INTEGRATED BIOGAS SYSTEMS

Local applications of anaerobic digestion towards integrated sustainable solutions

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Local applications of anaerobic digestion towards integrated sustainable solutions

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1. Executive summary

In 2015, the United Nations adopted 17 sustainable development goals (SDGs) and 169 targets as part of a global partnership. The biogas industry is well placed to achieve nine of the SDGs – conceivably more than any other sector (WBA 2017). These nine SDGs pertain to food and energy security, well-being, gender equality, sustainable water management and sanitation, resilient regions and cities, sustainable industrialisation and combating the effects of climate change.

To ensure that the biogas industry is on track to meet these nine SDGs it is imperative that the biogas sector is both economically and environmentally sustainable. Experiences from traditional biogas approaches have shown that significant government support is still required to make this market competitive and some of these systems are lacking sustainability in terms of high costs and environmental impact. Innovation, optimisation and implementation strategies are necessary to transform conventional digesters into more sustainable anaerobic digestion systems.

Economic and environmental diversity of biogas plants

Anaerobic digestion is a very versatile technology producing biogas, which can be used for cooking, heating, cooling and electricity production or upgraded and used for vehicle fuel or gas-grid injection. Biogas facilities range from micro-scale household digesters in developing countries, small-scale digesters used on farms and communities to large sale digesters encompassing centralised systems found in regions and cities.

The feedstock is sourced from a range of organic waste, from landfill and municipal waste, agro-industrial and livestock waste to purpose grown crops. Similarly, there is a wide range of different technologies used - from simple household digesters and covered lagoons to highly mechanized continuous stirred tanks reactors with modern sensors for process monitoring and control.

Economic drivers including the cost of energy, waste disposal and fertiliser plus the level of financial support vary across the globe; these economic drivers heavily influence the size of plant, feedstocks and technology used.

Challenges of sustainable anaerobic digestion

Some of the main challenges faced when implementing the use of anaerobic digestion systems include appropriate feedstock, operation and maintenance. Correct training and quality control, together with a consistent supply of feedstock and use of all anaerobic digestion end- and by- products are essential criteria for sustainable biogas systems, which must be an appropriate fit for the community and climate.

The choice of technology is also a crucial component. As methane is a strong greenhouse gas (GHG), methane emissions from the biogas process should be minimised to reduce environmental impact. Nevertheless, even with industrial biogas technology and strict regulations, emissions from digestate storage, combined heat and power (CHP), pressure valves, or leakages in the cover membrane can occur. It is assumed that GHG emissions from low cost systems, such as lagoons and small scale biogas plants, are higher, but often they are the only economic feasible solution, especially in developing countries, where energy prices are lower than in industrialised countries and where there is less or no financial support for biogas plant operators. Therefore it is important to improve such technologies to ensure decarbonisation, sustainability and improvement in the environment, without a disproportionate increase in costs and loss of economic viability.

Regional applications to provide sustainable solutions

The purpose of using anaerobic digestion is usually related to waste management (agricultural and food waste, animal or human excreta and other organic waste) and energy production. The remaining digestate is an added benefit, which creates additional value. Thus, the use of anaerobic digestion systems can ensure proper waste management, displacement of fossil fuels, production of biofertiliser and overall decarbonisation and improved environmental impact and sustainability.

Other benefits in addition to energy generation and by products particularly in regional areas include:

- Increases in local added value;
- Support for the agricultural and industrial sector in the region;
- Generation of high skill jobs in planning, engineering, operating and maintaining of biogas and biomethane plants;
- Increases in tax revenues in municipalities.

This report produced by IEA Bioenergy Task 37, addresses sustainability concepts of anaerobic digestion. Through case studies, examples of technical solutions, concepts, and strategies, which pertain to sustainable biogas production, are provided. Data has been gathered on anaerobic digestion facilities from seven countries with a focus on developing countries or countries with an emerging biogas sector which are not dependent or have little reliance on, or recourse to, financial support. Each of the case stories was selected on the basis of satisfying a large portion of criteria, which can be considered as key determinants for sustainable anaerobic digestion systems from both an environmental and socio-economic perspective.

2. Introduction

2.1 Biogas production and utilisation worldwide

The production of biogas across the globe has gained considerable momentum over the last 15 years; however, substantial variation exists among countries in terms of sector development and number of plants. While some countries, such as Germany and China, have shown rapid growth during the last decade, the biogas industry in others countries is just emerging. Globally, the generation capacity for biogas reached 16.9 GW in 2017, up from 6.7 GW in 2008. Table 2.1 shows biogas capacity in different regions of the world since 2008 (IRENA 2018).

In terms of installed electrical capacity Europe leads the sector with 17,662 biogas plants providing 9,985 MW_e (EBA 2017) followed by the USA with over 2200 digesters with an installed capacity of 977MW_e (American Biogas Council 2015).

The utilisation of biogas also varies significantly across the world. This ranges from the millions of small-scale biogas plants, which provide gas for cooking in China and India to electricity and upgraded biomethane as a vehicle fuel in Germany and Sweden respectively. These differences are the result of various factors such as energy prices, policies, and government incentives. Some countries use biogas as a tool for waste management, for example, to reduce environmental impact from wastewater, often just flaring biogas produced; whereas other countries focus on energy production and even grow energy crops to be used as substrates for biogas plants which, in itself, can generate negative environmental impacts.

Similarly, a vast range of different technologies is used – from simple household digesters and covered lagoons to highly mechanized continuous stirred tanks reactors (CSTR) or expanded granular sludge blanket (EGSB) digesters with modern sensors for process monitoring and control.

2.2 Benefits of integrated biogas systems

Experiences from traditional biogas approaches has shown that significant government support is still required to make this market competitive and some of these systems are lacking sustainability in terms of high costs and environmental impact. Innovation, optimisation and implementation strategies are necessary to transform conventional digesters into more sustainable anaerobic digestion systems.

Integrated biogas systems are essentially zero waste systems that make optimal use of nature to produce energy and nutrients in a synergistic integrated cycle of profit making processes where the by-products of each process becomes the feedstock for another process. Figure 2.1 illustrates how closed loop biogas systems act as a central link between residues and resources.

Table 2.1: Development of biogas capacity globally (MW)

	World	Africa	Asia	Central America + Caribbean	Eurasia	Europe	Middle East	North America	Oceania	South America
2008	6699	14	83	4	34	4474	12	1715	260	103
2009	8241	14	152	4	56	5873	16	1728	267	131
2010	9467	14	261	4	72	6871	24	1793	270	159
2011	11358	16	337	10	91	8471	32	1946	271	184
2012	13137	19	435	10	134	9752	34	2257	275	222
2013	13872	20	585	12	163	10141	39	2425	265	223
2014	14880	20	764	11	205	10770	47	2547	274	243
2015	15482	35	860	19	253	11183	58	2524	278	273
2016	16440	36	978	20	298	11620	58	2610	278	543
2017	16915	40	1115	23	347	12064	58	2634	279	355

Simple, cost effective integrated biogas systems can offer multifaceted solutions above financial benefits including social and environmental advantages in terms of rural employment, income diversification and opportunities for decentralised services such as energy production (Figure 2.2). These extend to rural communities, the agricultural and industrial sectors for small-scale systems and can include modifications to engineering systems for large-scale operations.

The objectives of this report are to showcase technical solutions, concepts, and strategies, which reflect the key qualities of sustainable anaerobic digestion systems. The key criteria, which define sustainable biogas systems together with economic, environmental and social considerations, will firstly be discussed. The report will then lead to a series of case stories, which highlight various integrated solutions undertaken worldwide with a focus on developing countries or countries with an emerging biogas sector which are not dependent on, or have little reliance on, or recourse to, financial support.

