

2. CBG Technology and By-Product

- Types of CBG Production Process
- Gasification
- Anaerobic Digestion
- Schematic of a CBG Plant
- Digestion Systems: Wet and Dry
- Types of Anaerobic Digesters
- Hydrogen Sulfide Removal Technologies
- CO₂ Removal Technologies from Biogas
- Ways to Transport CBG from Production Site
- Digestate: A By-product in CBG Plant
- Factors Affecting CBG Production

Glossary

Biochemical: Processes that involve chemical reactions in living organisms, like digestion or fermentation, often using enzymes or microorganisms.

Thermochemical: Processes that use heat and chemical reactions to break down or convert materials, such as in gasification or pyrolysis.

Syngas: A mixture of gases, mainly hydrogen (H_2) and carbon monoxide (CO), produced by heating materials like biomass or coal, used as fuel or for chemical synthesis.

Hydrolysis: A chemical reaction where water breaks down a compound into smaller parts, often the first step in converting biomass into sugars.

Acidogenesis: The stage in anaerobic digestion where microorganisms convert sugars and amino acids into organic acids and alcohols.

Acetogenesis: A process in anaerobic digestion where organic acids are converted into acetic acid, carbon dioxide, and hydrogen by bacteria.

Methanogenesis: The final stage of anaerobic digestion, where methane-producing microorganisms (methanogens) convert acetic acid, CO_2 , and H_2 into methane (CH_4) and water.

Glossary

Absorption: The process where a substance is taken into and distributed throughout the bulk of another material, like water being absorbed by a sponge.

Adsorption: The process where molecules stick to the surface of a material, such as gases or liquids adhering to activated carbon.

Hydraulic Retention Time: HRT refers to the average time duration for which a liquid/soluble compound stays in the reactor.

Digestate: The material or residue coming out of a biogas plant after anaerobic digestion

Organic Loading Rate: Refers to the feeding rate of feedstock into anaerobic digester, in kilogram of organic matter fed per unit working volume of the anaerobic digester, per day ($\text{kg}/\text{m}^3/\text{day}$)

Mesophilic: Refers to the temperature, process, or microorganisms living at temperature in the range of 20 degrees to 45 degrees Celsius.

Thermophilic: Refers to temperature, processes, or microorganisms living at temperature above 45 degree Celsius.

Types of CBG Production Process

Anaerobic Digestion	Biomass Gasification
Biochemical Process	Thermochemical Process
Products: Biogas and Digestate	Products: Syngas and Ash
Operates at Ambient Temperatures (30°C–60°C)	Operates at High Temperatures (800°C–900°C)
Requires a Biogas Purification Step that involves removal of CO ₂ , H ₂ S and moisture	Requires a Syngas Methanation Step, which converts components like CO and H ₂ to CH ₄
Lower Operational Costs	High Investment and Operation Costs

Gasification

- Gasification is achieved by reacting the material at **high temperatures** (above 700 °C), **without combustion**, with a controlled amount of **oxidizing agent**.
- It converts organic material into a **syngas** (mixture of hydrogen and carbon monoxide) and a solid by-product: **biochar**
- **Syngas** energy density can be up to 30% lower than that of natural gas and cannot be injected as such in the natural gas grid
- Gasification is usually combined with second-stage processing called **methanation to produce methane**
- **Biochar**, a solid material similar to coal is considered as a carbon sink. It is estimated that around **2.0-2.6 tons of CO₂** is trapped **per ton of biochar**



