IEA Bioenergy Task 37

Country Report Summaries 2016

This publication contains a compilation of summaries of country reports from members of IEA Bioenergy Task 37 (Energy from Biogas). Each country report summary includes information on the number of biogas plants in operation, biogas production data, how the biogas is utilised, the number of biogas upgrading plants, the number of vehicles using biomethane as fuel, the number of biomethane filling stations, details of financial support schemes in each country and some information on national biogas projects and production facilities. The publication is an annual update and is valid for information collected in 2016. Reference year for production and utilisation is as a rule 2015.

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IEA Bioenergy Task 37 - Country Reports Summary 2016

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Front Cover Photo: Used with permission of Rob Vanstone and Göteborg Energi, Sweden.

DIRECT DESCRIPTION OF PICTURE. The GoBiGas plant in Gothenburg is the first of its kind in the world, injecting biomethane from thermal gasification and methanation to the natural gas grid of Gothenburg. At full production, the 20 MWmethane plant will deliver 160 GWh/yr.

FACTS AND RELEVANCE FOR THE BIOGAS FIELD. In many projections for the technical biomethane potential, thermal gasification of woody biomass plays a vital role to achieve the higher end of the potential. The GoBiGas plant is to date the only larger scale facility that has been erected and run successfully. It is no doubt a success, testing out the technology of gasification with far more difficult substrates than fossil coal, and succeeding in achieving large scale methanation and grid injection. However, the scale was not intended to achieve economic feasibility. Göteborg Energi has come to a point where it no longer can continue to invest in a project that, under the current market conditions, isn't profitable, and is now trying to sell the existing plant to actors interested in establishing themselves in the thermal gasification and methanation sector.

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1. Introduction

The International Energy Agency acts as energy policy advisor to 29 Member Countries plus the European Commission, in their effort to ensure reliable, affordable, and clean energy for their citizens. Founded during the oil crisis of 1973-74, the IEA's initial role was to co-ordinate measures in times of oil supply emergencies. As energy markets have changed, so has the IEA. The IEA now has four main areas of focus: energy security, economic development, environmental awareness and engagement worldwide.

Activities within IEA are set up under the Technology Collaboration Programmes, formerly Implementing Agreements. These are independent bodies operating in a framework provided by the IEA. There are 39 currently active Technology Collaboration Programmes (Implementing Agreements), one of which is IEA Bioenergy. IEA Bioenergy is an organisation set up in 1978 by the International Energy Agency (IEA) with the aim of improving cooperation and information exchange between countries that have national programmes in bioenergy research, development and deployment. IEA Bioenergy's vision is to achieve a substantial bioenergy contribution to future global energy demands by accelerating the production and use of environmentally sound, socially accepted and cost-competitive bioenergy on a sustainable basis, thus providing increased security of supply whilst reducing greenhouse gas emissions from energy use. The work of IEA Bioenergy is structured in a number of Tasks, which have well defined objectives, budgets, and time frames.

IEA Bioenergy Task 37 addresses the challenges related to the economic and environmental sustainability of biogas production, by anaerobic digestion, and utilisation. While there are thousands of biogas plants in OECD countries, operation in the vast majority of cases can only be sustained with the help of subsidies to be able to compete with the fossil energy industrial sector. There is a clear need to enhance many of the process steps in the biogas production chain to reduce both investment and operating costs. Publications from Task 37 provide important information intended to be used to improve both economic and environmental performance of the biogas value chain where the end product can be heat, electricity or vehicle fuel, or combinations of these products. The other product from a biogas plant, the digestate, is a very important contributor to the overall sustainability of the biogas value chain and is also addressed in various Task 37 publications.

The Task 37 working group meets twice each year to discuss the progress of the work programme. At these meetings, the national representatives also present the latest information within the field of biogas from their respective countries. These presentations are available for free download at the homepage of Task 37[1]. This current publication is the fourth annual summary of Task 37 country reports collated from the presentations made at meetings and from additional background details provided by the national representatives. It is hoped that this publication will ease the dissemination of national biogas information to third parties.

The way information is gathered, recorded and reported varies from one member country to another and as a consequence direct comparison of country data is not always straight forward. Direct comparison is hampered by countries using different units to compile the available biogas statistics. The largest difference is how the biogas production is expressed. The following three methods exist: i) the energy content in the produced biogas from different plant types independent of losses and the utilisation; ii) the energy content in the produced and utilised energy (such as electricity, heat and vehicle gas); iii) installed capacity for energy production. While every attempt has been made to harmonise data in this publication, the different ways original data have been collected for national databases has made harmonisation and subsequent comparison difficult or even impossible in some cases.

