BIO-CNG: Renewable Energy from Biomass

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Abstract - *Increasing consumption of fossil fuels and environmental concern has led to increased use of compressed natural gas (CNG) in the transportation sector. Keeping in view limited resources of CNG, biogas is advised as potential fuel to provide continuous supply of CNG in the form of bio-CNG. Various technologies, that is, physical and chemical absorption (using water and amine solutions, respectively, for the absorption of carbon dioxide), pressure swing adsorption, membrane separation, and cryogenic separation, are available for purifying biogas and thus upgrading it, to bio-CNG with about 95% methane. Among these, water scrubbing and pressure swing adsorption are the best technologies with respect to various aspects including cost; however, suitability of a technology is decided by various factors including size/quantity of biogas generation, targeted quality of biogas, site of application, and economics of process.*

***Key Words*: biogas upgrading; bio-CNG; methane; purification.**

1.INTRODUCTION

India's economy is one of the fastest growing in the world, and there are plans for a sharp rise in energy consumption there. India possesses 1,488 billion cubic meters (BCM) of natural gas and 763 million metric tons (MMT) of crude oil in total, according to estimates from the Ministry of Petroleum and Natural Gas (MoP&NG). Approximately 77% of the nation's crude oil needs and 50% of its natural gas needs are now imported; hence, the Indian government has set a goal to reduce these imports by at least 10% by 2027. Additionally, it has set a goal to raise gas's share of India's energy mix from the current 6.5% (the country's average is 23.5%) to 15% by 2027 [1]

The four pillars of our strategy for India's energy future—energy access, energy efficiency, energy sustainability, and energy security—have been announced by the Hon. Prime Minister. A further goal established by the Indian government is to "Double Farmers Income by 2030." Anaerobic decomposition of waste or biomass sources, such as cow dung, agricultural residue, sugarcane press mud, municipal solid waste, sewage treatment plant waste, etc., results in the production of bio-gas. After the biogas is cleaned to remove water vapor, carbon dioxide (CO_2), and hydrogen sulfide (H_2S), it is compressed into compressed biogas, or compressed biogas (CBG), which contains more than 90% methane (CH_4). [1]

CBG has calorific value and other properties similar to CNG and hence can be utilized as green renewable automotive fuel. Thus, it can replace CNG in automotive, industrial and commercial areas, given the abundance biomass availability within the country.

1.1 Policy Support

The National Policy on Bio-Fuels 2018 has been made public by the Indian government by gazette notice no. 33004/99, dated 8.6.18. The program places a strong emphasis on promoting advanced biofuels,such as CBG. The Government of India launched the Galvanizing Organic Bio-Agro Resources Dhan (GOBAR-DHAN) project to transform solid waste and cattle dung in farms into compost and BioCNG (CBG). In 2018–19, the GOBAR–DHAN initiative plans to fund 700 projects nationwide.
Central Financial Assistance (CFA) for Bio-CNG has been notified by the Ministry of New and Renewable Energy.

1.2 Compressed Biogas in India (CBG)

With a capacity to generate 370 MMT of biomanure, India's projected CBG potential from diverse sources is close to 62 MMT. It is intended for CBG to be produced from a variety of biomass and waste sources, such as sewage treatment plant waste, sugarcane press mud, municipal solid waste, distillery wasted wash, cow dung, and agricultural residue. Biogas can be produced from other waste streams, such as rotting vegetables and potatoes from cold storage, dairy facilities, chicken and poultry litter, food trash, horticulture waste, forestry residues, and industrial Effluent Treatment facilities (ETPs) that process organic waste.

About 55% to 60% methane, 40% to 45% carbon dioxide, and trace levels of hydrogen sulfide are present in the biogas that is produced. To create CBG, biogas is refined to eliminate gases such as carbon dioxide and hydrogen sulfide. Pipelines or cylinder cascades can be used to deliver the CBG to retail locations.
Gazette Vide The Ministry of Road Transport and Highways, Government of India, approved the use of bio-compressed natural gas (bioCNG) for motor vehicles as an alternative to compressed natural gas (CNG) on June 16, 2015, under Notification No. 395 [1]

Compressed Bio Gas (CBG) to be supplied shall meet specifications of BIS (detailed below) and any other further revisions in the said specifications.