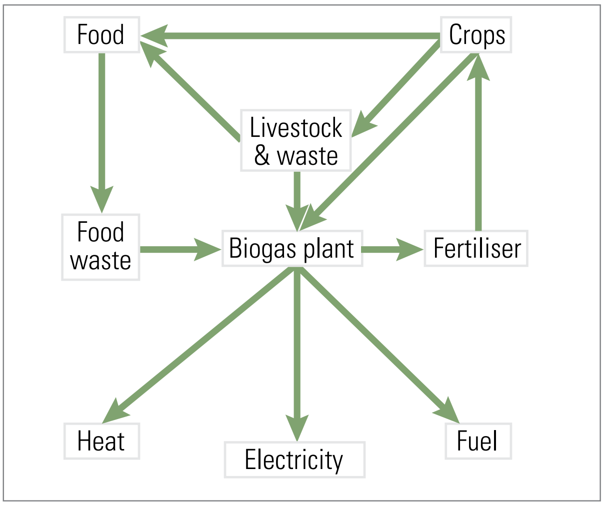


Figure 2.1 Integrated biogas systems forming a closed loop

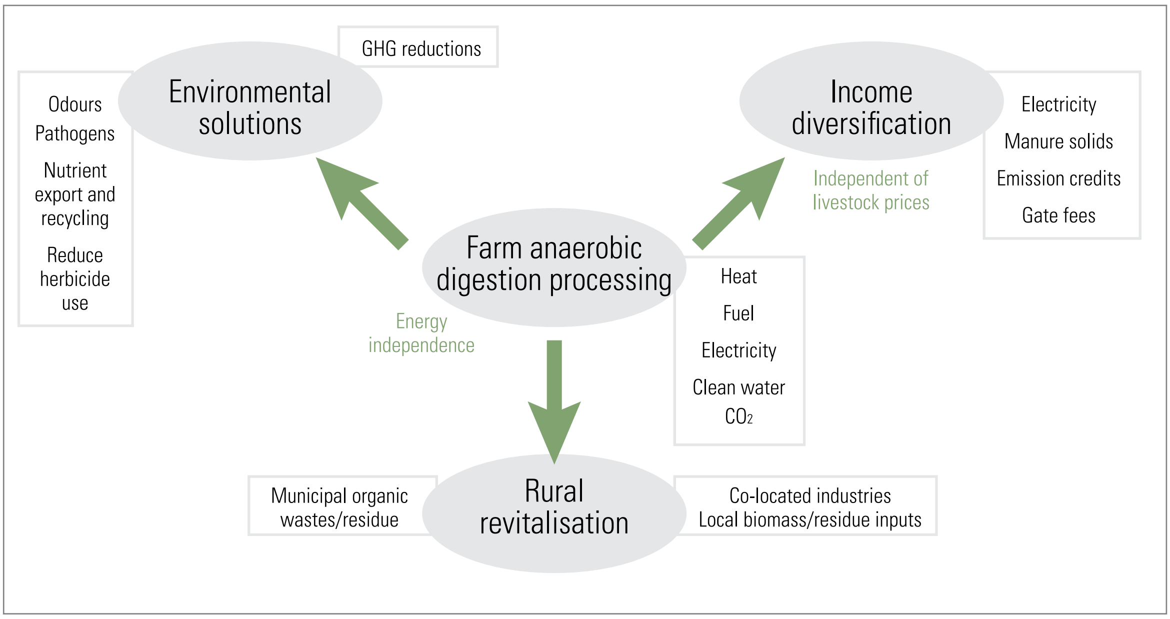


Figure 2.2 Multifaceted solutions of integrated biogas systems

3. Economic and environmental considerations

As a general rule, the aim of a growing biogas industry should be based on sustainable energy production and should be viewed through the lens of the three pillars of sustainability – a balanced approach to long term social, environmental and economic objectives – also known as the triple bottom line concept – People, Planet and Profit. In relation to sustainable anaerobic digestion the key criteria centre on the appropriate use of feedstock and technology for a given situation and the utilisation of biogas, which makes best sense in terms of economic, environmental and social benefits. Figure 3.1 provides a checklist of key elements, which can drive sustainable anaerobic digestion systems and the subsequent environmental and socio-economic impacts.

3.1 Feedstock

Biogas can be produced to some extent from most wet biomass and organic waste materials regardless of their composition. Feedstocks influence both economic and environmental sustainability of a biogas project depending on the costs for provision of feedstock and the carbon balance of the system including fugitive GHG emissions at the biogas facility. While some feedstocks, such as food wastes, may create additional benefits in the form of gate fees, disposal costs, and avoided methane emissions, other feedstocks such as energy crops can be costly to produce. Various scenarios for feedstock use should be assessed such as mono-digestion, co-digestion or in centralised or decentralised situations to determine best economic return, particularly in countries which receive little financial support (Gutierrez et al 2016).

When considering the overall carbon intensity of the produced biogas, some substrates such as manure, can have a negative GHG footprint due to the avoidance of fugitive methane emissions in open slurry tanks; while cultivation of energy crops cause GHG emissions due to the use of chemical fertilizers and fossil fuels needed for their production. Slurry digestion systems can have negative carbon intensity and energy crops can benefit greatly in terms of overall carbon sustainability in co-digestion systems (Liebetrau et al 2017).

The most prevalent feedstocks for anaerobic digestion may be categorised into five broad categories:

1. Organic fraction of landfill waste or organic fraction of municipal solid waste (OFMSW);
2. Sewage sludge;
3. Manure and slurry;
4. Energy crops and;
5. Agro-industrial waste streams.

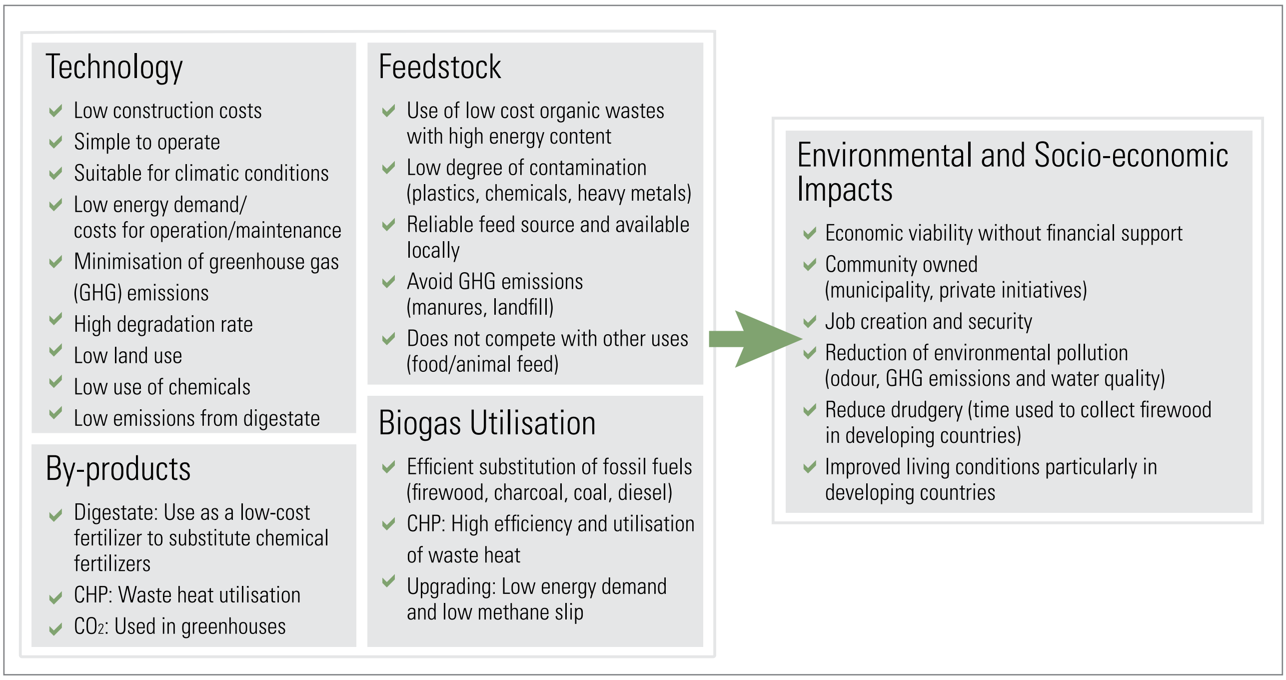


Figure 3.1 Key elements of sustainable anaerobic digestion

Landfills and OFMSW

Although the organic fraction in landfill waste can be processed to landfill gas (LFG) and reduce GHG emissions, if the landfill gas is used to produce combined heat and power (CHP), it is not considered to be the most efficient conversion technology in terms of renewable energy production from organic waste. Anaerobic digestion of OFMSW is more efficient in a bespoke bioreactor with a separate collection of the organic waste. This requires changes in waste management and collection and the cooperation of municipalities, companies and citizens (Al Seadi et al 2013).

