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Evaluation of chemical aspect of biogas upgradation (CBG production) techniques & their environmental impact

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Abstract
Biogas is a renewable source of energy derived from anaerobic digestion of biomass which mainly comprises of dairy waste widely available in form of cattle dung in the Indian villages. Its main constituent comprises of methane, carbon dioxide, hydrogen sulphide with trace of nitrogen, water vapour, hydrogen, oxygen, organic silicon compounds and ammonia, however, their composition varies with the source. In modern world compressed biogas is the fuel of choice and necessity, not only in India but for the world. Biogas upgrading is a gas separation task, finally yielding a methane-rich product. In order to obtain methane rich gas, the biogas must pass through two processes, a cleaning process & an upgrading process. In the later calorific value and other parameters are adjusted to meet the specifications of it as fuel by the removal of carbon dioxide, sulphur & moisture etc. This upgraded gas can be compressed to CBG, which is a good alternative to CNG and can be used as vehicle fuel and for running power plants and also it has other important uses in different industries. The upgrading systems used could be organic physical scrubbing, water scrubbing, amine scrubbing, pressure swing adsorption, membrane separation, water scrubber, cryogenic separation and liquefaction. The suitability of technology is decided by various aspects including cost, size and quantity of biogas generation, quality of biogas and process economics. The clean and upgraded biogas can be introduced in to the natural gas grid since it is comprised of mostly CH_4. The purified biogas can be bottled in CNG cylinders to obtain CBG and it can be used as an alternative to CNG.
The paper intends to summarize the technologies available for biogas upgradation that can be carried out for production of effective compressed biogas. The cost of storing and transporting biomethane along with the assessment of environmental impact of these methods is also reported.

Keywords: *Upgradation, Scrubbing, biomethane, CBG & CNG*

Introduction

In present era there is an utmost need to look in to the alternate sources of energy rather than solely depending on fossil fuels for energy requirements. Compressed biogas (CBG) is considered to be a potential alternative to CNG in the near future because of its compositional similarity [1]. Depending on the raw biogas composition, the separation task (purification) comprises the separation of carbon dioxide (and thus increasing the heating value and Wobbe-Index*), the drying of the gas, the removal of trace substances like oxygen, nitrogen, hydrogen sulphide, ammonia or siloxanes. After conditioning the biogas can be used for onsite power generation, to heat homes or can be added to the national natural gas grid. In recent years several research groups have shown the possibility of upgrading the biogas for biomethane production [2].

Anaerobic Digestion (AD) is a biological process that takes place naturally when bacteria break down organic matter in environment with or without oxygen. Controlled anaerobic digestion of organic waste in enclosed landfill will generate methane. Almost any organic material can be processed with aerobic digestion producing biogas which is comprised of around 60% methane (CH_4) and 40% carbon dioxide (CO_2). The enzymes in the IES (Induced enzyme solution), predominantly enhances the rate of bio methane production, suggesting that the enzymes increases the degradation rate of lingo cellulosic biogas substrate. It has been proved by researches that it is possible to influence the biogas production rate from lingo cellulosic substrates by addition of appropriate enzymes directly to an anaerobic digester [3]. Interestingly, Such enzymes could of course be of large value for the in situ treatment of lingo cellulosic substrates to increase biogas production rates and yields provided they can be identified, cloned, and produced at low cost in recombinant systems [4].

Out of various available biogas upgradation techniques, it is mainly the water scrubbing and PSA that dominated the market, but lately chemical scrubbers, and to minor extent, membrane separation units, have increased their market share. While cryogenic separation could achieve the best possible purification of biogas. Scholz *et al*. (2013) have highlighted the benefits of hybrid technologies (membrane-pressurized water scrubbing, membrane-cryogenic) in terms of techno-economics [5, 6]. Song *et al*. (2017) also showed that hybrid technology involving temperature-membrane-cryogenic process involved less energy consumption than conventional technologies.

It should also be remembered that there are safety and environmental concerns which are associated with biogas as its main content, methane is a greenhouse gas, and it forms explosive mixture when mixed with air. Therefore there is a need to reduce the amount of methane emissions into the atmosphere. To attain methane rich gas, the biomass undergoes two major processes, a cleaning process in which trace components harmful to the natural gas grid, appliances or end users are removed and an upgrading process, in which the calorific value and other parameters are adjusted in order to meet the specifications of vehicle fuel. Finally after upgradation, the gas goes to the filling unit via high pressure compressor [7]. The aim of the present paper is to thoroughly evaluate the existing and emerging technologies, with respect to basis of operations, energy requirement, methane purity and recovery and cost economics.