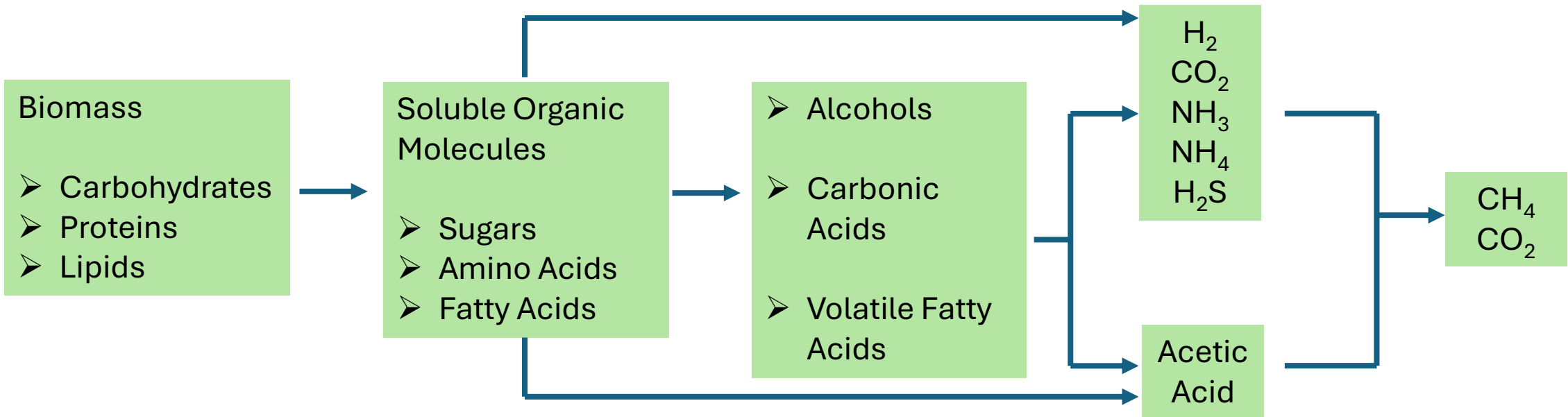
Gasification Reactors

- Gasification happens in the reactor, known as a **Gasifier**
- There are five principal types of gasification reactors:
 - Fixed Bed
 - Fluidized Bed
 - Dual Fluidized Bed
 - Entrained Flow
 - Plasma Reactors