Sewage sludge

The anaerobic treatment of sewage sludge is a proven technology; there are various examples across the globe that exemplify how anaerobic digestion can reduce the energy demand and costs of sewage treatment plants (Bachmann 2015). Some sewage treatment plants report energy self-sufficiency by optimisation of the anaerobic digestion process, such as by co-digestion of the sludge with grease trap waste or sludge disintegration; this significantly reduces the costs for municipalities and customers.

Manure and slurry

The use of animal manures and slurries is commonplace in developing countries as a feedstock for small-scale domestic biogas plants, but also in large-scale plants for co-digestion with other feedstocks or as a sole feedstock. In the absence of anaerobic digestion systems use of open tanks to store slurries leads to uncontrolled anaerobic digestion within the tanks producing methane that escapes to the atmosphere. Therefore anaerobic digestion not only reduces GHG emissions by substituting fossil energy, but also avoids GHG emissions from open storage of manure and slurries.

Energy crops and double cropping

The use of energy crops, such as maize, cereals, sweet sorghum and sugar beet is common practice in some countries, in particular Germany. However, there has been some criticism in terms of competition with food production, reduction of biodiversity, effects of digestate fertilisation on drinking water (NO^{3-}), and economic sustainability without subsidies. Blending manure or other wastes from processing with energy crops or other waste streams is an attractive option to increase sustainability and has become more important in countries like Germany where subsidies for energy crop production, and their share in the feedstock mix, is reduced (Daniel-Gromke et al 2018).

Other agricultural feedstocks in use for biogas can be catch crops that are planted after the harvest of the main crop; they allow a second harvest on the same piece of land within one year. A third harvest is also possible in countries such as Brasil due to the short growing season of the crop. Ley crops (crops planted on land resting between commercial crop cycles) also have some potential and are already used in some places (Wellinger, 2015). Also green cuttings and other fresh leafy materials from the maintenance of the landscape, such as from trimming of trees, bushes and grass, can be used for biogas plants as well.

Agro-industrial waste streams

Various residues of the food processing and prepared food production industries such as slaughterhouses, breweries, sugar mills, or fruit processing can be used as biogas feedstock. The economic profitability of these feedstocks is dependent on the biodegradability of the waste stream and the technology used. For example, feedstocks such as slaughterhouse waste have a high biomethane potential, however, the anaerobic process can be inhibited due to high protein levels potentially leading to ammonia inhibition (IEA Bioenergy, 2009); difficulties can also arise due to high levels of fats, oils and greases (McCabe et al 2013). Effective pre-treatment and suitable anaerobic digestion technology are important elements when assessing economic profitability of these wastes (Harris and McCabe, 2015).

3.2 Choice of technology

Many different types of biogas digesters are used throughout the world. A key requirement is that the technology does not have to be complex and difficult to operate. The most common technologies fall into two broad categories: 1. Engineered (concrete or steel), heated and continuous stirred tank reactors, and 2. Ambient

Table 3.1: Comparison of continuous stirred tank reactors and covered anaerobic lagoons

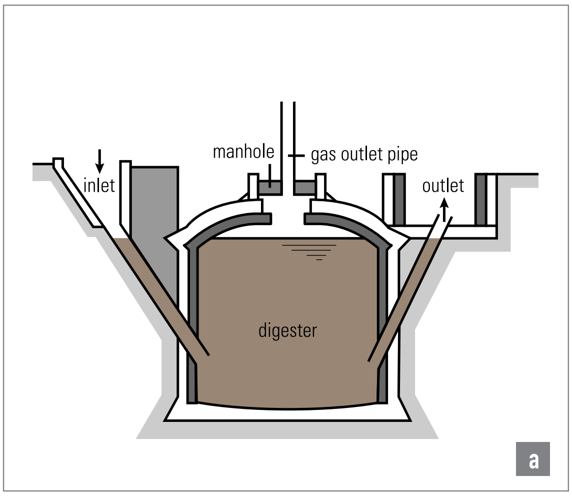
	Continuous stirred tank reactors	Covered anaerobic lagoons
Construction	Concrete or steel tank with insulation, heating, mixing and plastic membrane roof	Earthen lagoon with plastic cover (and plastic liner where required)
Substrate dry matter (DM) concentration	>4%	<5%
Operating temperature	Heated: 35 – 39°C (mesophilic) or 55°C (thermophilic)	Varies with ambient temperature (15 – 35°C)
Advantages	Applicable to a wide range of materials, shorter treatment time, small size, standard designs, applicable for use in all climates.	Lower construction cost using local resources, lower operation and maintenance requirement, no heat demand, tolerant of shock loads, cover also provides biogas storage.
Disadvantages	Higher construction and operation costs including heat demand, requires skilled operation.	Large size, suitable only for liquid organic materials and temperate to warm climates.

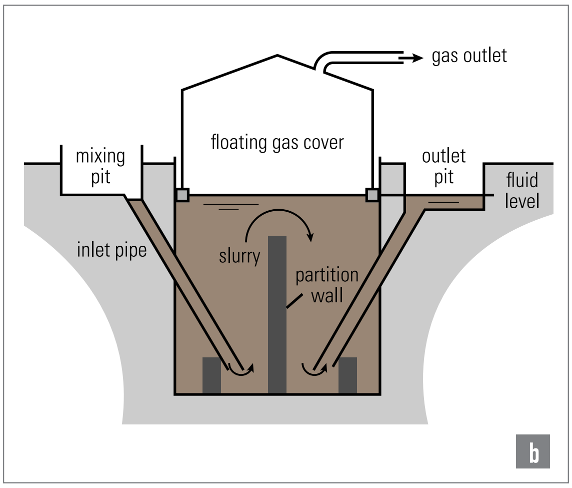
temperature, unmixed covered earthen anaerobic lagoons (Figure 3.2 a and b). Table 3.1 provides a comparison of continuous stirred tank reactors and covered anaerobic lagoons.

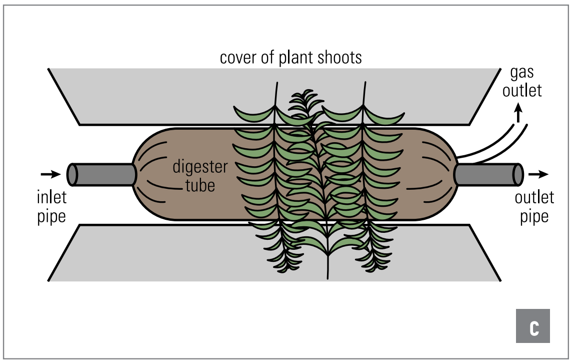
While countries in Europe use high rate engineered CSTR systems for the treatment of many feedstocks, countries such as Australia and Brasil use low rate covered anaerobic lagoons to treat livestock waste and agro-industrial wastewater from slaughterhouses and sugar cane. This technology is well suited to the abundant land space available and while these systems are not optimal treatment strategies, they are low-capital investments, which affect a large degree of organic degradation and methane generation (Jensen et al 2014).

Figure 3.2 (a) Continuous stirred tank reactor
(© Martin Dotzauer (DBFZ))

Figure 3.2 (b) Covered anaerobic lagoon
(source: Pork CRC Bioenergy Support Program)







Figures 3.3 Common digester designs in the developing world. (a) fixed dome digester (Chinese type). (b) floating cover digester (Indian type). (c) balloon or tube digester. Modified from Bond and Templeton (2011).

