Turning Organic Waste into Renewable Gas

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1.0 Introduction

Organic waste streams such as agricultural residues, food waste, animal waste, brewery by products, slaughterhouse residues, and industrial effluents present a significant opportunity to produce renewable gas and energy through anaerobic digestion.

As interest grows in practical decarbonisation pathways and circular economy outcomes, biomethane and biogas systems are gaining attention as integrated solutions that can recover value from waste while supporting emissions reduction, environmental compliance, and energy transition objectives.

This paper outlines:

- The biomethane production process;
- Compares major anaerobic digestion technologies;
- Examines pretreatment and digestate post treatment requirements;
- Considers the role of biogas to power generation in delivering commercially viable renewable energy outcomes.

2.0 Biomethane Production Process

A biomethane production plant converts organic waste into grid quality renewable gas through an integrated process that begins with feedstock reception and pretreatment, continues through anaerobic digestion, and ends with gas upgrading, biomethane handling, and digestate management. Organic feedstocks such as agricultural and animal waste, food and brewery waste, slaughterhouse residues, and agro-industrial by products are received and conditioned prior to digestion.

Figure 1: Types of feedstock

2.1 Pretreatment of feedstock

Pretreatment typically includes screening to remove contaminants, size reduction to improve biodegradability, slurry preparation or dilution for wet digestion systems, and hygienisation where animal by products is present. The objective is to deliver a stable, homogeneous, and pumpable feedstock stream with controlled solids content and loading rate, ensuring consistent digester performance.

2.2 Anaerobic digestion

Prepared feedstock is continuously fed into an anaerobic digester operating under mesophilic or thermophilic conditions. Within the oxygen free environment, organic matter is biologically converted through successive microbial stages into biogas and digestate. Mixing and temperature control ensure uniform reaction conditions, maximising methane yield while maintaining process stability.

2.3 Upgrade and injection to gas network

Raw biogas then undergoes conditioning to remove moisture, hydrogen sulphide, siloxanes, and other trace contaminants, before upgrading technologies such as membrane separation, water scrubbing, pressure swing adsorption, or chemical absorption remove carbon dioxide to produce biomethane with methane concentration typically exceeding 96 percent. Upgraded biomethane is compressed, metered, and monitored before distribution for pipeline injection, BioCNG, on site industrial heat, or further liquefaction to BioLNG where applicable, while gas quality monitoring and odourisation are applied to meet regulatory and safety requirements.

2.4 Digestate handling

Digestate is typically processed through solid liquid separation to facilitate downstream handling and compliance. The solid fraction is directed to composting, drying, or pelletising for use as a soil conditioner or fertiliser product, while the liquid fraction is either land applied under an approved nutrient management plan or subjected to further treatment where nutrient, discharge, or environmental limits are exceeded.