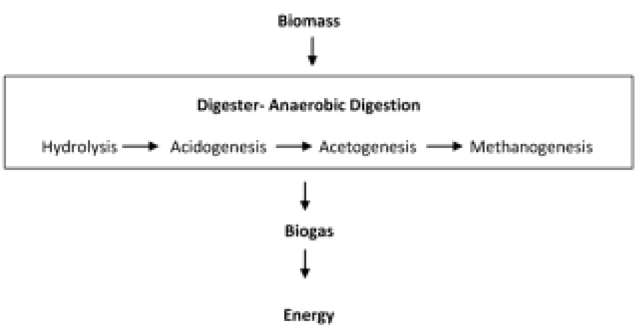
Background

Biogas Production

The use of anaerobic digestion for treating anaerobic waste is attractive for many reasons that involve economic as well as environmental aspects [8, 9]. AD is the collection of process by which microorganisms break down biodegradable material in the absence of oxygen[10]. The four stages of biogas production are hydrolysis, acidogenisis, acetogenesis and methanogenesis [11].

Fundamental Steps of Aerobic digester are mentioned below

Source: Biomass to biogas-Anaerobic digestion by Michael Biarnes



Hydrolysis

It is the essential first step of a chemical reaction in which the breakdown of water occurs to form H^+ and OH^- Through hydrolysis the large polymer namely proteins, fats and carbohydrates are broken down into smaller molecules such as amino acids, fatty acids and simple sugars.

Acidogenesis

Here, acidogenic bacteria further breaks down the biomass products after hydrolysis. These fermentative bacteria produce an acidic environment in the digestive tank while creating Ammonia, hydrogen, carbon dioxide, hydrogen sulphide, shorter volatile fatty acids, carbonic acids, alcohols, as well as trace amounts of other by products.

Acetogenesis

Acetogenesis is the creation of acetate, a derivative of acetic acid, from carbon and energy sources by acetogens. These microorganisms catabolize many of the products created in acidogenesis into acetic acid, carbon dioxide and Hydrogen. Acetogens break down the biomass to a point to which methanogens can utilize much of the remaining material to create methane as a bio fuel.

Methanogenesis

Methanogenesis constitutes the final stage of anaerobic digestion in which methanogens create methane from the final products of acetogenesis as well as from some of the intermediate products from hydrolysis and acidogenesis. There are two general pathways involving the use of acetic acid and carbon dioxide, the two main products of the first three steps of AD, to create methane in methanogenesis:

$CO_2 + 4\,H_2 \rightarrow CH_4 + 2H_2O$

$CH_3COOH \rightarrow CH_4 + CO_2$

While CO_2 can be converted into methane and water through the reaction, the main mechanism to create methane in methanogenesis is the path involving acetic acid. This path creates methane and CO_2, the two main products of anaerobic digestion.

The events in biogas power generation is depicted through flowchart

Fig. 1: Flowchart depicting the Biogas power generation

Source: (Biogas flowchart inspirational biogas steam boiler working principle, Herigemblong, 2018)

Main focus of the Chapter

Evaluation of Existing Biogas Purification Technologies

Biogas is a renewable source of energy which is typically a mixture of different gases produced by the anaerobic decomposition of organic matters with calorific values[12] that varies from 20-25 MJ/M^3. It is essential to upgrade raw biogas produced by digestion due to its low percentage of methane (about 60%) and corrosive contaminants such as hydrogen sulphide.

The existing technologies [13, 14], are evaluated to identify the promising options for biogas purification.

1. **Absorption:** This method uses an absorbent (such as water, glycol etc) and is more successful only if the gaseous impurities are more soluble in absorbent than methane.