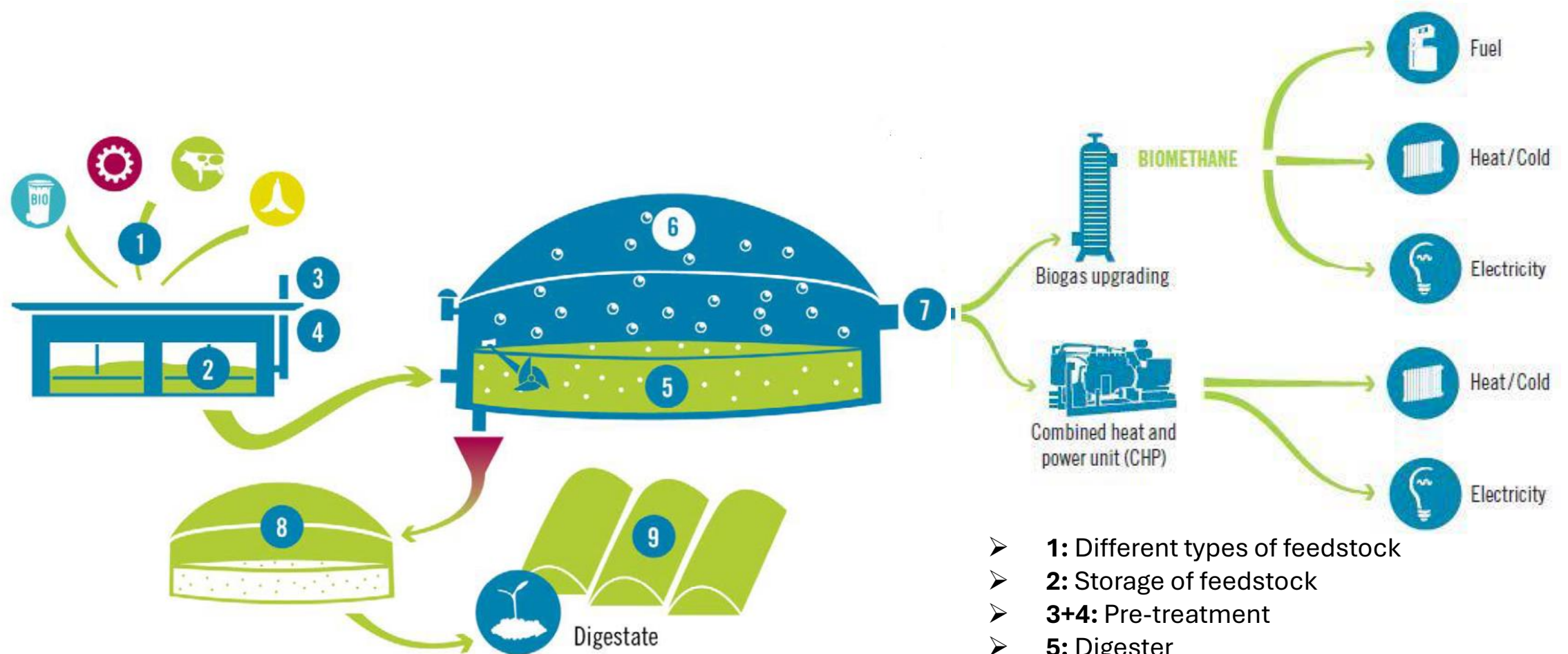
Anaerobic Digestion

- The anaerobic digestion process is a fermentation process, which takes place in a **closed airtight digester** where organic feedstocks are converted into **biogas and digestate** as products
- Biogas is composed of **methane (CH₄)**, which is the primary component of natural gas, at a relatively high percentage (50-65%), **carbon dioxide (CO₂)**, **hydrogen sulfide (H₂S)**, **water vapor**, and trace amounts of other gases
- The produced biogas is a mixture of gases which gets **purified to methane (>95%)** by various upgradation methods
- **Digestate** is the **residual material** left after the digestion process which is composed of liquid and solid portions

Anaerobic Digestion Steps



Schematic of Anaerobic Digestion Plant



- **1:** Different types of feedstock
- **2:** Storage of feedstock
- **3+4:** Pre-treatment
- **5:** Digester
- **6:** Biogas Storage,
- **7:** Biogas Upgrading and Various Applications
- **8+9:** Digestate Storage and Enrichment

Digestion Systems: Wet and Dry

Wet Digestion	Dry Digestion
The feedstocks are typically in slurry form and can be pumped	Designed for biomass with high solid and dry content
The consistency of these digesters contents is usually 3-15% total solids	Generally, processes feedstock with greater than 15% solids content
Higher methane yields compared to dry systems	Lower methane yields compared to wet systems
Sensitive to impurities and contaminants (e.g. plastic, metal, stones)	Insensitive to impurities and contaminants
High water consumption	Low water consumption
Requires robust and costly mixing equipment	Less equipment requirements

Types of Anaerobic Digesters

Sl. No	Type of Anaerobic Digester	Suitability Parameters		
		Total Solids (TS)% in Feedstock	Hydraulic Retention Time (in days)	Climatic Condition
1	Covered Anaerobic Lagoon Digester	0.5 - 5	30 - 60	Temperate and warm climate
2	Plug-flow Digesters	12 - 15	20	All climate
3	Continuously Stirred Tank Reactor	3 - 10	15	All climate
4	Upflow Anaerobic Sludge Blanket	< 3	5	All climate
5	Induced Blanket Reactor	6 - 12	5	All climate
6	Fixed Film Digester	1 - 5	5	All climate
7	Anaerobic Sequencing Batch Reactor	2.5 - 8	5	All climate
8	High Solids Anaerobic Digestion	> 25	20 - 30	All climate