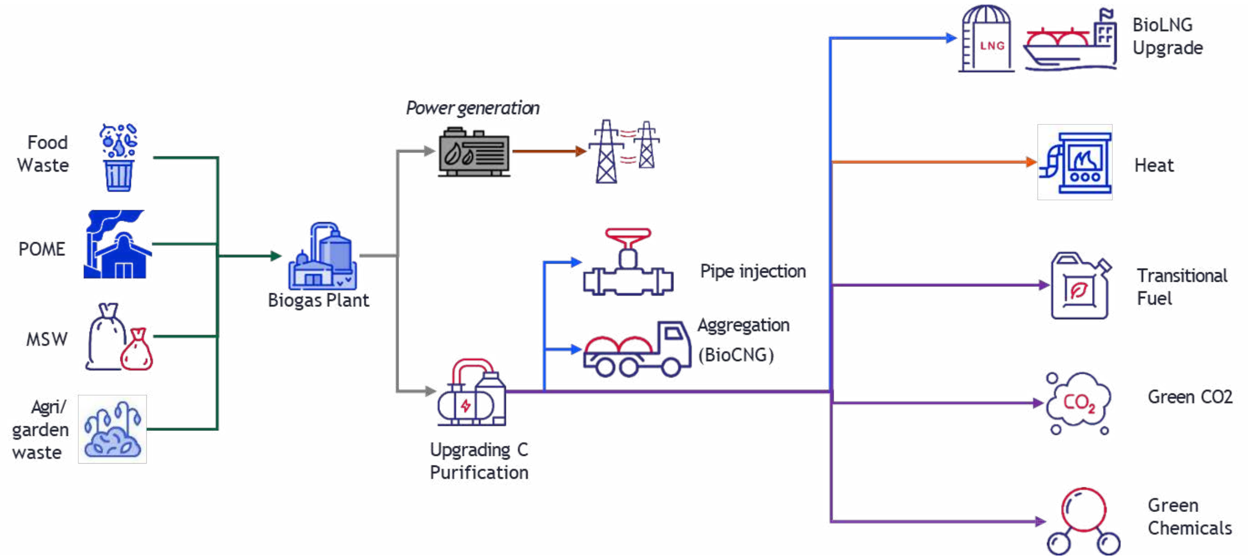

Figure 2: Illustration of application of biogas from organic resources

Alongside direct power generation through engines or turbines, upgraded biogas also enables higher value applications through biomethane production, while the upgrading process can generate green CO_2 for food, industrial, or agricultural applications and support downstream production of green chemicals and fuels. Overall, modern biogas facilities are increasingly designed with a biomethane first, flexible utilisation philosophy, allowing operators to route gas to the highest value market while maintaining system resilience. This integrated approach maximises renewable energy recovery, supports energy transition objectives, and enables scalable decarbonisation across power, gas, transport, and industrial sectors.

3.0 Anaerobic Digestion Technology

3.1 Continuous Stirred Tank Reactor (CSTR)

The Continuous Stirred Tank Reactor is the most established and widely deployed anaerobic digestion technology for biogas and biomethane production. It is particularly suited for wet and semi wet organic substrates that are heterogeneous and variable in nature, including agricultural residues, food waste, manure, brewery by products, and slaughterhouse wastes. The defining characteristic of the CSTR is complete mixing, which ensures uniform temperature, pH, nutrient distribution, and microbial contact throughout the reactor. This homogeneous environment supports stable biological activity and predictable methane generation, and as a result CSTRs are commonly adopted as the reference technology for diversified organic waste portfolios across Southeast Asia, Australia, and New Zealand.

CSTR systems deliver high methane conversion efficiency across a broad range of organic substrates and are considered the industry benchmark for reliability, supported by several decades of commercial operating experience worldwide. They typically operate under mesophilic or thermophilic conditions, with pH of 6.8 to 7.5, total solids typically between 3 and 12 percent, organic loading rates of approximately 2 to 6 kg VS/m^3·day, and retention times of 15 to 30 days. CSTR systems are designed for robust wet digestion, prioritising biological stability over maximum volumetric loading, and key design considerations include mixing systems, heating integration and insulation, management of foam and scum, and feedstock preprocessing such as size reduction, dilution, and grit removal. Overall, CSTR technology is best suited for mixed agricultural, agro-industrial, food processing, brewery, and slaughterhouse waste streams where feedstock variability and co digestion flexibility are important, despite its relatively larger footprint, higher capital cost, and increased energy demand for mixing and heating compared to high-rate anaerobic systems.