Table 1.2 : Composition of Fuel [2]

S No.	Characteristic	Requirement
1	Methane percentage (CH_4), minimum	90.0 %
2	Only Carbon Dioxide percentage (CO_2),, maximum	4%
3	Carbon Dioxide (CO_2) + Nitrogen (N_2)+ Oxygen (O_2) percentage maximum	10%
4	Oxygen (O_2) percentage maximum	0.5%
5	Total Sulphur (including H_2S) mg/m^3, maximum	20 mg/m^3
6	Moisture mg/m^3, maximum	5 mg/m^3

1.3 Envisaged Business Model for Oil Marketing Companies (OMCs)

The establishment of BIOCNG plants will primarily be carried out by independent entrepreneurs, while OMCs may take the lead in certain circumstances. Producer(s) / Seller(s) (Party/Entrepreneur) shall use cascades to transport CBG to Public sector Oil Marketing Companies' existing or new retail outlet / stand-alone selling point (within a maximum distance of 25 km, as indicated). Public sector Oil Marketing Companies shall install and maintain the CBG dispensing equipment at their new or existing retail outlets and stand-alone selling points; nevertheless, RO Dealers will be in charge of staffing and operating the CBG nozzles.

The Party paying the actual costs will be compensated for electricity used to dispense CBG through the sale point. The point of sale for CBG will be the outlet flange of the cascade or the inlet flange of the compressor at the retail location. Until the dispensing is operationally possible, the cascade at the retail store will stay connected to the compressor. [2]

1.3 Pricing Framework of CBG

Item	Unit	Price
Basic Price of CBG meeting, compressed at 250 bar and delivered at OMC Retail Outlet in cascades	Rs /kg	46.00
GST at 5%	Rs /kg	2.30
Total supply price (incl. GST) to be paid to party	Rs /kg	**48.30**

Additionally, an element of Rs. 2 per kg of CBG towards cost of setting up of infrastructure e.g. booster compressor, dispensing unit, etc. at retail outlet and Rs. 0.50 per kg of CBG towards electricity charges for operation of booster compressor, dispensing unit, etc at retail outlet, shall be provided to OMC or APPLICANT, as per whosoever sets up infrastructure at retail outlet. [7]

2. METHODOLOGIES

Anaerobic digestion is a process that turns organic waste materials into biocng, a sustainable and renewable energy source. This green energy option offers a workable way to cut greenhouse gas emissions in addition to addressing waste management issues. Biocng is put through stringent production, waste impurity removal, and purification procedures to guarantee its safe and effective use. This all-encompassing method ensures that superior Biocng is produced, fit for a range of uses such as industrial and transportation applications. We will examine the processes used in the manufacturing, purification, and elimination of waste impurities related to Biocng in this talk, illuminating the creative methods used to establish this renewable energy source as a pillar of the sustainable energy environment.

When it comes to innovation in the search for sustainable energy, Biocng stands out. Anaerobic digestion of organic materials produces biogas, which contains methane, which is the main ingredient in natural gas. This biogas is purified using methods like moisture reduction and carbon dioxide elimination to make it fit for general consumption. To achieve the best gas yield, the production process requires meticulous feedstock digestion and preparation. Concurrently, waste pollutants are carefully eliminated, improving the quality of the biogas. This two-pronged strategy not only turns garbage into energy but also shows how green technology may help create a cleaner, greener future.

2.1 Production Technologies of Bio-CNG

Upgrading biogas creates additional opportunities for its larger-scale application because it may then be utilized as a natural gas alternative. On the other hand, upgrading biogas involves financial investment. Thus, it is critical to have an updated process that is designed for low energy consumption, high efficiency, and a high methane content in the upgraded gas. Additionally, while upgrading, there should be as little methane loss with the reject gas as feasible. The success of evaluating laboratory data on current technologies, their use in creating new technologies, and their deployment in real-world settings all contribute to the process optimization for any industrial application.

Upgrading biogas mostly entails removing carbon dioxide to raise its fuel value after a cleaning process that removes water and hydrogen sulfide. To prevent operational issues throughout the upgrade process, cleaning is required. [6]; but, because to its acidic nature, traces of nitrogen and hydrogen sulfide can be eliminated in addition to carbon dioxide. [14]

2.1.1: Desulfurization:

Sulfide precipitation is used to accomplish in situ desulfurization. By adding liquid combinations of different metal salts (such as iron chloride or iron sulfate) to the digester, sulfur present in the substrate is precipitated, and the resultant sulfide is removed with the digestive.

$$3H_2S + 2FeCl_3 \rightarrow 6HCl + Fe_2S_3\downarrow$$

This is an inexpensive procedure that can also aid in the removal of hydrogen sulfide and ammonia. This method is commonly employed in digesters that generate biogas with elevated levels of hydrogen sulfide.