[1] http://task37.ieabioenergy.com/country-reports.html

Biogas production is presented for the following plant types:

- Wastewater treatment plants
- Biowaste – co-digestion or monodigestion of food waste and other types of biowaste
- Agriculture – digestion at farms (mainly manure and energy crops)
- Industrial – digestion of waste stream from various industries (e.g. food industries).
- Landfill – landfills with collection of the landfill gas

2. Australia

Renewable energy provided 14.6% of Australian electricity generation during 2015 with bioenergy contributing an estimated 9.1% to renewable generation[2] (1.34% to total generation). The majority of bioenergy comes from the combustion of sugarcane bagasse. However, electricity generation from AD installations has shown highest growth rates over the past six years.

2.1 Production of biogas

In order to provide an accurate picture of biogas activity a short survey was originally compiled during 2015 requesting information on type of feedstock used, biogas production data, how the biogas is utilised and digestate handling[3]. The total number of respondents at the time of this publication was 46. The production of biogas in GWh/year is difficult to quantify due to the variety of ways in which data are expressed. The biogas production (GWh/year) in Table 1 is derived only from the 46 respondents and is a probable figure calculated on 50-80% methane content of biogas and corrected for efficiency losses.

The total number of AD plants is estimated at around 242. The majority are associated with municipal waste water treatment plants (WWTP) and landfill gas power units. WWTP use various technologies for the mono-digestion of sewage sludge. The majority of agricultural AD plants use waste manure from piggeries (20 systems) with the remainder using manure slurry from dairies and poultry. Over one half, (approximately 18) of industrial AD plants use waste water from red meat processing and rendering plants as feedstock for biogas production. Although a number of different technologies are used, covered anaerobic lagoons (CAL) are widely employed in AD plants treating agricultural and industrial waste.

There has been recent interest in the feasibility of using co-digestion (e.g. using trucked organic waste, other waste streams and glycerol) at WWTP, intensive agriculture industries and red meat processing plants. Australia does not use energy crops for the production of biogas.

Table 2.1: Status of biogas production in Australia (data from 2016)

Substrate/Plant type	Estimated Number of plants	Number of plants from survey	Potential Production (GWh/year)*
Sewage sludge (WWTP)	52	22	221
Biowaste	5	3	15
Agriculture	22	9	27
Industrial	34	12	39
Landfill	129**	-	1,140**
Total	**242**	**46**	**1,442**

* Calculated from the estimated electricity production and an assumed efficiency of 35% with 70% methane content in biogas.
** From 2006 Sustainable Power Plant Register, Australian Business Council for Sustainable Energy

Goals for 10,624 and 72,629GWh for bioelectricity were set for 2020 and 2050 respectively, to which AD using agricultural and industrial organics are key contributors (Clean Energy Council (CEC), 2008[4]). Opportunities exist for the urban waste industry, driven by a combination of rising landfill gate fees and falling technology costs, and the intensive livestock and food processing industries, driven by readily

[2] http://www.cleanenergycouncil.org.au/cleanenergyaustralia
[3] http://biogas.nceastg.usq.edu.au
[4] http://biomassproducer.com.au/wp-content/uploads/2013/11/01AustralianBioenergyRoadmap.pdf

available feedstock from process waste, higher electricity process and demand for onsite electricity, heat or steam. The Clean Energy Finance Corporation (CEFC) projected 2020 target for agricultural biogas production is 791 GWh. The CEFC estimates a bioenergy investment opportunity of up to $5 billion by 2020, potentially doubling the current level of installed capacity (see Australian bioenergy and energy from waste report accessed at http://www.cleanenergyfinancecorp.com.au/media/107567/the-australian-bioenergy-and-energy-from-waste-market-cefc-market-report.pdf).

2.2 Utilisation of biogas

The main use for biogas in Australia is for electricity production, heat and combined heat and power. Excess biogas is flared at WWTPs, agricultural industries and industrial food processing. This is due in part to uncertainty of quantity of biogas produced and associated sizing of generators.

