Document 1: Carbon dioxide Capture integrated Biogas Plant with Methanol production – Concept Note

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INTRODUCTION

Carbon Dioxide capture and utilization (CCU) is a popular as well as developing area of research nowadays. The emissions from industrial activities, automobile, anthropogenic emissions, etc. has considerably increased the amount of carbon dioxide in the atmosphere, subsequently decreasing the air quality and leading to global warming. Hence, the reduction of the same is highly recommended for the healthy and sustainable life on earth. The primary and most recommended solution for this is afforestation. However, considering the economic growth as well as space utilization for various activities, there is a limit for this solution. Scientists and engineers has come up with solutions for CO_2 capture process, such as Direct Air Capture, which is capable to replace millions of trees in terms of CO_2 capture, utilizing a small space.

This concept paper discuss about CO_2 capture and utilization integrated biogas plant. Biogas plant is a highly recommended solution for treating biodegradable waste. The biogas generated from the waste can be used for cooking gas, power generation etc. due to its decent calorific value (around 20,000 kJ/m^3). Even though biogas plant provides an excellent solution for waste disposal and recycle, the end use of biogas for power generation and cooking leads to emission of considerable quantity of CO_2. This project is an attempt to make waste disposal and recycle using biogas plant a cleaner process in terms of net CO_2 emission by incorporating CCU.

The proposed unit consists of biogas plant integrated with power generation, CO_2 capture and methanol production.

PROCESS DESCRIPTION

Biogas mainly contains methane and carbon dioxide, which is being generated by the anaerobic digestion of the biodegradable waste. Biogas generated from biogas plants undergoes oxy-combustion (with 100% oxygen) for power generation. The flue gas hence, generated contains CO_2 which is captured using absorption with amine solvent (or other suitable solvent). The absorption is followed by stripping which gives out pure CO_2 and allows solvent recovery. The CO_2 hence separated and H_2 obtained from the electrolysis of water are compressed and transferred to the methanol reactor, where CO_2 and H_2 reacts to form methanol and CO as given below.

$$CO_2 + 3H_2 \leftrightarrow CH_3OH + H_2O \tag{1}$$

$$CO_2 + H_2 \leftrightarrow CO + H_2O \tag{2}$$

Suitable catalyst shall be used to increase the conversion of CO_2 and selectivity of methanol. The unreacted products are recycled back to the reactor for increased overall conversion. The product is purified in a distillation column for the production of methanol.

In the above process, the power generated from the biogas is used for meeting the partial energy demand for electrolysis of water for the generation of H_2. The O_2 produced along with H_2 is used for the oxy-combustion for the power generation.

The process flow diagram is provided below as figure 1:

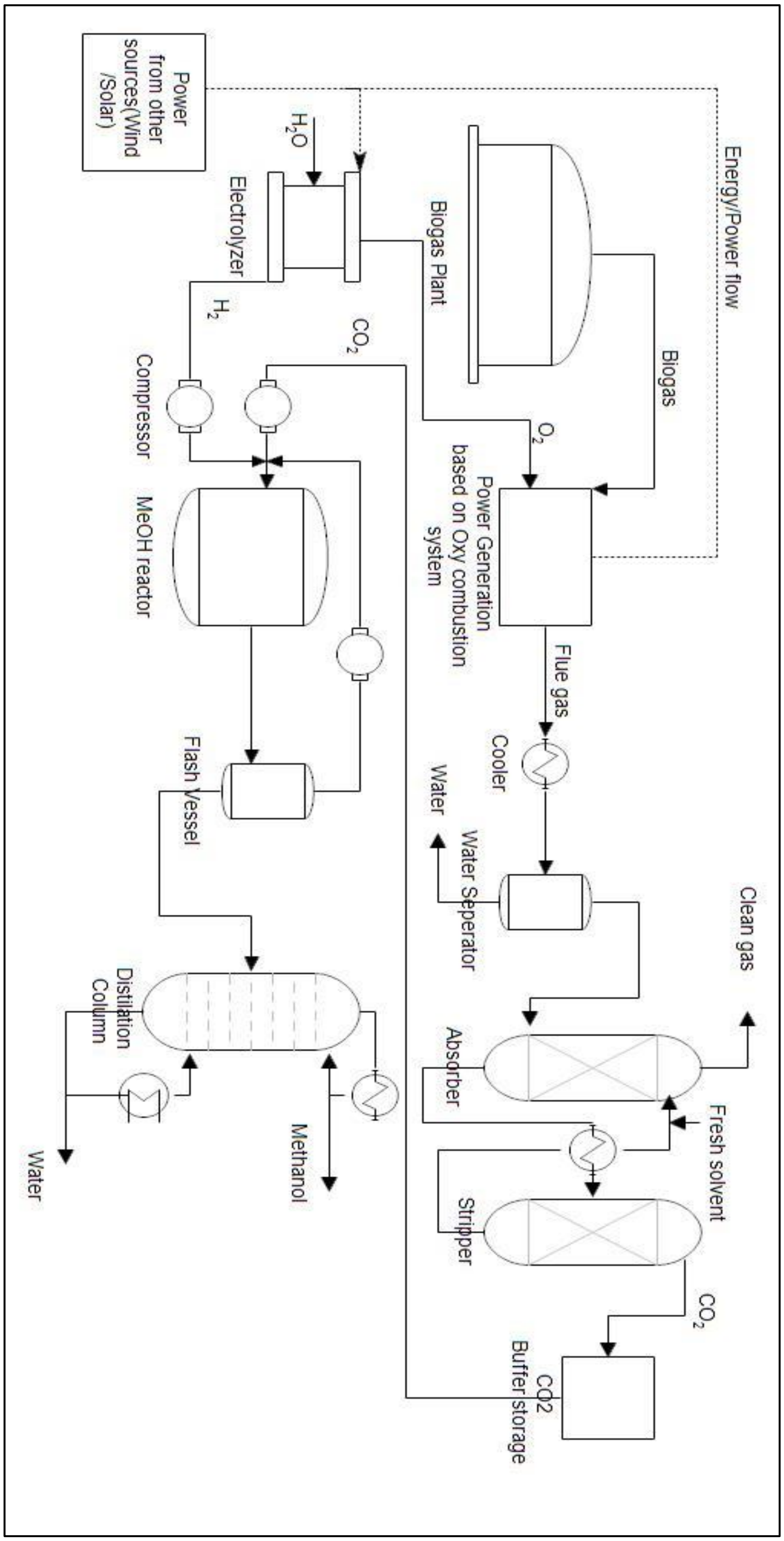

Fig1: Process Flow Diagram

KEY FEATURES

- The proposed unit produces methanol from CO_2 and CH_4 obtained from anaerobic digestion of disposed waste in a biogas plant and H_2 obtained from water electrolysis making the process revenue generating which will help in contributing the operating expenses for the plant.
- General usage of biogas such as cooking gas and power generation leads to the emission of CO_2. *This integrated approach ensures a cleaner technology by the integration of CO_2 capture and utilization.*
- The practice of production of bio-methane by removing CO_2 from biogas and enriching the gas with methane is an established area. However, further use of bio-methane to produce energy leads to CO_2 emission. The concept proposed here eliminates this problem and also gives the solution for waste disposal and CO_2 utilization thus showing potential for being a carbon neutral process.
- The energy required for electrolysis of water to produce H_2 shall be partially met by power generated from biogas. A 2000 kg/day processing capacity CCU integrated biogas plant (pilot scale) is capable of generating approximately 2.7 GJ/day. The electrolysis process required for the methanol generation for the same plant requires approximately 9.5 GJ/day. The excess energy requirement shall be met from renewable energy sources such as solar or wind energy. A calculation sheet explaining the above figures is provided in the next section.
- The oxygen generated from the electrolysis process (which is used for H_2 production for methanol process) shall be used for the oxy combustion of biogas plant for the power generation. In a 2000 kg/day CCU integrated biogas plant (pilot scale), the oxygen generated in the electrolysis process is approximately 20 kmol/day. The oxygen required for the oxy combustion is approximately 16 kmol day. The complete oxygen demand for the oxy combustion shall be met internally. A calculation sheet explaining these figures are provided in the next section
- Oxy combustion leads to efficient combustion and burden related to N_2 is also solved
- The manure from the biogas plant is also a sellable product as fertilizer, which can also generate revenue

CALCULATION FOR A PILOT PLANT

In order to establish figures for the better evaluation of the process in terms of process attractiveness and financial aspects and to get a quantitative idea at the same time, certain indicative calculations were carried out and the same is presented below. The calculations are performed considering a pilot plant with capacity 2000 kg/day solid waste processing.

Energy generation by combustion of the biogas		
Calorific value of the biogas considered	20920	kJ/m^3
Considered biogas plant capacity (Pilot Plant)	2000	kg/day