2.1.2: Biological desulfurization:

In the presence of oxygen, a variety of biological species are employed to extract hydrogen sulfide from raw biogas. Microorganisms belonging to the species Thiobacillus or Sulfolobus are a typical illustration.

This approach has low operating costs and a modest initial expenditure. This approach has shown to be straightforward, stable, and chemical-free. [17]

The biological system can extract even very high concentrations of hydrogen sulfide from the biogas, but it is not very adaptable to changes in the hydrogen sulfide content of raw biogas. The technique works best when the amount of hydrogen sulfide in raw biogas is low to moderate; variations in this content are not as strong.

2.1.3: Chemical-oxidative:

With this process, hydrogen sulfide is oxidized to elemental sulfur in the presence of chemicals. For this aim, caustic solutions—especially sodium hydroxide—are frequently used at pH levels that are regulated to cause the separation selectively.

Although steady operation can result in hydrogen sulfide concentrations as low as 5 ppm, the most cost-effective operation involves controlling the H2S content in the filtered gas around 50 ppm, with any remaining hydrogen sulfide to be eliminated by adsorption on metal oxides. If high or significantly fluctuating hydrogen sulfide concentrations are anticipated in the feed gas, this technique can be advised. [19]

2.1.4 Adsorption on metal oxides:

Hydrogen sulfide can be eliminated easily by allowing it to adsorb on activated carbon or the surfaces of metal oxides such as iron, zinc, and copper oxide. Water vapor is emitted and sulfur from hydrogen sulfide is bonded as metal sulfide during this process.

$$MO + H_2S \rightarrow MS + H_2O$$

Metal that has been completely loaded with H2S needs to be replaced. Adsorption on activated carbon typically involves a tiny amount of oxygen added in order to oxidize the gas that has been adsorbed on sulfur and strengthen its bond with the surface. An specifically impregnated activated carbon material is utilized if oxygen dosage is prohibited.[20] This method yields products with concentrations lower than 1 ppm and is incredibly effective. However, due to its high total specific costs, this approach is often only advised for final and fine desulfurization operations (usually up to 150 ppm hydrogen sulfide in the raw biogas).

2.2 Bio-CNG Purification Technology

Anaerobic bacteria break down organic matter, producing biocng as a byproduct. The four consecutive chemical and biological reactions that make up the biogas generation process are the hydrolysis reaction, acidogenesis reaction, acetogenesis reaction, and methanogenesis reaction. Organic molecules including proteins, lipids, and carbs are broken down into glucose, amino acids, and fatty acids, respectively, by a process called hydrolysis. With the aid of bacteria, acidogenesis transforms those produced tiny organic molecules into volatile organic acids. Bacteria belonging to the acetic group break down volatile organic acids and produce acetic acid as a byproduct of the acetogenesis process. The final step in the methanogenesis process is the conversion of acetic acid to methane gas and other gases including carbon dioxide and hydrogen sulfide by anaerobic bacteria in the group of bacteria that produce methanogens. [19]

Table2.2: Comparative analysis of technologies to remove Hydrogen Sulphide [9]

Method	Efficiency	Cap Cost	O&M
Biological Fixation	Moderate	Moderate	Low
Iron chloride dosing	Moderate	Low	Moderate
Water scrubbing	High	High	Moderate
Activated Carbon	High	High	Moderate
Iron Hydroxide or Oxide	High	Moderate	Moderate
Sodium Hydroxide	High	Moderate	High

2.2.1 Pressure Swing Adsorption System

Large bio-cng systems are the most common use of this technology in India. By using this method, carbon dioxide is extracted from the biogas through surface adsorption at high pressure. The technique gets its name from the progressive decrease in pressure that regenerates the adsorbing material, which is often activated carbon or zeolites, before the column is reloaded. Water and hydrogen sulfide must be eliminated prior to the PSA-column. Methane is significantly lost (20–30%) during this process. [1]

2.2.2: Chemical scrubbing - Monoethylammine (MEA) system

One of the greatest systems for biogas purification, it achieves 99.9% purity with very little methane loss. In Germany, the systems are widely utilized for biogas purification. In addition to being absorbed by the liquid, carbon dioxide also engages in a chemical reaction with the amine. As a result of the great selectivity of the chemical reaction, the methane loss may be as low as <0.1%.