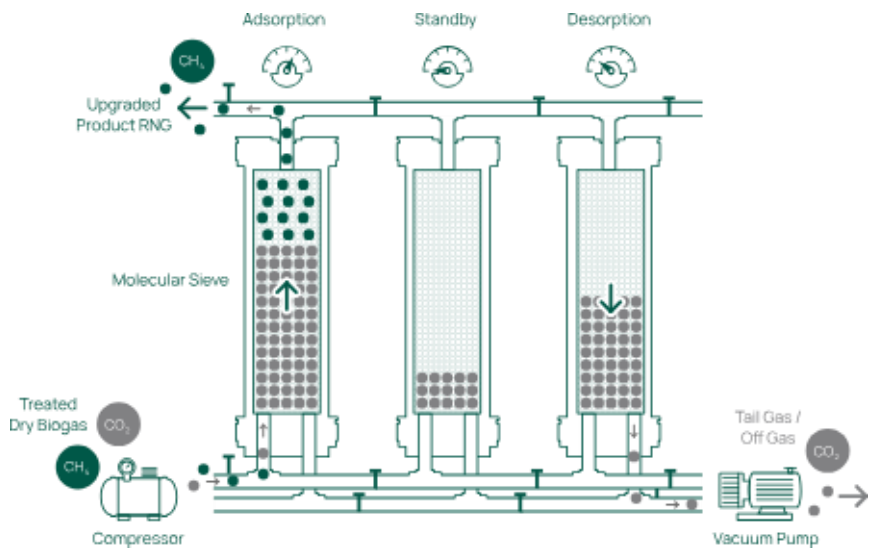
Source: *Fueling the Future: A Report on Bio-CNG (GGGI)*

Hydrogen Sulfide Removal Technologies

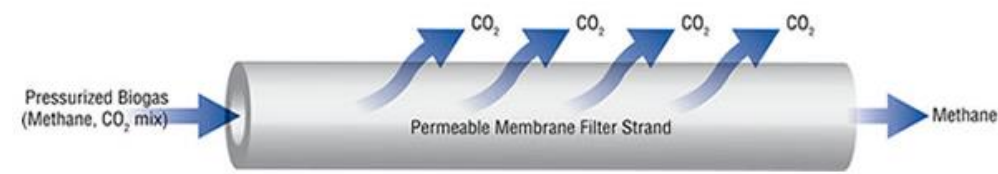
Sl. No	Technology	Parameters			
		Efficiency	Capital Cost	O&M Requirement	Complexity
1	Biological Fixation	Moderate	Moderate	Low	Moderate
2	Iron Chloride Dosing	Moderate	Low	Moderate	Low
3	Water Scrubbing	High	High	Moderate	High
4	Activated Carbon	High	High	Moderate	Moderate
5	Iron Hydroxide or Oxide	High	Moderate	Moderate	Moderate
6	Sodium Hydroxide	High	Moderate	High	Moderate

CO₂ Removal Technologies from Biogas

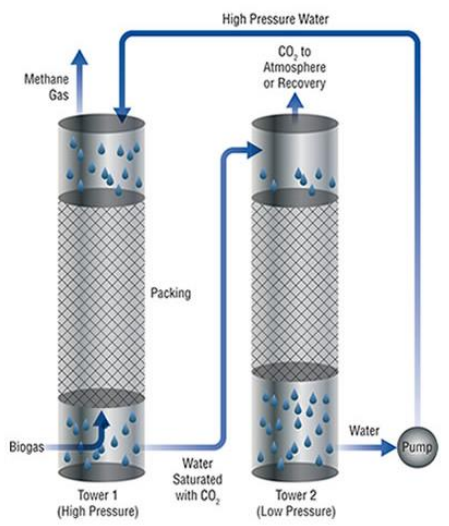
Sl. No	Technology	Performance				
		Pre H ₂ S Removal	Working Pressure (bar)	Methane Loss	Methane Content in Upgraded Biogas	Electricity Consumption (kWh/m ³)
1	Pressure Swing Adsorption	Yes	4 - 7	20 – 30%	>96%	0.25
2	Water Scrubbing	No	4 - 7	5 – 10%	>97%	<0.25
3	Mono-ethyl amine System	Yes	No Pressure	<0.1%	>99%	<0.15