1.1 Physical Absorption

1.1.1 Pressurised Water Scrubbing: Water scrubbing is used to remove carbon dioxide and hydrogen sulphide from biogas since these gases are more soluble in water than methane at a particular temperature, pressure and mole fraction. Usually the biogas is pressurized and fed to the bottom of a packed column while water is fed on the top and so the absorption process is operated counter-currently. Carbon dioxide has a higher solubility in water than methane and will therefore be dissolved to a higher extent, particularly at lower temperatures and higher pressures. In addition to carbon dioxide, hydrogen sulphide and ammonia can also be reduced in the bio methane stream using water as a scrubbing liquid [15]. The effluent water leaving the column is saturated with carbon dioxide and is transferred to a flash tank where the pressure is abruptly reduced and the major share of the dissolved gas is released. If the water is to be recycled back to the absorption column, it has to be regenerated and is therefore pumped to a desorption column where it meets a counter current flow of stripping air, into which the remaining dissolved carbon dioxide is released.

The drawback of this method is that the air components – oxygen and nitrogen – are dissolved in the water during regeneration, and thus are transported to the upgraded biomethane gas stream. Other disadvantage is that, it requires a lot of water even with regeneration, as well as has limitations on hydrogen sulphide removal, because the carbon dioxide decreases pH of the solution and corrosion of the equipment is caused by hydrogen sulphide [16]. As the produced biomethane stream is also saturated with water, the final upgrading step typically is gas drying. According to de Hullu *et al*. [17] the cost of the water scrubbing method is 0.13 €/Nm3 biogas.

1.1.2 Polyethylene Glycol Scrubbing
This method relies on the same underlying mechanism as water scrubbing, with a physical absorption process that works because both carbon dioxide and hydrogen sulphide are more soluble in this solvent. The trade name for one of the common solvent used for this process is selexol. The big difference between water and solvents used, is that carbon dioxide and hydrogen sulphide are more soluble in selexol which results in a lower solvent demand and reduced pumping. The process is designed in a similar way as a water scrubber with slight differences. Before injecting into the columns, the organic solvent is cooled to keep the absorption column around 20^0C. The temperature will always affect the Henry's constant so it is essential to maintain the temperature throughout. The carbon dioxide is absorbed in the organic solvent and the upgraded biogas is dried before it is delivered to the compressor or gas grid or fuelling station. The advantages of scrubbing is that no special chemical is required (except relatively inexpensive glycol) for removal of both carbon dioxide and hydrogen sulphide.
Fig. 2: Working of a Biogas Scrubber
Source: (K S Group Sustainability[2])

1.2 Chemical Absorption
This process involves the removal of impurities from raw biogas through chemical reaction between absorbent and carbon dioxide molecules. Chemical absorption involves formation of reversible chemical bonds between the solute and the solvent. Regeneration of the solvent, therefore, involves breaking of these bonds and correspondingly, a relatively high energy input is required. Chemical solvents generally employed are either aqueous solutions of amines (i.e. mono-, di- or tri-ethanolamine) or aqueous solution of alkaline salts (i.e. sodium, potassium and calcium hydroxides). Nowadays, the most common amine system used industrially is activated MDEA (a mixture of MDEA and piperazine) [18, 19]. The advantages of chemical absorption are complete hydrogen sulphide removal, high efficiency and reaction rates compared to water scrubbing, and the ability to operate at low pressure. Because of these advantages, the process is commonly used in industrial applications, including natural gas purification. The disadvantages are the additional chemical inputs needed to treat waste chemicals from the process.

1.2.1 Amine Scrubbing
Amine based purification is gaining popularity nowadays though it is still less popular in comparison to water scrubbing and PSA. The chemical reaction is highly selective and the amount of methane absorption in the liquid is very low, resulting in very high methane recovery and very low methane slip. Due to the high affinity of especially carbon dioxide to the solvents used (mainly aqueous solutions of MEA, DEA MDEA and blends of methyl di-ethanolamine), the operating pressure of amine scrubbers can be kept significantly lower compared to pressurised water scrubbing plants of similar capacity. Typically, amine scrubbing plants are operated at the slightly elevated pressure already arising in the raw biogas, and no further compression is needed [20, 21]. The loaded amine solution is heated up to about 160°C where most of the carbon dioxide is released and leaves the regeneration column as a considerably pure off gas stream. It is advisable to remove hydrogen sulphide component prior, to the amine scrubber as it could be absorbed from raw biogas.