Generally, designs used in developing countries for digestion of livestock waste are classified as low-rate digesters, being simpler than those in more temperate regions and lacking heating and stirring capability (Plöchl and Heiermann 2006). This is also related to climate, since unheated plants and those without insulation do not work below 15°C.

Figure 3.3 illustrates the three major types of digesters used in developing countries for livestock waste which include:

1. Chinese fixed dome digesters;
2. Indian floating drum digesters and
3. Balloon (or tube) digesters.

Floating drum digesters are normally made from concrete and steel, whereas fixed dome digesters are constructed with various available materials, such as bricks. Balloon (or tube) digesters are fabricated from folded polyethylene foils, with porcelain pipes for inlet and outlet. Prefabricated biogas digesters (PBDs) continue to be developed, tested, and extensively applied in developing countries to compensate for the disadvantages of traditional domestic digester models (Cheng et al, 2014). These prototypes are derived from the three major types of domestic biogas models named above. Two main streams of PBDs are represented by composite material digesters (CMDs) and bag digesters.

The impacts of individual technologies on environmental sustainability, particularly in relation to GHG emissions, is difficult to measure and are influenced by many factors such as energy for construction/ manufacturing, risks of leaking, and gas permeability of materials. Studies on fugitive methane emissions from manufactured biogas plants in Europe have identified various points of methane losses, such as uncovered digestate storage tanks, CHP exhaust, flare, overpressure valves, composting of digestate and digestate application (Liebetrau et al 2017).

Most issues related to GHG emissions from manufactured biogas plants are not related to a certain type of digester, but to individual plant components, on site-plant management and maintenance, and regulations. Typical methane losses between 1% and

3% of total methane production for biogas plants are reported (Holmgren et al 2015). These are minimal compared to the avoided 14.6% fugitive emissions (based on the biogas potential of manure) associated with open slurry tanks, (Liebetrau et al 2017). It may be said that in a well-managed optimised biogas facility losses are low and biogas production based on residues has a positive GHG balance (Bachmaier et al 2010); this may not always the case for mono-digestion of energy crops.

Lagoon digesters have a higher potential for leakages and gas emissions due to the high surface area covered and the permeability of some cover materials. For example, Stark and Choi (2005) reported CH_4 permeability of cover materials to be 901, 687, and 302 ml/m^2/d for polyvinylchloride (PVC), linear low-density polyethylene (LLDPE), and high-density polyethylene (HDPE) respectively. Not only can the cover itself be a source of emissions, the area where the cover is fixed to the wall can also be prone to leakages. GHG emissions due to land application of treated liquids should also be considered.

Little information is available on emissions from low-cost digesters in developing countries, but it is likely that the technology commonly employed produces more emissions in relation to the total biogas production compared to large-scale systems. Bruun et al. (2014) reported approximately 40% methane losses from small-scale digesters via a combination of emissions from the inlet and outlet, leaking from cracked or broken cap on the digester or non-airtight gas valves and intentional releases. It was estimated that about 2 m^3 of gas emissions per year occur from the inlet and outlet from a fixed dome biogas digester. The study also reported that up to 15% of gas produced in Thailand was released from intentional release of excess biogas.

Other reasons for the high emissions from small-scale household digesters are:

a) Digester design: Floating dome digesters have a gap between the dome and the wall, where gas can escape; in fixed dome digesters the content is pressed out of the digester when no gas is used and pressure increases inside (see figure 3.3);
b) Construction: Often self-made, not by professionals; no regulations, no commissioning or testing;
c) Awareness: Plants are operated by farmers who may not have a complete understanding of the complexity of GHG emissions and therefore do not manage plants appropriately to reduce GHG emissions.

3.3 Use of biogas and by-products

The end utilisation of the biogas can influence sustainability in a number of ways, depending on whether the gas is used directly in boilers for heat or in an on-site CHP to generate electricity and heat, or if it is upgraded for use as a vehicle fuel or in an off-site CHP. The optimum use in terms of environmental sustainability and GHG emissions can be achieved by replacing fossil fuels, such as coal or diesel.

When biogas is used to produce electricity, the process efficiency depends on the size and technology of the CHP and ranges between 31% and 43% for electricity, 35% and 60% for heat, with an overall efficiency of 78% to 91%. As more thermal energy is generated compared to electricity in most CHPs, the use of heat is essential for efficient biogas utilisation (Rutz et al 2015). Different end use of heat can include heating of buildings, drying of agricultural crops, and provision of heat for industrial processes. In general, the incentive to utilise heat can be quite low and depends on the market, which can be influenced by seasonal demand and low prices. For example, only 36% of agricultural biogas plants in Germany use more than 50% of the heat produced and 30% only use 10% or less (Murphy et al 2011).

Upgrading the biogas to biomethane and feeding it into the natural gas grid can increase the total efficiency of the system despite the losses in energy and methane slip during upgrading. The biomethane may be transported via the gas grid to a site with optimal conversion efficiency and maximum utilisation of the produced energy. An example of this is a heat led CHP system. Many breweries and creameries have high heat demand, which is presently met with natural gas. The

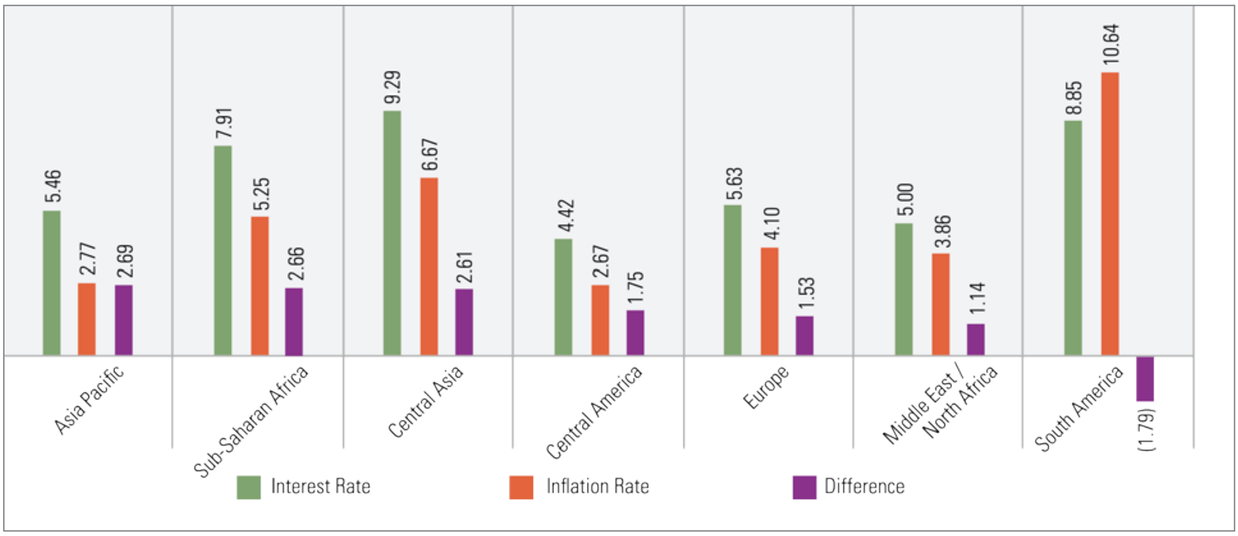


Figure 3.4: Average interest rates and inflation rate by region (Shum 2015)

obvious choice to decarbonise is the use of biomethane or green gas (Wall et al., 2018). It is also possible to use biomethane in combined cycle gas turbines (CCGT), which can achieve electrical efficiencies of up to 65% at power plant scale.