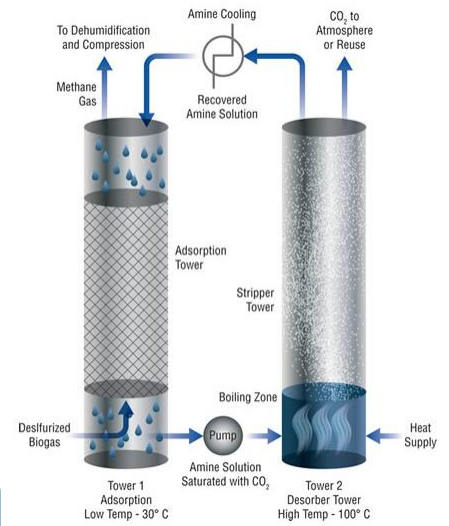
Pressure Swing Adsorption



Membrane Separation

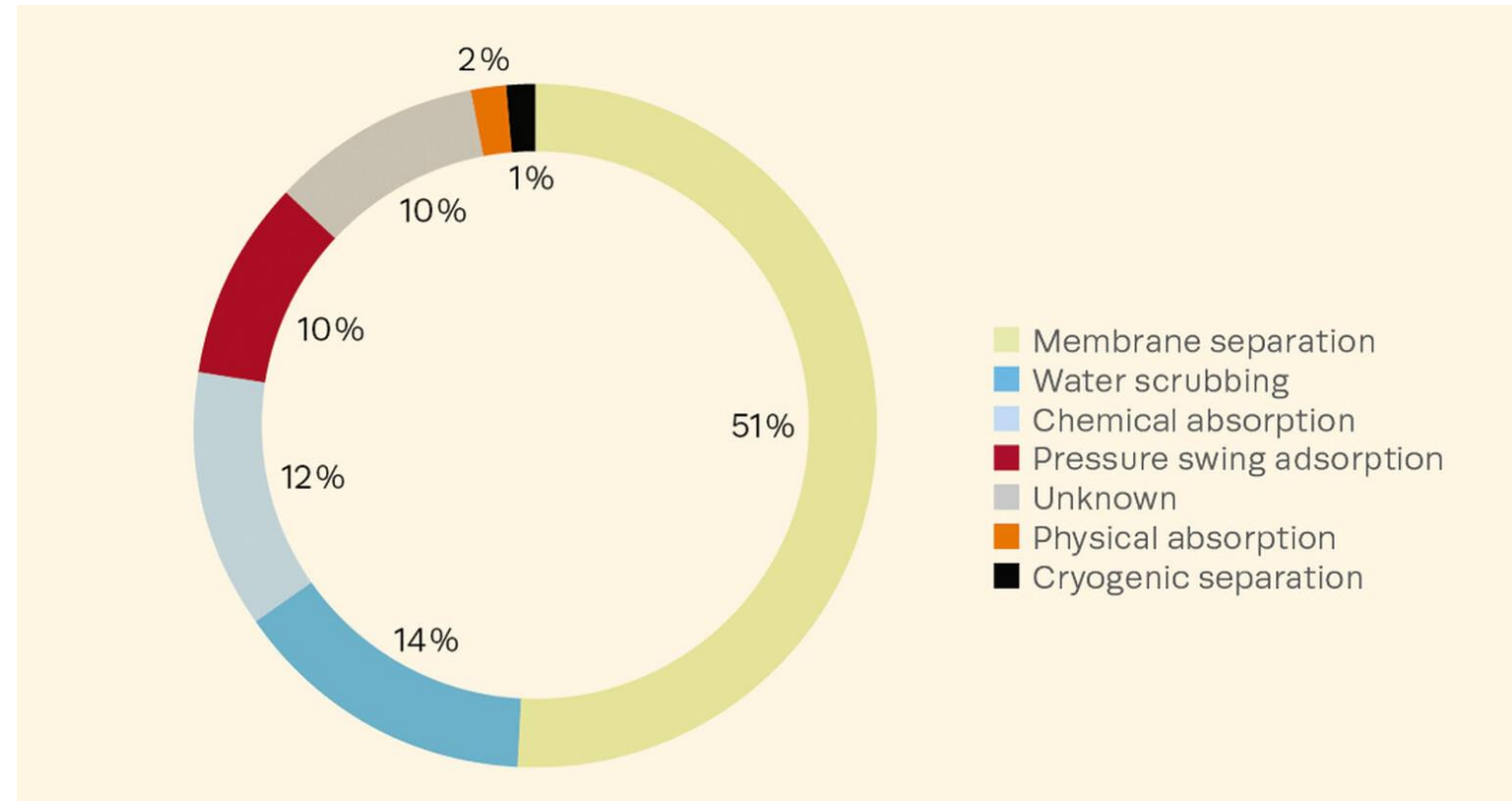


Water Scrubbing



Amine Scrubbing

**Different
Biogas
Upgradation
Methods Used
in Europe
(2022)**



Ways to Transport CBG from Production Site

- **Cascades:** a system of interconnected high-pressure cylinders that store and transport compressed gas
- **Injection Into the Gas Grid:** a network of pipelines that move natural gas from production facilities to consumers for residential, commercial, and industrial use



Digestate: A By-product in CBG Plant

- It is the **leftover or un-digested component** of the input feedstock generated during the biogas production process
- **Rich in organic and inorganic nutrients** making it an excellent soil conditioner
- Digestate is also referred by several other names, including **biofertilizer, organic/natural fertilizer, and fermented organic manure**



Different Forms of Digestate

- Digestate typically comes in three forms:

1. Whole Similar in appearance to livestock slurry, often with less than 5% dry matter (DM)

2. Liquor/Liquid: A liquid component where most of the dry matter has been removed. It has high flowability and can, therefore, easily drip off the plant and enter the soil. Due to the enrichment of NH_4 , this fraction is a fast-acting nitrogen fertilizer that is immediately available to plants

3. Fibre/Solid: A solid biofertiliser is composed of the separated dry matter. It has a dry matter (DM) content of 20-40% and is more cost-efficient in terms of transportability. In this fraction, carbon and phosphate are enriched, which makes it suitable as good phosphorus and humus fertilizer

Applications of Digestate

- Organic fertilizer for crops and farms
- Increase the carbon content in the soil
- Improves soil structure and water retention



Factors Affecting CBG Production



Temperature



Substrate
Composition



pH



Mixing



Loading rate



Hydraulic
Retention Time



Factor 1: Temperature

- **Mesophilic (30–40°C):** Most biogas plants operate in this range as it provides a balance between microbial activity and energy input
- **Thermophilic (50–60°C):** Higher temperatures increase reaction rates but require more energy and are sensitive to environmental fluctuations