2. Adsorption
Adsorption is a surface phenomenon, which involve selective adhesion or binding of
One or more components of a mixture, on the surface of a micro-porous solid, preferably with a large surface area per unit mass. Depending on the force involved, the process could be classified as physisorption and chemisorption. Following are few adsorption techniques

2.1 Pressure Swing Adsorption
PSA is a technology used to separate some gas species from a mixture of gases under pressure, according to the species molecular characteristics and affinity for an adsorbent material. The task of separating the gas using adsorption depends on the type of the absorbing materials used undergoing increasing pressure [22, 23]. The PSA process is based on the fact that under pressure, gases tend to be attracted to solid surfaces, or "adsorbed". The higher the pressure, the more gas is adsorbed; when the pressure is reduced, the gas is released, or desorbed. PSA processes can separate gases in a mixture because different gases tend to be attracted to different solid surfaces more or less strongly. It operates at near-ambient temperatures and so differs from cryogenic distillation techniques of gas separation. Special adsorptive materials (like zeolites and active carbon etc.) are used as a molecular sieve, preferentially adsorbing the target gas species at high pressure. Biogas upgradation through PSA takes place over 4 phases: pressure build-up, adsorption, depressurization and regeneration. The pressure build up is achieved by equilibrating pressure with a vessel that is at depressurization stage. The gas exits as 97% methane from the top of the adsorber vessel. It is obligatory to remove the water and hydrogen sulphide contents in the gas before it reaches the adsorption column as they cause harms to the absorbent material.
Fig. 3: Depicting Pressure swing absorption technique.
Source: (Zhao *et al*. 2010)

3. Membrane Technology: Gas Permeation
The history of membrane separation started some-where in the beginning of the 1990s in the USA for upgrading the landfill gas [24] although the units were built with less selective membranes and a much lower recovery was achieved for methane. Membranes for biogas upgrading are made of materials that are permeable for carbon dioxide, water and ammonia. Typical membranes for biogas upgrading are made of polymeric materials like polysulfone, polyimide or polydimethylsiloxane. Selective membranes with suitable design are essential to meet these requirement, gaseous components are generally separated by selective permeation through polymeric semi-permeable

membranes [25]. Based upon the material used, two types of membranes are used for this purpose, viz. glass polymeric membranes and rubbery-substituted or glassy-substituted polyacetylenes polymeric membranes. The first type separates the gases based upon their molecular size, while the second type separates gases on the basis of their solubility in the polymer. After the compression to the applied operating pressure the raw biogas is cooled down for drying and removal of ammonia.
Modern upgrading plants with more complex design offer the possibility of very high methane recoveries and relatively low energy demand. Even multi-compressor arrangements have been realised and proved to be economically advantageous. The operation pressure and compressor speed are both controlled to provide the desired quality and quantity of the produced biomethane stream.

Fig. 4: Depicting membrane gas separation technique
Source: (Harasek, Michael 2006)

4. Cryogenic Separation

The fact that cryogenic separation uses no chemicals makes this separation an environmental friendly technique, the only waste stream consists of high % of carbon dioxide with traces of hydrogen sulphide and methane. Cryogenic separation is based upon the ability to condense and distil different gases at various temperatures [26] this separation process operates at low temperature and at high pressures. These operating requirements are maintained by using a linear series of compressors and heat changers in the process. Raw biogas is cleaned with respect to hydrogen sulphide, sulphur dioxide, halogens and siloxanes in order to avoid freezing [27]. This is performed by compressing the raw biogas to 17–26 bars, followed by cooling it to around -260 °C. Biogas is gradually cooled down to temperature where carbon dioxide in the gas can be liquefied and separated through heat exchangers and methane can be collected in liquid form (-1610 ^{0}C). The advantages associated with it is the ability of it to recover pure component in liquid form (99% methane), occupying less space, making it convenient to be transported[28]. This can also be a source for producing solid carbon dioxide.
The limitations of cryogenic separation being that, it involves the need of high pressure and low temperature with adequate insulation of the system. Its capital cost and utility requirement is also high while thermal efficiency is low.
Fig. 5: Depicting Cryogenic separation technique
Source: (I. Ullah Khan *et al*. 2017)