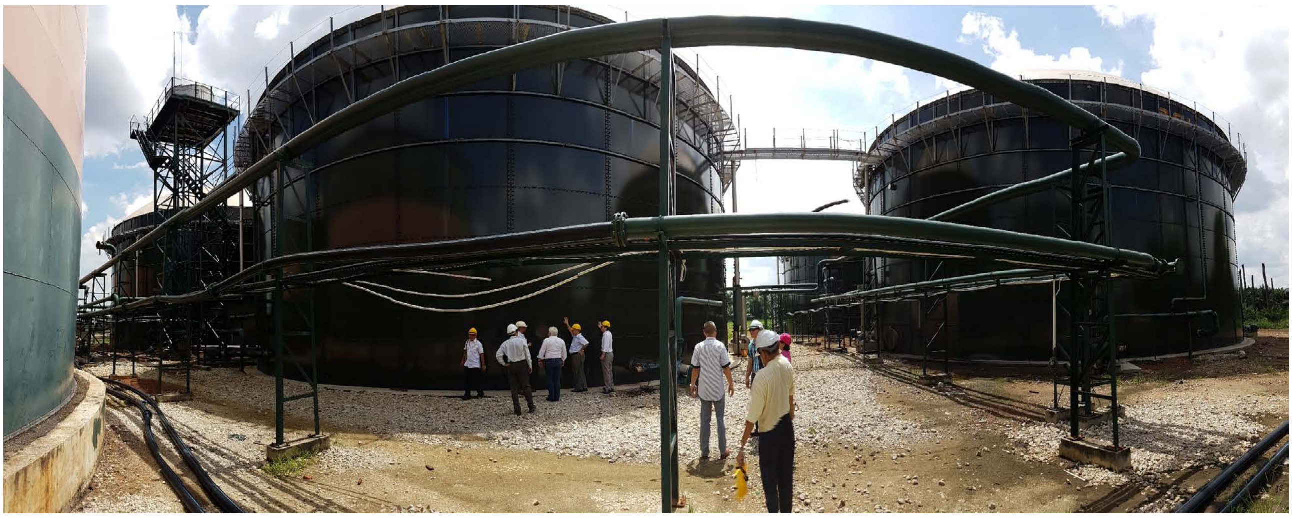

Figure 3: CSTR AD Tanks

3.2 Plug Flow Digester (PFD)

The Plug Flow Digester is an anaerobic digestion technology primarily applied to high solids organic feedstocks with relatively consistent physical and chemical characteristics. It is most commonly used in agricultural and agro-industrial settings where feedstocks such as manure, crop residues, and brewery by products are generated in a steady and predictable manner. Unlike fully mixed systems, material in a plug flow digester moves through the reactor in a near piston flow pattern, resulting in uniform exposure time to anaerobic microorganisms. This configuration enables effective digestion of fibrous substrates while requiring lower mechanical complexity and reduced mixing energy compared to stirred tank systems.

Plug flow digesters achieve moderate to high methane conversion efficiencies for fibrous and semi solid substrates, with volatile solids destruction typically ranging from approximately 55 to 75 percent depending on feedstock preparation and operating conditions. They generally operate under mesophilic or thermophilic conditions, with pH of 6.8 to 7.5, total solids generally between 15 and 30 percent, organic loading rates of approximately 2 to 6 kg VS/m^3·day, and retention times of 15 to 30 days. Plug flow digesters are designed for simplicity and reliability in treating high solids, homogeneous feedstocks, with key design considerations including feedstock size reduction, consistent feeding regimes, moisture management, and uniform heating along the reactor length. Overall, plug flow digestion is best suited for agricultural and agro-industrial wastes such as manure, cereal residues, and brewery spent grains where feedstock characteristics are stable, with strengths in low operational complexity and reduced energy consumption but less flexibility for mixed or variable feedstocks.

Figure 4: View inside digester

3.3 Upflow Anaerobic Sludge Blanket (UASB)

The Upflow Anaerobic Sludge Blanket reactor is a high-rate anaerobic digestion technology developed for the treatment of liquid effluents with high concentrations of soluble organic matter. The core of the system is a dense blanket of anaerobic granular sludge through which wastewater flows upward, providing intensive contact between substrate and microorganisms while allowing very short hydraulic retention times. UASB systems are commonly applied in industrial and agro-industrial wastewater treatment, particularly in warm climates where stable mesophilic operation can be maintained with minimal heating.

UASB reactors typically achieve COD removal efficiencies of 70 to 90 percent for suitable wastewater streams, with high methane recovery due to excellent biomass retention, although performance is strongly dependent on influent quality. They generally operate under mesophilic conditions of 35 to 45°C, with pH of 6.8 to 7.5, total solids preferably below 2 to 5 percent, organic loading rates of approximately 5 to 15 kg VS/m³·day, and retention times typically noted as 20 to 40 days in this paper. UASB systems are designed to maximise volumetric treatment efficiency for liquid wastewater, with critical design considerations including upstream solids removal, hydraulic control to protect the sludge blanket, and post treatment of effluent to meet discharge standards. Overall, UASB technology is best suited for high strength, soluble industrial wastewater such as brewery, food processing, slaughterhouse effluent, and pretreated POME, but is less flexible for mixed feedstocks and sensitive to solids, fats, fibres, or toxic shocks.