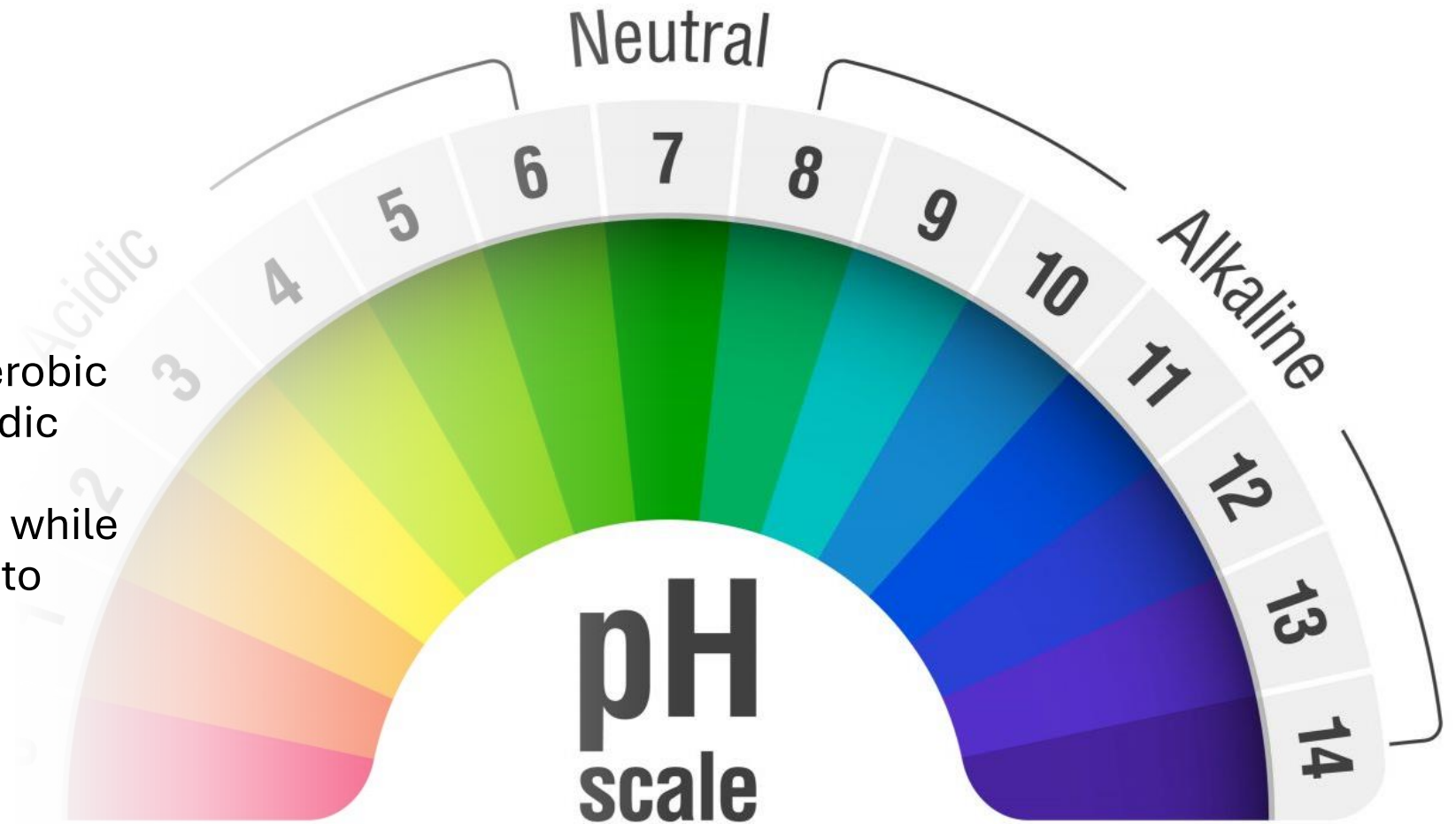


Factor 2: Substrate Composition

- **Organic Content:** The type and concentration of organic matter in the substrate are critical. Substrates rich in carbohydrates, proteins, and lipids generally enhance biogas production
- **C:N Ratio:** The carbon-to-nitrogen ratio should ideally be around 20–30:1. Low nitrogen levels can limit microbial growth, while excessive nitrogen may lead to ammonia toxicity

Factor 3: pH

- The optimal pH for anaerobic digestion is **6.8–7.4**. Acidic conditions inhibit methanogenic archaea, while high alkalinity may lead to ammonia toxicity



Factor 4: Mixing

- Proper mixing ensures uniform distribution of microbes and substrate, prevents scum formation, and avoids sedimentation



Factor 5: Loading Rate

- Overloading the digester can lead to the accumulation of volatile fatty acids, causing system instability. Organic loading rates (OLR) are generally kept between 1–4 kg VS/m³/day



Factor 6: Retention Time

- The hydraulic retention time (HRT) must be sufficient for complete digestion of organic material. It varies with the substrate and system design, typically ranging from 15-40 days