In addition to the aforementioned, new technologies like cryogenic upgrading are also being developed. [10]

Table 2.2.2: Comparative analysis of technologies to remove Carbon Dioxide[23]

Parameter	PSA	Water Scrubber	(MEA) system
Pre- H_2S removal required	Yes	No	Yes
Working pressure (bar)	4-7	4-7	No pressure
Methane loss	20-30%	5-10%	<0.1%
Methane content in upgraded gas	>96%	>97%	>99%
Electricity consumption (kWh/m³)	0.25	<0.25	<0.15

2.2.2 Water scrubbing

Methane is less soluble in water than carbon dioxide. Because of this, carbon dioxide will dissolve more readily than methane, especially at lower temperatures. Methane content in the gas phase rises when carbon dioxide dissolves in the water within the scrubber column. Consequently, there is more methane in the gas that exits the scrubber. Technologies exist that can produce methane with a purity of 97% and less than 5% methane loss. [23]

Water, ammonia, and carbon dioxide can all pass through the materials used to make dry membranes for biogas upgrading. While nitrogen and methane only very slightly penetrate through the membrane, hydrogen sulfide and oxygen do so to some level. Membranes typically take the shape of coiled hollow fibers. [9]

2.3 Removal of water and trace impurities

Water can be extracted from biogas by compression, cooling, and physical adsorption on silica and activated carbon. As the temperature drops, water condenses and is easily removed. Particulate contaminants can be eliminated by mechanical filters. By physical adsorption on activated carbon, carbon molecular sieve, or membrane, nitrogen and oxygen traces can be eliminated. Ammonia can be eliminated either by gas drying or by enhancing the bio-cng process. Siloxanes can be eliminated by chilling the gas or by physical adsorption on silica gel, activated carbon, or active aluminum. They can also be absorbed in liquid hydrocarbon mixtures.

CO2 is being extracted from biogas using a range of techniques, such as membrane separation, cryogenic separation, adsorption on a solid surface, and physical or chemical absorption. The diffusion of gas phase components into liquid as they move across the interfacial area is known as absorption. Because the solubility of the solute (gas impurities) in the solvent is a crucial component of the absorption separation principle, the procedure can only be successful if the gaseous impurities are more soluble in the absorber (scrubber) than in methane.

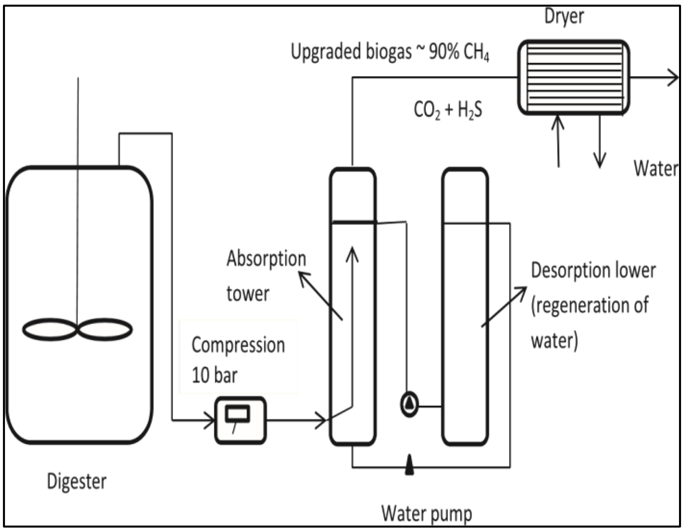
The most important step in the absorption process is choosing an appropriate solvent. A solvent must have the following qualities in addition to being suitable for gas solubility: availability, cost stability, volatility, and non-hazardousness.

By adopting this method, an upgrading plant removes contaminants from the biogas stream by keeping raw biogas in touch with scrubbing liquid in a column where the impurities settle at the base with the scrubbing liquid. Maintaining absorption performance requires the regeneration of the scrubbing liquid, which can be done by either replacing it with new or regenerating it. The absorption method has the disadvantage of little corrosion of the column, despite being easy to use, affordable, requiring less infrastructure, and effective even at low flow rates that biogas facilities often operate at. CO2 is being extracted from biogas using a range of techniques, such as membrane separation, cryogenic separation, adsorption on a solid surface, and physical or chemical absorption [10].