Figure 5: Sludge drying bed

3.4 Dry Fermentation Technology

Dry fermentation is an anaerobic digestion technology developed for high solids organic waste where dilution is undesirable or impractical. Feedstocks are treated in stacked or tunnel type reactors with minimal free liquid, relying on percolate recirculation for microbial contact. The technology is characterised by high solids digestion without dilution, batch or semi batch operation, low water consumption, simple reactor construction, and long digestion cycles.

Dry fermentation achieves moderate volatile solids destruction, typically 50 to 65 percent, and while reliability is high for solid waste streams, efficiency and gas productivity per unit volume are lower than wet systems. It generally operates under mesophilic conditions of 35 to 45°C, with pH of 6.8 to 8.0, total solids of 20 to 40 percent, organic loading rates of approximately 5 to 10 kg VS/m³·day, and retention times of 21 to 40 days. Dry fermentation systems are designed to minimise water use and mixing energy, but they require large footprints and careful moisture management. Overall, dry fermentation is well suited for solid rich organic waste streams such as agricultural residues and source separated organics, with advantages in low water use and physical robustness, but with limitations including long retention times, large footprint, and reduced flexibility.

Figure 6: Almond shell processing

3.5 Anaerobic Digestion Technology Summary

Below is the summary of anaerobic digestion technology for reference, including technology not elaborated in this paper.

Technology	Footprint	Efficiency (%)	Operation Complexity	Suitable Feedstock	Robustness	Example Technology Providers
CSTR	Large	75–95	High	Mixed	High	Cenergi, Veolia, Weltec, EnviTec, Global Methane Systems, YL Tanks, Lipp Engineering, Hochreiter
Plug Flow Digester	Large	55–75	Low	Fibrous	Medium	AGRA Industries, RCM Digesters, Bio4Gas
UASB	Large	70–90	Medium	Liquid	Medium	Paques, Veolia, IHI, Biothane, Cenergi, GLT, Hochreiter
EGSB	Small	80–95	High	Dilute	Low	Paques, Biothane, Veolia, Nijhuis
AnSBR	Medium	70–90	High	Variable	High	Veolia, Evoqua, Aquatech,

Fixed Film Digester	Medium	70–90	Medium	Soluble	Medium	Veolia, Evoqua, BioprocessH2O
Dry Fermentation	Medium - Large	65–85	Medium	Solid	High	BEKON, Eggersmann, Strabag PFS, Hitachi Zosen Inova, Hochreiter

3.5.1 Anaerobic Digestion Technologies fit per feedstock source

Technology	Food	Agri Residues	Brewery	Manure	Slaughterhouse	Wastewater
CSTR	5	5	5	5	5	3
Plug Flow	3	5	4	5	3	1
UASB	1	1	4	1	4	5
EGSB	1	1	4	1	3	5
Fixed Film	3	2	4	2	4	4
Dry Fermentation	5	5	3	1	3	1

Scoring scale: **5** = Excellent fit, **4** = Good fit, **3** = Design dependent, **2** = Poor fit, **1** = Not suitable

3.5.2 Ranking of different Anaerobic Digestion Technologies

Technology	Ranking	Advantages
CSTR	1	Dominates when: • Feedstocks are **diverse** • Solids and liquids coexist • Codigestion flexibility is required Lowest biological and commercial risk
Dry Fermentation	2	Excels for: • Agricultural residues • Source separated organics Penalised by limited manure and wastewater compatibility
Plug Flow	3	Strong performer for: • Consistent manure and fibrous residues Limited adaptability for mixed or evolving feedstock portfolios

UASB	4	Strong only if: • Project is **waste water dominant** • Solids are minimal and well pretreated Not suitable for mixed organic portfolios
EGSB	5	Remain viable **only if the project becomes waste water dominant** Structurally unsuitable for solids heavy or mixed feedstock strategies

Case Study

An analysis of the Best Anaerobic Digestion Technologies for Agriculture Wastewater & Biomass Waste in Malaysia

The Upflow Anaerobic Sludge Blanket (UASB) is the most appropriate and defensible anaerobic digestion technology for high water and low solid content agricultural and animal waste applications in Malaysia. Its strong track record, robustness in feedstock changes, low capital and operation cost compared to other technologies and regulatory acceptance make it the preferred baseline technology.