The use of the digestate as organic fertilizer can affect sustainability in a variety of ways. It can substitute mineral fertilizers and thereby reduce the environmental and carbon footprint and costs of fertilizer application. Generally, the composition of the digestate depends on the feedstock and the relative composition of nitrogen (N), phosphorous (P), potassium (P) and sulphur (S) can vary significantly. Negative environmental effects of digestate application include nitrogen losses through N_2O and NH_3 emissions and washout into the groundwater as NO_3^-, as well as methane emissions, but these effects can be minimised by appropriate storage and application. Digestate from slurry should have higher fertiliser value (through mineralisation and availability of nutrients) than undigested slurries and reduce the need for fossil fertiliser. Digestate may be seen as a decarbonised fertiliser.

3.4 Drivers and support policies

The main economic drivers for the implementation of biogas technology are the costs of biogas production as compared to the revenues available for the sale or use of biogas produced. Furthermore, gate fees, avoided prices of fertilizer and avoided disposal costs through reduction in sludge volume in sewage treatment or reduction in wastewater strength, are crucial factors which affect the economic viability of biogas projects.

Biogas production generates high local added value, especially if it is sourced from domestic biomass/wastes, which are processed at local plants (Stambasky et al 2016). Despite higher market price compared to non-renewable natural gas, the increased local added value generated by biogas production needs to be taken into account. Energy generation from biogas in regional areas offers benefits such as:

- Increases in local added value;
- Support for the agricultural and industrial sector in the region;
- Generation of qualified jobs in planning, engineering, operating and maintaining of biogas and biomethane plants;
- Increased tax revenues in municipalities.

Financing and capital costs can also affect the implementation of biogas projects. In many countries, particularly developing ones, interest rates on loans are very high making biogas projects difficult to finance due to the very short amortisation period required by investors (Figure 3.4). The prices for electricity and natural gas vary significantly in different countries around the world and therefore influence the economics of biogas production. As shown in Figure 3.5 average electricity price ranges from 8 US cent /kWh in China and India to 41 US cent / kWh in Denmark and prices for natural gas from 2.5 to 11.3 US cent/kWh.

Biogas may include landfill gas, sewage treatment plant gas, gas from farm wastes (manure), or gas from a host of other sources. Some jurisdictions lump these sources together, others calculate a separate tariff for each while also varying the tariff by project size. For example, Ontario offers five tariffs for biogas depending upon project size. Germany and France offer separate tariffs for landfill gas, sewage gas, and gas from on-farm anaerobic digestion. It is important to note that large variations in feed in tariffs for biogas between countries exist (IEA Bioenergy Task 37 2016) and this can affect economic viability and deployment.

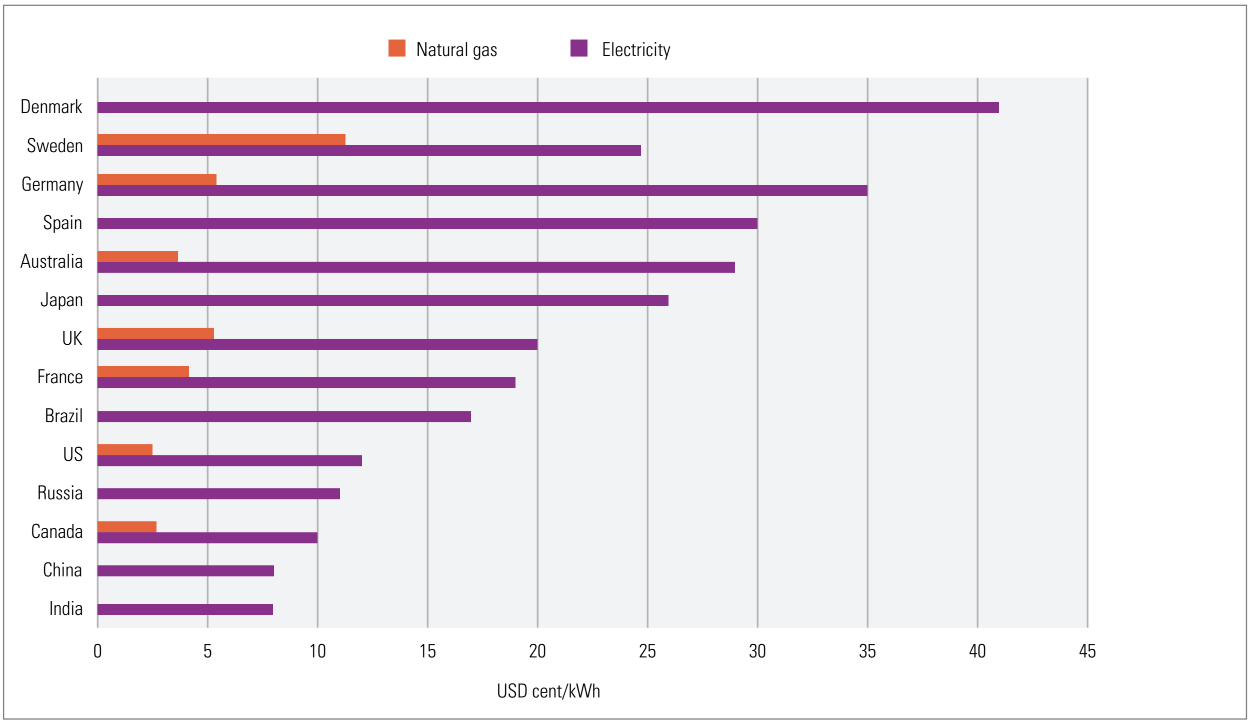


Figure 3.5: Average electricity and natural gas prices for selected countries in US cent/kWh (OVOEnergy 2011, Statista.com 2014); prices for a natural gas supply of 1.25 million kilowatt hours per month.

4. Socio-economic impact

Biogas plants provide multiple benefits at the household, local, national, and international level. These benefits can be quite unique in the context of different countries, and can be classified according to their impact on energy security, employment, environment and poverty. The previous sections on feedstocks, choice of technology and end use of biogas and byproducts demonstrates that there are wide ranging environmental and economic impacts when biogas is produced on a sustainable basis. The socio-economic impact is equally important and includes aspects such as:

- **Increased employment**

Biogas plants result in the creation of jobs and regional development. Planning, construction, cost estimation, production, control and distribution are all required to ensure the successful development of biogas facilities.

- **Decentralised energy generation**

One of the unique characteristics of biogas technology is that it can be established locally, without the need for long-distance transportation or import of raw materials. Small or medium-sized companies and local authorities can establish biogas plants in any location and are not dependent on being located in or close to large cities. This also enables remote areas to become energy independent and move away from the reliance of fossil fuels thus contributing to the development of a sustainable energy supply and enhanced energy security for these regions.

- **Improved livelihoods**

For isolated, rural and less wealthy populations, the benefits of sustainable anaerobic digestion systems are even more direct than for a Western urban population and engender the energy independence needed by these communities. When combined with food security they provide a powerful case for city and rural communities alike. The social benefits include:

– **Quality of life**

Biogas plants help improve beneficiaries' quality of life. First, they reduce the workload usually required for typical tasks such as firewood collection and fire tending. In addition, cooking with biogas stoves is more convenient and faster than with firewood or charcoal stoves. Moreover, biogas is much cleaner than firewood or charcoal. Indeed, cooking with firewood or charcoal usually results in the production of soot, which usually soils the kitchen and cooking utensils and effects the respiratory system of the inhabitants (more on this below).

– **Gender equality**

Improved gender equality is a direct consequence of the previous point, since women are predominantly involved in the housework. Thanks to the reduction of their workload, women can spend more time on other activities and on education; hence biogas systems can bring about a reduction in gender disparity.

– **Health and sanitation**

Indoor smoke pollution related to the use of firewood or charcoal may induce health risks such as respiratory diseases (no particulate matter emission unlike firewood or charcoal). In addition, bio-digesters reduce the pathogen content of organic materials. The sanitary condition of the household can consequently be enhanced thanks to domestic biogas units.