5. Combined Method of Absorption and Adsorption for Biogas upgradation

A laboratory scale method which combines absorption and adsorption chemical process to remove contaminants from anaerobically produced biogas using cafeteria (food), vegetable, fruit, and cattle manure wastes is developed by Rashed *et al*, they have shown the possibility to upgrade methane above 95% in biogas using chemical or physical absorption or adsorption process. The removal efficiency of carbon dioxide, hydrogen sulphide and water depends on the mass of removing agent and system pH. The results showed that Ca $(OH)_2$ solutions are capable of reducing carbon dioxide below 6%. The hydrogen sulphide concentration was reduced to 89%, 90%, 86%, 85%, and 96% for treating with 10 g of $FeCl_2$, FeO (with pH), Fe_2O_3, FeO and activated carbon, respectively. The H_2O concentration was reduced to 0.2%, 0.7%, 0.2%, 0.2%, and 0.3% for treating raw biogas with 10 g of silica gel and Na_2SO_4 for 5 different runs. Thus, given the successful contaminant elimination, the combined absorption and adsorption process is a feasible system for biogas purification [29].

Environmental impact of Impurities

Environmental impacts of different impurities and their concentration in biogas [30] has been presented in Table 1.
Source: (Valerio Paoline *et al*. J Env. Sci. & Health, 2018)

Table 1: Environmental impacts of different impurities and their concentration

Component in Biogas	Amount	Effect (s)
Carbon dioxide	25–30%	• Lowers the calorific value • Increases anti-knock properties of engines • Causes corrosion in wet condition
Hydrogen sulphide	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 NOx emissions • Increases anti-knock properties of engines
Water vapour	1-5% by volume	• Causes corrosion in equipment and piping • Due to condensation, it damage instrument and plant. • Poses risk of freezing of piping system
Dust	>5 µm	• Blocks nozzles
Nitrogen	0.5% by volume	• Lowers the calorific value • Increases anti-knock properties of engines
Siloxane	0–50 mg/m	• Damages engines

Applications of Upgraded Biogas

The Upgraded biogas with more than 95% methane is used in various industries[31] for wide range of industrial purposes. Few of them are as listed below in Table 2.
Source (https://anaerobic-digestion.com/ by Biogasman)

Table 2: Applications of Upgraded biogas in different Industries

S. No.	Industry	Application
1.	Agriculture	Grain drying, Weed killing, Preservation of fruits, Tobacco curing, Tea drying
2.	Automobile	Heat treatment, Paint baking
3.	Chemicals and Drugs	Heating and Drying
4.	Electrical	Bulbs and Tube lights manufacturing, Filament manufacturing, Battery manufacturing
5.	Food	Baking, Boling, Frying, Milk drying
6.	Glass	Melting, Holding, Feeding, Working, Fire Polishing
7.	Metallurgical	Annealing, Bullet heating, Melting, Descaling, Stress relieving, Mould, Cupola, Ladle heating
8.	Metal Working	steel cutting, Hole Piercing, Welding of non-ferrous metals
9.	Transport	Lights, Medium and Heavy duty vehicles & Transit Buses
10.	Grid Injection	The upgraded biomethane can also be injected into the national or regional level grid network. This can be a high pressure gas transmission grid or a local low pressure gas distribution network.

Comparison of different biogas upgrading technologies

As most of the essential parameters strongly depend on local circumstances therefore, it is difficult to give a universally valid comparison of the above discussed biogas upgrading technologies. Furthermore, the technical possibilities of a certain technology (for example regarding the achievable quality of biomethane) often do not correspond with the most economic operation. It is mainly a question of finding a plant design providing the most economic operation for biomethane production. Among various available cleaning and upgrading systems along with the various compressors available, there are some points which lead to conclude that water scrubbing and pressure swing adsorption are most commonly used method because of their simplicity and effectiveness. Cryogenic upgrading is a good choice because it produces purified biogas in liquid state, and it seems that this technology may break through with in short period of time resolving existing problems while membrane separation technology looks promising. On the basis of gas purity, requirement of pretreatment, methane slip, energy consumption, advantages and limitations of all the discussed process, each have their pros and cons. A comparative account of these techniques has been compiled in Table 3 on the basis of few important above mentioned parameters [32, 35].