Assumed water content in the waste	50	%
Solid content in the waste	1000	kg/day
Biogas production from kitchen waste	0.33	m^3/kg dry waste
Biogas generation from the plant under consideration	330	m^3/day
Energy generation by combustion of the biogas	6903600	kJ/day
	6903.6	MJ/day
	6.9036	GJ/day
Power generation efficiency considered	40	%
Actual energy generation from biogas	2.76144	GJ/day
Composition considered for Biogas		
Methane	60	%
CO2	39	%
Other gases	1	%
Quantity of biogas produced	330	m^3/day
Quantity of methane in biogas	198	m^3/day
(Calculation based on Ideal gas law)	8097.58	mol/day
	8.09758	kmol/day
Quantity of CO2 in biogas	128.7	m^3/day
	5.26343	kmol
CO2 after combustion		
(Complete conversion of CH4 considered)		
CH4+2O2->CO2+2H2O		
CO2 produced in combustion	8.09758	kmol/day
Total CO2 in the flue gas	13.3610	kmol/day
Overall conversion for methanol reaction taken	80	%
Methanol production	10.6888	kmol/day
	342.042	kg/day
Stoichiometric H2 requirement	40.0830	kmol/day
Water required to be electrolyzed for the production of H2	40.0830	kmol/day
Energy required for 1 mol H2O splitting	237.13	kJ
Energy requirement for the process under consideration	9504893	kJ/day
	9.50489	GJ/day
Excess energy required for electrolysis	6.74345	GJ/day
Oxygen produced from electrolysis	20.0415	kmol/day
Requirement of Oxygen for Methane combustion	16.1951	kmol/day
Excess Oxygen from electrolysis	3.84635	kmol/day

BUSINESS CASE

The process overall is not a financially viable process due to the high energy requirement for the process and capital investment. The major revenue streams are from methanol and manure. The methanol produced in the above mentioned sample case for a pilot plant is 342 kg/day, which will bring a revenue of approximately 26,676 Euro per annum. The increase in demand of methanol and hike in market price will favor the proposed process. The size of the unit is also important in revenue stream. The sample case considered here for the calculation is 2000 kg/day biogas plant. Bigger units can increase the revenue in the expense of increased capital and operating cost. For the implementation it is always better to go for higher capacity plants considering capital and operating expenses. A 100 tons per day waste processing plant can produce around 17 tons per day methanol.

However, the whole project is not about making profit by selling methanol. The social and environmental benefits of the project makes the process attractive. Waste is being disposed in the cleanest way avoiding the negative impact on the environment to a large extent. CO_2 is effectively captured and converted to methanol which also can be a key performance indicator for the plant. The project can be viewed in two ways, one the modification of existing biogas plants with adequate capacity into “carbon capture integrated” methanol units. This requires proper assessment of the existing plants and modifications for maximum efficiency. Other is to build new units of suitable capacity as centralized units.

The suggested business model for the project is Public Private Partnership model due to the social importance of the project. The stake of government and private entities are the most important requirement for such a project. A design, built, finance, operate and transfer (DBFOT) model can be adopted. However the final plan shall be based on detailed analysis. The units shall be established with justifiable size with waste collection area coverage decided considering transportation.

PROCESS VARIATION WITH PLASMA TECHNOLOGY

A process variation is suggested using plasma pyrolysis with carbon black and hydrogen production. The block diagram briefly explaining the process is given below:

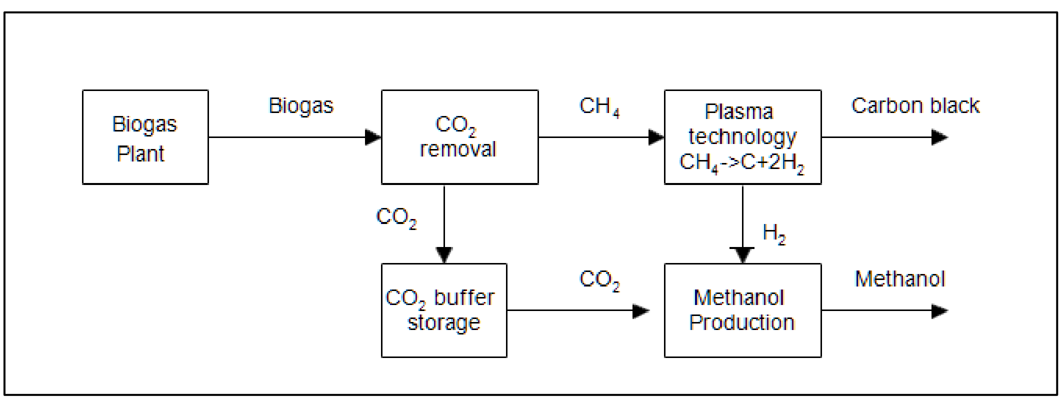

Fig 2: Process variation Block diagram

The biogas after CO_2 removal using absorption or adsorption will contain mainly methane which undergoes plasma pyrolysis in the plasma reactor leading to the splitting of methane molecule to carbon black and hydrogen. This is one of the cleanest ways of producing hydrogen without generation of oxides of carbon. The hydrogen thus produced and the captured CO_2 from biogas reacts to form methanol. The carbon black obtained from plasma pyrolysis is a marketable product.

The key feature of the process is generation of hydrogen from methane without production of other compounds such as CO_2 and CO. Normal process of reforming will lead to the production of oxides of carbon. Hence, no additional CO_2 is generated in pyrolysis based process. We are so keen to work more on this also to come up with exciting solutions.