UASB systems can reliably treat a broad range of feedstocks typical to the region, including molasses, sewage effluent, slaughterhouse wastewater, and agriculture wastewater such as POME, cassava effluent or other complex pressed wastewater fluids. This versatility is critical given the consistent high volume of organic wastewater of various organic waste streams in Malaysia.

The temperate climate supports stable mesophilic operation with moderate energy input, while continuous feeding aligns well with farm operations. UASB technology offers high tolerance to feedstock input changes, making it easy to operate and well understood by Malaysian operators, regulators, financiers, and insurers, reducing approval and investment risk.

Typical applications include on palm oil mill effluent, farm dairy digesters, poultry manure co digestion, and regional hub facilities aggregating agricultural waste. Overall, UASB provides the optimal balance of ease of operation, lean engineering economics, reliability, and regulatory confidence for agricultural biogas projects in Malaysia.

4.0 Pretreatment of Feedstock for Anaerobic Digestion

Pretreatment is applied prior to anaerobic digestion to enhance hydrolysis, stabilise digester operation, protect mechanical equipment, and increase biogas yield. The selection of pretreatment methods depends on feedstock characteristics and project objectives, enabling reliable processing of diverse organic wastes including agricultural residues, food and brewery wastes, slaughterhouse residues, municipal organics, and industrial wastewater.

4.1 Pretreatment Approaches

Physical pretreatment forms the foundation of most anaerobic digestion projects and is applied to improve handling, uniformity, and digestion kinetics. Size reduction through shredding or milling is essential for fibrous materials such as crop residues and garden waste, while screening and separation remove plastics, stones, metals, and grit, protecting pumps and mixers and preventing grit accumulation. Slurry preparation and dilution using water, wastewater, or recycled digestate produce a homogeneous, pumpable feed, stabilising organic loading and improving heat transfer. Mechanical pretreatment further disrupts feedstock structure beyond basic size reduction and pulping or wet maceration is commonly used for food and supermarket waste, often combined with de packaging, to produce a uniform slurry and reduce clogging risk.

Thermal pretreatment is applied selectively where hydrolysis or sanitisation is limiting, while hygienisation or pasteurisation is commonly required for animal by products to meet regulatory and biosecurity requirements. Chemical pretreatment, such as alkaline treatment of lignocellulosic biomass, improves cellulose accessibility but is used selectively due to chemical costs and pH control requirements, while biological pretreatment including aerobic conditioning or ensiling is mainly used for fibrous agricultural residues to improve digestibility. In practice, pretreatment is tailored to feedstock type, with agricultural residues typically undergoing chopping, milling, and co digestion with manure, brewery wastes requiring dewatering and maceration, slaughterhouse residues involving fat separation, sludge thickening, hygienisation, and controlled blending, food waste being de packaged, pulped, and screened, and industrial wastewater such as POME undergoing cooling, grit removal, equalisation, and oil control. Commercial anaerobic digestion facilities therefore rely primarily on robust physical and mechanical pretreatment, with thermal, chemical, or biological methods applied only where justified by feedstock complexity or regulatory requirements.

Figure 7: Pre Treatment Shredder

5.0 Post Treatment of Digestate

5.1 Digestate Post Treatment

Anaerobic digestion produces biogas and digestate, comprising a solid fraction and a liquid fraction. While digestion stabilises organic matter, digestate retains nutrients, residual COD, pathogens, and trace contaminants, requiring post treatment to meet environmental, land use, and regulatory requirements. Solid liquid separation is typically the first post treatment step and is widely applied across anaerobic digestion projects, using technologies such as screw presses, decanter centrifuges, belt presses, or gravity settling to improve solids handling, reduce nutrient and solids loading in the liquid fraction, and lower downstream treatment demand. The solid digestate fraction is most commonly treated through composting, which provides further stabilisation, odour reduction, pathogen destruction, and production of a marketable soil amendment, while drying or pelletising may be applied where long distance transport or fertiliser product standardisation is required.