Source (J. Energy Res., 2017)

Table 3: Comparative analysis of different Biogas upgrading techniques

Methods	Absorbent/adsorbent	Methane Slip	Advantages	Disadvantages
Water Scrubbing	Water	<2, medium	▪ No pre clean required ▪ Simple in operation	▪ External heat required ▪ Requires huge amount of fresh water
Physical absorption	Organic solvent (polyethylene glycol)	< 4, high	-	-
Chemical Absorption	Amines (MEA,DMEA), Alkali solutions	< 0.5, low	-	-
Pressure swing Adsorption	Molecular sieves	<3, medium	▪ Dry process ▪ No chemical usage	▪ H_2S pre-treatment required ▪ Complex setup
Membrane separation	Membrane of polymer of silicone rubber, cellulose acetate hollow fibers	<5, high	▪ Dry process ▪ No chemical required	▪ Pre-treatment required ▪ High investment
Cryogenic separation	No requirement	<0.1, lowest	▪ High methane purity ▪ No chemical required	▪ High capital and operation cost ▪ High amount of energy required

The comparison of the available upgradation techniques could be made on following basis.

- Methane Slip: Cryogenic separation and Amine scrubbing promises close to zero methane slip.
- Space Requirement: Space optimization study was conducted on discussed techniques and it was seen that L-PSA needs the least space. It provides a suitable space allowance for installation, operation and maintenance of the plant.
- Start-up Time: It is the time required to get the steady state process. In water scrubbing, low temperature needs to be achieved, whereas Amine, organic, and physical scrubbing consist of heating source. Only PSA, L-PSA and Membrane could be considered as on/off process.
- Technology: PSA offers the possibility of carbon dioxide co-removal in an economical way. LPSA is concluded to be a low cost and is simple to operate, by this technique raw gas can easily be cleaned from moisture as well. In almost all other techniques an additional drier is needed but LPSA consists of drying media in the column itself. The vented carbon dioxide can also be recovered by means of purification and liquefaction during the CBG Production. Cryogenic Separation has still got the operational problem as carbon dioxide will sublime under simple cooling condition.
- Consumables: Water scrubbing needs antifouling agents. The process is followed by drying step, which may additionally need the drying agent. Amine scrubbing uses amine solution which is considered to be hazardous and

corrosive. PSA normally uses non-hazardous activated carbon, which can be disposed easily or can be used for other purposes. Cryogenic as well as Membrane technology doesn't require any specific consumables except that in hydrogen sulphide removal step.

- Sustainability: Water scrubbing, Organic physical scrubbing, Amine scrubbing requires heating source. Attributing to the low pressure, L-PSA has got the lowest demand of energy, whereas organic physical scrubbing has got the maximum demand of energy. Considering water and energy as the vital aspects of sustainability, L-PSA can be used as an optimal technology.

Estimated Cost for Storing and Transporting Biomethane

The estimation of total cost of producing biogas and upgrading it to biomethane should also consider the costs of storing and transporting the biomethane, in whatever format required by the end market. Even if a dairy converted all of its on-farm equipment to run on biomethane (an unlikely scenario), and used only part of its digester biogas as a feedstock for producing biomethane, it could prove necessary to store more than one day's production of biomethane. Small scale storage can be expensive. Storage tanks for CNG, which can also be used to store biomethane, have a typical capacity of 1,000 ft^3 and cost \$2,250 to \$5,000 each. Capital costs for storage vary considerably with the length of time for which the gas must be stored. Each day's storage will add to the capital cost. For example, enough storage capacity to store a day's worth of CBM produced from a 45,000-ft^3 /day plant would add \$100,000 to \$225,000 to the cost of the facility or \$0.60 to \$1.40 per 1,000 ft^3 to the cost of the biomethane production. Two days' worth of storage would double those numbers. Transportation of biomethane incurs additional costs. Typically, biomethane produced on-farm would need to be transported to a location where it could be used or further distributed, such as an industrial plant or a CNG fuelling station. Thus, the costs of trucking the biomethane or pumping it through a dedicated pipeline would need to be added to its production price. The only way a dairy biomethane producer could avoid incurring the costs of storage and transportation for off-farm use of the biomethane would be to place the biomethane directly into a distribution line connected to the natural gas pipeline grid. Access to a natural gas pipeline is subject to the same kind of regulation and interconnection issues that face distributed electricity generators. Obtaining contracts to place biomethane in the natural gas grid would take a pioneering effort. In addition, most dairies are not serviced by a natural gas pipeline, which means they have no immediate physical access. However, if obstacles such as these could be overcome, direct placement of biomethane into the natural gas pipeline grid would be the most cost-effective way of getting the gas to market.