– **Education**

The installation of a biogas lamp can enable children to study later in the evening. The lighting quality of biogas lamps is generally better than traditional lighting methods (such as kerosene lamps). Children that have access to a proper lighting can study up to 2 hours more per evening than children with poor lighting conditions.

– **Food security**

The use of slurry as a biofertiliser improves crop yields compared to traditional manure (Gurung, 1997). It consequently contributes to food security for beneficiaries and the community in general.

5. Case stories

The following case stories provide examples of technical solutions, concepts, and strategies, which exhibit sustainable anaerobic digestion practice. Data has been gathered on biogas facilities in seven countries, including Australia, Brasil, Ghana, Nepal, New Zealand, Rwanda and India. Each case story provides an overview of technical data, including the types and amounts of feedstocks and utilisation of the products of anaerobic digestion. A brief description is also provided which explains the motivation behind the project's conception, construction of the plant, financial conditions and resulting socio-economic impacts.

5.1 Covered anaerobic pond treating piggery waste: Australia

Located near Young in New South Wales, Blantyre Farms has approximately 22,000 pigs, and was the first piggery in Australia to install a commercial-scale system to generate power from methane from an anaerobic (covered pond) system (Figure 5.1). The piggery was also the first farm-based project eligible to earn carbon credits from destroying methane generated.

Hot water is also heated from the generator and used to heat areas for the piglets, further reducing the amount of energy needed. The piggery converts methane from pig manure into electricity, powering the entire operation of the farms. An Australian company, Quantum Power, built the technology and machinery.

Having researched European and Northern American systems that weren't suited or economically viable for the Australian Industry, Australian Pork Limited identified a transferable low cost system based on New Zealand research, which has a similar industry and needs to Australia's. The system is suited to smaller as well as larger piggeries. The technology is applicable to the pig industry across Australian.

Summary

Feedstock	Pig manure and pig feed by-products
Technology	Covered anaerobic pond
Use of biogas and by-products	Generation of electricity and heat, which is used at the piggery
Simple payback	Total capital investment US$ 733,000; payback 3.5 years
Energy saved	Blantyre Farms has reduced its power and gas bill from US$ 11,400 per month to now being paid in excess of US$ 3,800 per month for excess power sold to the grid.
Other attributes	Biological oxidation for H_2S removal in an external vessel, biogas chilling for moisture removal

Figure 5.1 (a) HDPE covered anaerobic lagoon
Source: Pork CRC Bioenergy Support Program

(b) CHP Unit

5.2 Commercially viable biogas from food waste: Australia

Leading Australian garden product supplier Richgro is using in vessel anaerobic digestion technology supplied by Biogass Renewables to meet all its power needs (Figure 5.2).

Using organic waste from its onsite operations, a US$ 2.5 million anaerobic digestion plant with a capacity of 2MW_e produces enough electricity to power Richgro's operations at Jandakot in the south of Perth, Western Australia. The by-product from the plant can be used as a raw material in Richgro's garden products, meaning the company produces zero net waste from its operations. The plant has the capacity to process more than 35,000 tonnes a year of commercial and industrial organic waste, diverting it from landfill.

Future plans include the use of biomethane for Richgro's onsite vehicle fleet and CO_2 from the exhaust of the cogeneration unit for use within the blueberry hot houses. Over a 20 year life the project is expected to save 142,722 tonnes of $CO_{2\text{-equiv}}$. Low Carbon Australia, now the Clean Energy Finance Corporation, provided finance for the project, which also received an Australian Government Clean Technology Investment Program grant.

Summary

Feedstock	Commercial and industrial food waste (35,000 – 50,000 t/a)
Technology	Wet in vessel mesophilic anaerobic digestion. 5000m^3 total digestion capacity
Use of biogas and by-products	Designed to produce over 2MW_e capacity electricity – 1.7MW_e sold to the grid; up to 2.2MW_{th} heat for utilisation; up to 100m^3 per day of liquid biofertiliser at 6% dry solids
Simple payback	Total capital spend US$ 7.2 million; Gate fee revenue and export of power from the grid; less than 5 year payback on capital (before grants)
Energy saved	Onsite power use of 300 kW_e
Other attributes	It is expected to save 142,722 tonnes of $CO_{2\text{-equiv}}$ over 20 years

Figure 5.2 (a) Digesters and gas management

(b) Liquid handling

Source: Biogass Renewables

5.3 Stein Ceramics – Biogas from piggery waste: Brasil

The model employs a completely mixed digester, a biomass heating system, gas drying and hydrogen sulphide removal by means of biological desulphurisation (Figure 5.3).

Approximately 750 m³ of biogas is produced daily, which is converted into electrical energy in a generator set of 112 kVa (estimated at ca. 64 kW_e). The facility has generated an avoided cost of between US$ 4350 to US$ 7250 per month and paid for itself in a 2 year period.

The primary benefits were twofold: the environmental service of manure treatment and the economic benefit of revenues from biogas electricity. The size of this unit is similar to many other farms in the South of Brasil – a region, which produces 50% of the swine meat in the country.

A key aspect of biogas project success is that the suppliers of technologies are all from the same region, demonstrating that it is a model of success that has been adapted and deployed throughout a region.

Summary

Feedstock	Pig manure
Technology	Covered anaerobic lagoon with agitation. Digester volume 1,400m³
Use of biogas and by-products	Installed generation 112 kVa (estimated 64 kW_e). Biogas production of 750m³/day to generate electricity
Simple payback	2 years
Energy saved	39 kWe
Other attributes	Companies involved: Biokohler Ltd and Biogas Motores Ltd.

Figure 5.3 (a) Covered anaerobic lagoon
Source: Cibiogas

(b) Electricity generator

5.4 The Omnis/CPFL Biogas Project – Biogas from Sugarcane Vinasse: Brasil

This biogas plant is a R&D project, which was operated from April 2011 to November 2014. The plant generated biogas from sugarcane vinasse, a wastewater derived from ethanol production with high pollution potential, in a low-rate lagoon-based UASB reactor (OLR of 2 kg COD/[m³/d] and HRT of 15 d) with a design throughput of 40 m³ per hour.

This low-cost anaerobic reactor was designed to require no heating system as well as to avoid the use of chemical additives for substrate neutralization. The biogas was biologically desulfurized in a packed-bed external tower and used as fuel in a 1.1 MW_e CHP (GE Jenbacher) for electricity production (Figure 5.4).

The full-scale R&D facility had an ambition to optimize the biochemical process and assess the quality of digestate for sugarcane cultivation. Besides the avoidance of methane and nitrous oxide emissions that occurred during temporary storage, transport and application of vinasse to the fields, the renewable electricity generated was able to displace fossil fuel from power plants of the national grid resulting in additional carbon relief of 1,500 $CO_{2\text{-equiv.}}$ per year.

Summary

Feedstock	Sugarcane vinasse from an annexed sugarcane mill (sugar + ethanol production)
Technology	1 x 14,400 m³ lagoon-based UASB reactor (3 cells), mesophilic; ca. 3,200,000 m³ biogas per year (533 m³/h); 255 operation days/ year
Use of biogas and by-products	Biogas is biologically desulfurized in a packed-bed external tower and used as fuel in a 1.1 MW_e CHP unit to produce electricity for export to the grid; digestate is used as a fertilizer for sugarcane cultivation
Simple payback	Investment costs: US$ 2,000,000. No feed in tariff or subsidy; Sale of electricity
Energy production	Exporting about 5,500 MW_eh of electricity per year to the grid
Other attributes	The total carbon relief amounts to ca. 1,500 $CO_{2\text{-equiv.}}$ per year; reduction of potential pollution by 60% (based on COD)

Figure 5.4 (a) Overview of the Ester biogas plant desulfurization tower (left), lagoon-based UASB reactor (left, behind), and CHP system (front) Source: Omnis Biotechnology

Figure 5.4 (b) Distribution pipeline (right)

5.5 Biogas Technologies Africa Ltd for institutions: Ghana

The sewage system in Ghana is under developed and often institutions pay for sewage to be tankered off site; this sewage may end up untreated in local rivers or in the sea.