The liquid fraction is the primary driver of environmental risk and regulatory control. Direct land application is often the intended end use, enabling nutrient recycling and replacement of synthetic fertilisers, but risks such as nitrate leaching, ammonia emissions, phosphorus runoff, and odour may necessitate further treatment. Where additional treatment is required, biological post treatment using aerobic systems reduces residual COD and nitrifies ammonia to improve discharge quality, while physical chemical treatment methods including struvite precipitation, chemical phosphorus removal, and ammonia stripping are applied where nutrient limits are stringent. For reuse or sensitive discharge environments, advanced polishing such as membrane treatment or passive systems including constructed wetlands and polishing ponds may be employed. Anaerobic digestion therefore does not complete treatment on its own, and successful projects integrate digester and post treatment design, align treatment pathways with land use and discharge constraints, and prioritise nutrient management alongside biogas production.

Figure 8: Post Treatment Sludge Dewatering

Table: Impact and consequence of post process digestate to the environment

Potential Impact	Source	Why Additional Treatment May Be Needed
Nitrate leaching	Liquid digestate	Risk to groundwater quality
Ammonia emissions	HighN digestate	Air quality and odour concerns
Phosphorus runoff	Digestate land application	Eutrophication of water bodies
Residual COD/BOD	Incomplete digestion	Non compliance with discharge limits
Pathogens	Animal derived feedstocks	Biosecurity and public health
Salinity / conductivity	Industrial wastes	Soil degradation risk
Heavy metals	Some food & industrial wastes	Long term soil accumulation
Odour	Volatile compounds	Public nuisance and permitting risk

6.0 Biogas to Power Generation

Biogas to power generation converts biogas produced through anaerobic digestion into renewable electricity and usable heat. Organic feedstocks such as agricultural residues, animal waste, food and brewery waste, and agro industrial effluents are digested under anaerobic conditions, producing biogas rich in methane. Instead of upgrading this gas to biomethane, the biogas is combusted directly in gas engines or turbines to generate electricity, typically as combined heat and power (CHP). This pathway is widely applied due to its technical maturity, proven reliability, and relatively low integration complexity.

6.1 Process and Technical Attributes

Raw biogas is collected from the digester headspace and conditioned prior to combustion through moisture removal, hydrogen sulphide removal, and siloxane removal where engine protection is required. Conditioned biogas is then fed into gas engines or micro turbines coupled with generators, with exhaust heat and jacket water heat recovered through heat exchangers to improve overall energy efficiency.

Biogas to power systems is based on proven, commercially mature technology with extensive global deployment. Gas engines designed for biogas operation offer high availability and flexible load response, and the system tolerates moderate fluctuations in biogas flow and composition provided that basic gas conditioning is maintained. Typical electrical efficiencies range from 35 to 42 percent for gas engines, while total system efficiencies can exceed 80 percent when heat recovery is fully utilised. From a commercial perspective, these projects benefit from lower capital complexity and shorter development timelines compared to biomethane focused facilities, with revenue typically generated through electricity export to the grid, on site power displacement, and where applicable renewable energy certificates or feed in tariff mechanisms. Biogas to power is particularly attractive where electricity infrastructure is available, gas grid access is limited, or project scale does not justify biomethane upgrading.

From a sustainability and policy perspective, biogas to power plants deliver greenhouse gas reductions through two independent and complementary mechanisms: methane capture and destruction from organic waste degradation, and renewable electricity generation that displaces fossil fuel based power. Organic wastes such as animal manure, food waste, agricultural residues, and agro-industrial effluents naturally decompose under anaerobic conditions, and without controlled treatment this process releases methane directly to the atmosphere. Biogas plants intercept this natural decomposition pathway by processing organic waste in sealed anaerobic digesters, where methane generated during digestion is captured rather than emitted and subsequently combusted in power generation equipment. In addition, the renewable electricity produced offsets grid electricity that would otherwise be generated from coal, gas, or other carbon intensive sources. As a result, biogas to power projects often achieve high net abatement per unit of energy produced and are well suited for emissions reduction targets, carbon credit mechanisms, and corporate ESG strategies, while also improving local waste management outcomes, reducing odour and pollution risks, and supporting circular economy principles by converting waste into useful energy.

Figure 9: Biogas Plant

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