As with the storage costs, transportation adds to the capital cost of the plant. Transportation costs will depend on the distance that the gas needs to be moved. Trucking requires more on-site storage than piping because enough biomethane must be accumulated to fill a tanker. Typically, trucking would occur on a cyclical basis; alternatively enough additional trucks could be purchased or made available so that one truck is always available on-site for filling, thus eliminating the need for other on-site storage. However, trucks also have associated capital costs, as well as operating costs such as fuel and maintenance for the truck, and labour costs for the driver.

The biomethane industry, a renewable energy sector, needs tax credits, public subsidies or market rules that will help earn a premium for the product during its start-up phase. In contrast to anaerobic digester systems that generate electricity, which have higher capital costs than operating costs, biogas upgrading plants that produce biomethane typically have higher operating costs than capital costs. Subsidies that cover even a large portion of the capital costs may be insufficient to stimulate industry growth. If biomethane facilities are to become viable, ongoing sources of renewable energy, they will likely need the support of ongoing production tax credits, a long-term fixed price contract, and/or market rules that provide a premium for its output [36, 37].

Future Research Directions

Biomethane has good future prospects, however it faces criticism, on it being a contributor in carbon emissions as compared to solar and wind. Consequentially, for obtaining biogas of higher efficiency and for its better commercialization, it is necessary not only to upgrade raw biogas but also utilize the energy value of off-gas. This review evaluate the upgradation technologies available currently there comparison, and the ones which are promising [38, 40]. It tends to provide platform to develop novel technologies such as hybrid technologies which are presently in a very nascent stage and develop methods/techniques for advancements in biogas enrichment. Therefore an intensive and elaborative research is still in progress to optimise and further develop these technologies as well as to apply advance technologies to the field of biogas upgradation.

Conclusion

This review is aimed at presenting the state-of-art upgradation technologies currently available and those which looks promising. It also highlights the comparative account of the available technologies for understanding and overcoming the challenges associated with each of the technique, therefore could be a rich source for developing technological advancement. This rigorous analysis is also expected to help in picking a suitable upgradation technique depending upon the inputs and the quality of biogas required as an output.

A detailed assessment of upgradation techniques, leads to the opinion that the eventual success of a proposed technology could come from a combination of technologies (hybrid technologies) resulting in low operating costs, less energy consumption and high carbon dioxide and sulphur capture efficiency. However, these are still in premature stage and thus such evaluation report could bridge the knowledge gap between advancement required and the existing technologies.

Key terms & Definitions

1. **Compressed Biogas (CBG): Biogas** typically refers to a mixture of different gases produced by the breakdown of organic matter in the absence of oxygen. Biogas can be compressed, the same way as natural gas is compressed to CNG, and used to power motor vehicles.
2. **Biogas Upgradation:** It is the purification processes whereby contaminants in the raw biogas stream are absorbed or scrubbed, leaving more methane per unit volume of gas.

3. **Anaerobic digestion:** Anaerobic digestion is a series of biological processes in which microorganisms break down biodegradable material in the absence of oxygen. One of the end products is biogas.
4. **Wobbe index:** Also known as Wobbe number is an indicator of the interchangeability of fuel gases such as natural gas, liquefied petroleum gas (LPG), and town gas and is frequently defined in the specifications of gas supply and transport utilities.
5. **Mesophiles:** A mesophile is an organism that grows best in moderate temperature, neither too hot nor too cold, typically between 20 and 45 °C (68 and 113 °F). The optimal temperature is 37 °C. The term is mainly applied to microorganisms. Organisms that prefer extreme environments are known as extremophiles.
6. **Thermophiles:** A thermophile is an organism that thrives at relatively high temperatures, between 41 and 122°C (106 and 252 °F).
7. **Scrubber:** Apparatus used for scrubbing or purifying gases**.**
8. **Absorption:** It is a physical or chemical phenomenon or a process in which atoms, molecules or ions enter some bulk phase – liquid or solid material.
9. **Adsorption:** It is the adhesion of atoms, ions or molecules from a gas, liquid or dissolved solid to a surface. This process creates a film of the adsorbate on the surface of the adsorbent.
10. **Hybrid Technology:** Technology combining the benefits of two or more techniques.
11. **Methane Slip:** Methane can be emitted through methane leakage during fuel production, storage, transportation and bunkering and through methane slip, unburned methane emissions released during various operations.

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