Table 2.3 Components with their effects[21]

Component	ontent	Effect
Carbon dioxide	25-30%	Lowers the calorific value Increases anti-knock properties of engines Causes corrosion in wet condition
Hydrogen sulfide	0–0.5% by volume	Causes corrosion in equipment and piping system Leads to the emission of sulfur dioxide Spoils catalyst
Ammonia	0–5% by volume	Causes NO_x emissions Increases anti-knock properties of engines
Water vapor	1–5% by volume	Causes corrosion in equipment and piping system Due to condensation, it damages instrument and plant. Poses risk of freezing of piping system and nozzles
Dust	>5 µm	Blocks nozzles
Nitrogen	0.5% by volume	Lowers the calorific value Increases anti-knock properties of engines

Fig.2.3: Schematic Diagram of Impurities removal system [21]



3. BIO-CNG VEHICLES

Vehicle and refueling station technologies make up bio-CNG technology. Because every part of the bio-CNG vehicles and the refueling station must be kept at a high pressure, the bioCNG refueling station is far more sophisticated than the traditional diesel/petrol refueling station.

However, compared to quick filling refueling stations, which typically supply fuel overnight, slow filling refueling stations are more straightforward.
By adding certain components, vehicles powered by petrol (spark ignition) or diesel (compression ignition) engines can be transformed into bio-CNG-powered vehicles. It provides the benefit of allowing one to choose between utilizing conventional gasoline or bio-CNG.

The process paths for producing bio-CNG and filling vehicles at refueling stations are shown in Figure 3.1 In this instance, converting a conventional gasoline car to a bio-CNG vehicle requires new fuel lines, a new secondary injector, and a new fuel tank with a regulator. The secondary injector and tank pressure are both lowered by the regulator from 3,600 psi to 125 psi [16].

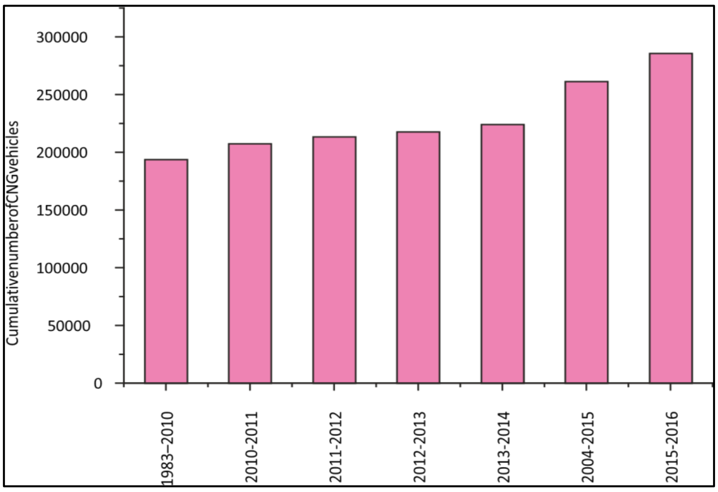


Fig.3.1: Comparative Analysis of bioCNG Vehicles [4]

4.COMPARATIVE ANAYISIS AS TRANSPORTATION FUEL

The economic, technological, environmental, and safety aspects of the conversion of biogas into bio-CNG as a fuel for transportation are the main determinants of the viability of this process. The fuel qualities of bioCNG are competitive when compared to other automotive fuels like diesel and gasoline, and they are almost identical to those of ordinary CNG.

BioCNG has a greater methane content (>97%) than natural gas (93%) that is extracted from several Bangladeshi gas fields. In addition, Table 4.1 shows that the calorific value of bioCNG is around 52 MJ/kg, greater than the calorific values of gasoline (48 MJ/kg) and diesel (44.8 MJ/kg). The cost of energy, expressed in kJ/BDT, is 2.25 times that of diesel and nearly 3.5 times that of gasoline.

Additionally, the price of gasoline and diesel fuel in Bangladesh is very expensive, costing roughly BDT 96 and BDT 68 per liter, respectively. Alternatively, the cost of bio-CNG and CNG is about BDT 14.22 and BDT 30 per m3, respectively. Given that bio-CNG has an equivalent ratio to other transportation fuels, using one liter of bio-CNG instead of one liter each of gasoline and diesel can result in savings of approximately BDT 84.62 and BDT 54.20, respectively. [4]
Furthermore, the level of pollutants in bio-CNG is small compared to diesel and gasoline fuel, with less than 4% CO2 and 8 ppm H2S among no other impurities.