Biogas Technologies Africa Limited (BTAL) was set up to build anaerobic digestion systems to treat sewage from institutions such as hospitals, school, colleges, universities, and businesses, including hotels. These sewage treatment / biogas plants can be used to replace LPG for cooking in the institutions, where the sewage was generated. The sewage plants use secondary treatment of the treated sewage, using aerobic filters, so the effluent water can be discharged to local drains.

The main saving is that the institutions do not need to pay for tankers and the sewage does not cause pollution in receiving waters.

The biogas plants are made from brick rings formed into a hemispherical domes, which are then covered in soil. The volume of each hemisphere is between 50 and 80 m³. Larger plants are made up of a series of domes connected together. The system together with the biogas storage in flexible bags is pictured in Figure 5.5.

Summary

Feedstock	Human sewage
Technology	Underground brick dome
Use of biogas and by-products	Gas for cooking for institutions
Simple payback	3 years
Energy saved	6,900,000 MJ/yr or 220 kW (heat) in 15 plants
Other attributes	Replaces inadequate sewage systems

Figure 5.5 (a) Building underground domes
Source: David Fulford

(b) Biogas stored in flexible bags

5.6 Biogas Support Programme: Nepal

The Nepal biogas programme was started by the Nepal government in 1976. It was taken over by a consortium that included the Developing and Consulting Services of the United Mission to Nepal and the Agricultural Development Bank of Nepal, who set up the Gobar Gas Company.

In 1992, the Netherlands Development Organisation (SNV) took over the work and formed the Biogas Support Programme (BSP). In 2003, BSP became the Biogas Sector Partnership, an independent NGO, accountable to the government Alternative Energy Promotion Centre (AEPC), supervising 65 biogas plant construction companies (now about 112 companies).

The plant uses an underground dome made from concrete cast over a mud mould (Figure 5.6). BSP provides training for the biogas construction companies and also ensures a high standard of quality control. Surveys show that 95% of all plants constructed are still working after 5 years.

The gas is mainly used for cooking, although many customers also use gaslights. The plants are fed daily with cattle dung. The benefits include improved health as a result of replacing firewood. Many plants include a latrine, which provides further health benefits. Women also save about 3 hours a day of work associated with fuel collection in the form of wood from local forests. Thus there is reduced deforestation. A typical plant saves about 4 tonnes fossil CO_2 per year.

Summary

Feedstock	Cattle dung
Technology	Fixed dome underground digesters (GGC 2047 design)
Use of biogas and by-products	Biogas for cooking, effluent used as fertiliser
Simple payback	6.1 years from savings (without subsidy)
Energy saved	64.5 MJ/day per plant (= 0.747 kW heat) for 300,000 plants gives 224 MW (heat) or 7PJ/a of heat
Other attributes	About 300,000 biogas units built for individual rural families in Nepal

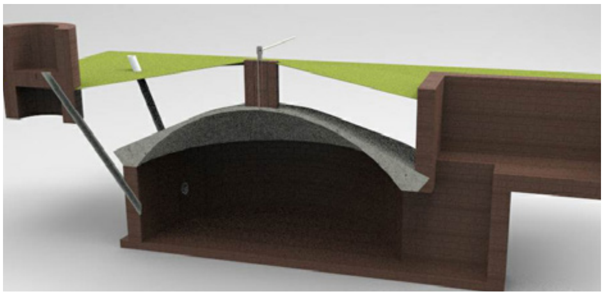


Figure 5.6 (a) Cross section diagram Source: David Fulford

(b) Construction of fixed dome underground digester.

5.7 High Rate Co-Digestion: New Zealand

Industrial and municipal trade waste materials with high fat, oil & grease (FOG) content (5-10 % FOG) and high water content (> 90 %) are often a disposal challenge. This project converted a FOG disposal problem into a commercial opportunity.

Existing mesophilic sludge digesters (2 x 1350 m^3 volume; Palmerston North, NZ; Palmerston North City Council (PNCC)) were retrofitted with recuperative sludge thickening at low capital costs to achieve digester stability under high FOG loading rates (Figure 5.7). This more than tripled their biogas production capacity.

The PNCC digester upgrade added the ability to divert approximately 15,000 tonnes/year of high FOG content trade waste from landfill and digest it producing biogas in existing digesters at a total investment cost of only US$ 1.06 million. This was the first installation of its kind in New Zealand.

Stable FOG loading rates in excess of 1.5 kg FOG/m^3digester/day and stable digester operation with high FOG loading rates was achieved for more than 3 years. Biogas productivities (m^3biogas/m^3digester/day) were in excess of 320 % of the equivalent maximum biogas productivities when operated with municipal sludge alone.

The digester upgrade project was completed in 2012; the produced biogas is used to replace natural gas for co-generation with electricity export into the grid. A second successful installation was added to the Hamilton WWTP digesters in 2014.

Summary

Feedstock	Fat, oil & grease, dairy factory DAF sludge, grease trap waste
Technology	Recuperative thickening (RT) municipal digesters
Use of biogas and by-products	Natural gas substitution for electricity co-generation
Simple payback	3.3 years at gate fees of US$ 21 /t trade waste, no financial subsidies needed
Energy saved	5.1 million kWh natural gas over 330 operation days/annum
Other attributes	Potential for production of up to 10 million kWh gas in 330 days/annum

Figure 5.7 (a) Digester with mixing system for co-digestion of primary sludge, grease trap waste, and dairy factory DAF sludge.
Source: Jürgen Thiele

(b) Recuperative thickening system – tripling biogas production

5.8 Kigali Institute of Science and Technology for prisons: Rwanda

After the civil war in Rwanda, many people were put in prison. The prisons became overcrowded and the sewage systems could not cope. The Red Cross asked the Kigali Institute of Science and Technology (KIST) to work on a solution to this problem. A Tanzanian Engineer used the training he had obtained in KIST to build biogas plants to process the sewage.

The gas generated by the sewage is used in the prison kitchens to cook food, saving 50% of the firewood that was previously needed. The effluent slurry has very little smell and is used to fertilise crops (such as maize) in the prison gardens. Flowers are often grown on the soil used to cover the biogas plants.

The biogas plants are made from brick rings formed into a hemispherical domes (Figure 5.8), which are then covered in soil. Each hemisphere has a total volume of about 100 m^3, and several of these units are linked together to form the volume required (up to 1,200 m^3). The prison inmates acted as a source of labour for the work and some were trained in masonry work.

Summary

Feedstock	Human sewage
Technology	Underground brick dome
Use of biogas and by-products	Gas for cooking for prison inmates Effluent for fertilising gardens
Simple payback	Plant for 5000 inmates [500 m^3 total internal volume (TIV)] costs US$ 65,000 (paid for by government and Red Cross)
Energy saved	1866 kW (heat) from plants serving 30,000 inmates in total
Other attributes	Saves raw sewage polluting local environment

Figure 5.8 (a) Building underground domes
Source: Ashden (www.Asden.org)

(b) Garden over a sewage treatment plant

5.9 SKG Sangha: South India

SKG Sangha build individual biogas plants for rural families in the States of Karnataka, Tamil Nadu and Andhra Pradesh in India. The plants are made of rings of brick formed into a hemisphere and are mainly underground (Figure 5.9).

Each plant costs about US$ 530 and many also include a vermi-compost unit that costs $US 361 extra; total cost of US$ 889. The compost can be used on the farmer's land, but half can be sold to make $US 387 per year. The plants are fed daily with cattle dung, as many farmers in India keep cattle for milk and also for agricultural uses (as draft animals). The gas is used mainly for cooking in locally made biogas stoves, usually replacing firewood.

The health benefits from replacing wood fuel by biogas for cooking is estimated as being worth $US 1100 a year by BP Target Neutral, as a typical domestic biogas plant saves 4 tonnes of fossil CO_2 per year. Cooking over wood fuel causes indoor air pollution, which irritates eyes, nose and the respiratory system. This allows infections to develop, such as bronchitis, which are expensive to treat.

