:

The effects of the capital cost, fuel cost, interest rate, and electricity price on the economic performance of systems were analysed. Capital cost and fuel cost were set to ±10% variation while interest rate is varied from 6% to 10%. The result was analyzed for the base case scenario. The variation of fuel cost results in 2% deviation of energy the cost. Here the impacts of interest rate is greater, for example, the energy cost is 16% higher when interest rate is increased from 6% to 7%.

Sensity analysis of three systems

Effect Of Location:

Beijing has the better economic performance due to the low cost in China. This is because of solar and wind power capital cost in China are low, that is only 27% and 64% of the installed cost in Sweden. Prices of electricity are 0.047, 0.050, and 0.085 €/kWh respectively for biomass power plants in Sweden, China, and US.