In addition, bio-CNG has minuscule levels of pollutants compared to diesel and gasoline fuel, such as less than 4% CO2 and 8 ppm H2S, and it has no additional impurities. This results in a 90% reduction in emissions when compared to traditional transportation fuel. The nations that produce the most biomethane globally are Sweden, Germany, and the Netherlands. Bangladesh can learn from Sweden, which uses 97% bio-CNG for vehicle fuel while Germany only uses 1.4% of the entire bio-CNG fuel effectively.

Consequently, it is evident that bio-CNG is a potential future fuel for cars. While bio-CNG offers a number of benefits over traditional vehicle fuel, it also has a number of drawbacks. The availability of decentralized feed materials can lead to very expensive production costs for bioCNG these days.
Furthermore, the government's and other investors' support is hampered by the lack of knowledge on the advantages of bio-CNG over other fuels.

Table 4.1: Competitive analysis of bio-CNG among other fuels [8]

Fuel	Calorific value (MJ/Kg)	Tariff/rate/cost (BDT/Kg)	Cost of energy (KJ/BDT)
CNG	52	42.10	1232.81
Bio-CNG	53	40.91	1271.08
LPG	46	56	821.43
Petrol	48	133.44	359.71
Diesel	44.8	79.97	560.21

It is abundantly clear that using bio-CNG as vehicle fuel has major advantages in terms of economy, emissions, and engine performance.
Nonetheless, the effective application of this technology in India's development
The main obstacles to the widespread use of bio-CNG as vehicle fuel are thought to be the need for an adequate supply of feed materials, the expense and necessity of upgrading equipment, a shortage of technically qualified labor, and refueling infrastructure. A biogas unit, purification unit, compression unit, and storage unit are often needed for a bioCNG plant, along with additional accessories that must be kept under high pressure. The primary obstacle to the economical manufacturing of renewable bio-CNG is the absence of technology standards[3]

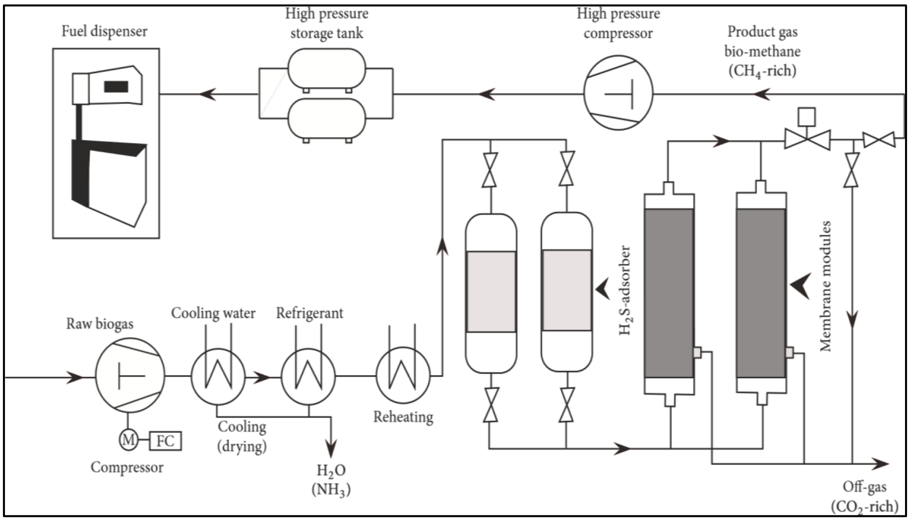


Fig4.1: Schematic diagram of total bio-CNG process and vehicle fueling method [5]

5. CONCLUSION

The Bio CNG operation's results can be used to identify the output points and problems that occasionally arise. Additional study can be done on these issues to boost the production of biogas.

In order to increase the productivity of the Renewable BioCNG plant, follow the following recommendations:

- It has been observed that the press mud is untreated in present scenario, 72% more methane yield can be obtained, if pretreated.
- Bio-methanation can be improved by liquid hot water pre-treatment
- The co-digestion of press mud with vinasse will also enhance the methane yield up to 64%
- A novel high rate bio-methanation digester can be designed and operated
- The dry absorbent based biogas purification system can be developed to improve the efficiency of purification

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