Other benefits of domestic biogas include the saving of the time of women (typically 3 hours a day), since they do not need to collect and process firewood. It also reduces deforestation (1000 plants saves 33.8 ha of forest per year according to WWF).

Summary

Feedstock	Cattle dung
Technology	Fixed dome underground digesters (Deenbandhu design)
Use of biogas and by-products	Biogas for cooking, effluent mixed with dry biomass, composted and then vermicomposted to give valuable compost/fertiliser
Simple payback	2.3 years from vermicompost
Energy saved	64.5 MJ/day per plant (= 0.747 kW heat) for 300,000 plants gives 224 MW (heat)
Other attributes	Well over 300,000 biogas units built for individual rural families in South India

Figure 5.9 (a) Cross section diagram
Source: David Fulford

(b) construction of underground biogas plants

6. Conclusion

There are several principles, which fulfil the sustainable implementation of methane capture and utilization of biogas from economic, environmental and social standpoints. The criteria centre on the appropriate use of feedstock and technology and the end use of anaerobic digestion products. The case stories contained in this report have been chosen on the basis of satisfying a large majority of these criteria.

The case stories demonstrate that there is no 'ideal' integrated solution, as each anaerobic digestion application has different feedstocks available, constraints and end products. What needs to be considered and encouraged is adaption of exemplar systems, which suit individual situations. The result of sustainable anaerobic digestion is therefore a unique set of applications, which provide sustainable solutions, and avoid high input costs to maximise the value of both direct and indirect outcomes.

References

AL SEADI, T., QWEN, N., HELLSTRÖM, H., KANG, H. 2013. Source separation of MSW. IEA Bioenergy: Task 37.

AMERICAN BIOGAS COUNCIL 2015. Current and Potential Biogas Production. Available from: https://www.americanbiogascouncil.org/pdf/biogas101.pdf.

BACHMAIER, H., EFFENBERGER, M., LEHNER, A., GRONAUER, A. 2010. Greenhouse gas balance and resource demand of biogas plants. Landtechnik, 65(3), 208-212.

BACHMANN, N. 2015. Sustainable biogas production in municipal wastewater treatment plants. IEA Bioenergy: Task 37.

BOND, T., AND TEMPLETON, M.R. 2011. History and development of domestic biogas plants in the developing world. Energy for Sustainable Development. 15, 347-354.

BRUUN, S., JENSEN, L. S., VU., V. T. K. , and SOMMER, S.G. 2014. Small-scale household biogas digesters: An option for global warming mitigation or a potential climate bomb? Renewable and Sustainable Energy Reviews, 33, 736-741.

CHENG, S., LI, Z., MANG, H-P., HUBA, E.M., GAO, R., WANG, X. 2014. Development and application of prefabricayted biogas digesters in developing countries. Renewable and Sustainable Energy Reviews, 34, 387-400.

DANIEL-GROMKE J., RENSBERG N., DENYSENKO V., STINNER W., SCHMALFUSS, T., SCHEFTELOWITZ M., NELLES M., LEIBETRAU J. 2018. Current developments in production and utilization of biogas and biomethane in Germany. Chemie Ingenieur Technik, 90, 17-35.

EUROPEAN BIOGAS ASSOCIATION. 2017. 7th edition of the Statistical Report on European anaerobic digestion industry and markets.

GURUNG, J.T. 1997. Review of literature on effects of slurry use on crop production. Final report. The Nepal Biogas Support Program (BSP).

GUTIERREZ, E.C., XIA, A., MURPHY, J.D. 2016. Can slurry biogas systems be cost effective without subsidy in Mexico? Renewable Energy, 95, 22-30.

HARRIS, P.W. AND MCCABE. B.K. 2015. Review of pre-treatments used in anaerobic digestion and their potential application in high-fat cattle slaughterhouse wastewater. Applied Energy, 155, 560-575.

HOLMGREN, M.A., HANSEN, M.N., REINELT, T., WESTERKAMP, T., JØRGENSEN, L., SCHEUTZ, C., DELRE, A. 2015. Methane emission measurements from biogas production – data collection and comparison of measurement methods, final report (2015:158). Energiforsk.

IEA Bioenergy Task 37 2009. Biogas from slaughterhouse waste: Towards an energy self-sufficient industry. Information from IEA Bioenergy Task 37 Energy from Biogas and landfill gas.

IEA Bioenergy Task 37 2016. Country Report Summaries. Available from: file:///C:/Users/mccabe/Downloads/IEA%20Bioerg+T37CRS+2016+FINAL%20(7).pdf

IRENA 2018. Renewable energy capacity statistics.

JENSEN, P., SULLIVAN, T., CARNEY, C., BATSTONE, D, Analysis of the potential to recover energy and nutrient resources from cattle slaughterhouses in Australia by employing anaerobic digestion. Applied Energy, 136, 23-31.

LIEBETRAU, J., REINELT, T., AGOSTINI, A., LINKE, B. 2017. Methane emissions from biogas plants -Methods for measurement, results and effect on greenhouse gas balance of electricity produced. IEA Bioenergy: Task 37: 2017: 12.

MCCABE B. K., HARRIS, P., BAILLIE, C., PITTAWAY, P., YUSAF, T. 2013. Assessing a new approach to covered anaerobic pond design in the treatment of abattoir wastewater. Australian Journal of Multidisciplinary Engineering, 10, 81-93.

MURPHY, J., BRAUN, R., WEILAND, P., WELLINGER, A. 2011. Biogas from crop digestion. IEA Bioenergy: Task 37.

OVOEnergy. 2011. Average electricity prices around the world: $/kWh. Available from: https://www.ovoenergy.com/guides/energy-guides/average-electricity-prices-kwh.html

PLÖCHL M., HEIERMANN, M. 2006. Biogas farming in central and northern Europe: a strategy for developing countries? Invited overview. Agriculture Engineering International 8(8):1-15.

RUTZ, D., MERGNER, R., AND JANSSEN, R., 2015. Sustainable heat use of biogas plants. A handbook. 2nd Edition. Available from: http://www.biogasheat.org/wp-content/uploads/2015/03/Handbook-2ed_2015-02-20-cleanversion.pdf

SHUM, M. 2015. Where are the highest interest rates in the world? Investment Frontier. Available from: https://www.investmentfrontier.com/2015/04/13/where-are-the-highest-interest-rates-in-the-world/

STAMBASKY, J., WELLINGER, A., SCHEIDL, S. 2016. Best regional-integrated biogas plants. Biogas Action Project: Promotion of sustainable biogas production in the EU. Available from: https://www.biorefine.eu/sites/default/files/publication-uploads/biogas-action-brochure.pdf

STARK, T. D. AND CHOI H. 2005. Methane gas migration through geomembranes. Geosynthetics International, 12,120-125.

Statistica. com 2014. Energy prices - Statistics and Facts. available from https://www.statista.com/topics/1323/energy-prices/

WALL, D., DUMONT, M., MURPHY, J.D. 2018. Green gas: facilitating a future green gas grid through the production of renewable gas. IEA Bioenergy: Task 37: 2018 IEA Bioenergy: Task 37: 2018: 2.

WBA 2017. World Biogas Association Fact Sheet 3: How to achieve the sustainable developemnt goals through biogas. Available from: http://www.worldbiogasassociation.org/wp-content/uploads/2017/07/WBA-SDGs-Biogas-factsheet-3.pdf

WELLINGER, A. 2015. Biogas plant technologies and sustainable substrate management. European Biogas Association Conference, Vienna. Availabke from: https://www.unido.org/sites/default/files/201507/1_Sustainable_substrate_management_and_biogas_plant_technologies_Wellinger_0.pdf.

Task 37 – Energy from Biogas

IEA Bioenergy aims to accelerate the use of environmentally sustainable and cost competitive bioenergy that will contribute to future low-carbon energy demands. This report is the result of the work of IEA Bioenergy Task 37: Energy from Biogas.

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