Table 2.2 below shows how biogas is utilised across each of the categories for the 46 survey respondents. There are insufficient data at present to obtain a reliable % value for how the biogas is utilised and the associated quantity in terms of GWh.

Table 2.2: Utilisation of biogas in Australia (data from survey at end of 2016 – 46 respondents)*

Plant type	Electricity (%)	Heat (%)	CHP (%)	Flare (%)
Biowaste	40.0	20.0	20.0	33.3
Sewage sludge	33.3	26.2	21.4	19.0
Industrial	17.6	29.4	-	52.9
Agricultural	80			20

*No data for landfill

Australia does not use biogas for vehicle fuel *per se* and there are no biogas upgrading facilities. However, the use of biogas as a vehicle fuel is currently being explored by some industries.

2.3 Financial support systems

In Australia, there are limited financial support systems in place for biogas installations. National incentives include large-scale generation certificates (LGCs) which is currently at around $87MWh (Dec 2016). The Emissions Reduction Fund (ERF), launched in April 2015, is a voluntary scheme that aims to provide incentives for a range of industries to adopt new practices and technologies to reduce their emissions.

Direct on-site use of biogas energy provides the greatest financial benefit. Exports of electricity provide income, but with significantly lower dollar value than the savings associated with on-site energy use. This is because power purchase arrangements have been typically poor (4-8 Australian dollar cents per kWh).

The Clean Energy Finance Corporation (CEFC) (operating under the Clean Energy Finance Corporation Act 2012) provides loan support and financing instruments. In November, 2015 the CEFC announced a $100 million commitment to the Australian Bioenergy Fund to provide equity in addition to debt finance for bioenergy projects.2.4 Innovative biogas projects

2.4 Innovative biogas projects

Yarra Valley Water Waste to Energy Facility – Biogas production using commercial organic waste from local food markets and manufacturers

Yarra Valley Water is currently constructing a waste to energy facility next to the Aurora Sewage and Recycled Water Treatment Plant in Melbourne's north. The plant, which will be operational in 2017, will provide an environmentally friendly disposal solution to divert 33, 000 tonnes of organic waste per year from landfill. Businesses will also have access to an easier and more affordable way of recycling commercial organic waste. Commercial organic waste from local food markets and manufacturers will be processed into biogas via anaerobic digestion. It is expected that enough energy will be generated to run the facility and the neighbouring treatment plants. Any surplus energy will be exported to the electricity grid, helping to reduce greenhouse gas emissions, and Yarra Valley Water's reliance on traditional sources of electricity. While using food waste made co-digestion economically viable, the initiative was sparked by a paradigm shift: Yarra Valley Water already processed 75% of the regions waste – so why not expand into other waste streams? Instead of treating organics as waste, they are treated as a product with value.

Figure 2.1 Yarra Valley Water Waste to Energy Facility, Victoria – Commercial organic waste from local food markets and manufacturers

More information is available from [https://www.yvw.com.au/about-us/major-projects/waste-energy-facility.](https://www.yvw.com.au/about-us/major-projects/waste-energy-facility)

Oakey Beef Exports, Queensland –Biogas production from slaughterhouse wastewater

One of Australia's largest beef processing plants, Oakey Beef Exports in Queensland's Darling Downs region is using GWE covered, high-rate anaerobic lagoon system (COHRAL™) technology to replace up to 50,000 gigajoules natural gas a year to fire boilers to heat water for sterilising and rendering. Installed by CST Wastewater Solutions and commissioned in 2015, the technology is new to the Australian red meat processing industry. Unlike other covered anaerobic lagoon technology, it has a sub-surface membrane to prevent methane leaks and a unique waste water distribution and settling system which reduces water retention from 25 days to 15. A flexible storage system – one of the world's largest of its type - reserves biogas for peak operating demand. The project was entirely self-funded and did not attract support under former Federal government carbon abatement grants. Project research funding came partially from Australian Meat Processor Corporation (AMPC) & Meat and Livestock (MLA) Donor

Company as a Plant initiated Project. Current research funding from Queensland State Government in partnership with University of Southern Queensland is assisting in monitoring and process control.

Figure 2.2 Covered High Rate Lagoon Technology (COHRAL) Oakey Beef Exports, Queensland – producing biogas from slaughterhouse waste water (Photo courtesy University of Southern Queensland)

More information is available from [http://www.cstwastewater.com/oakey-beefs-spectacular-green-energy-orb-opens-the-way-to-environmentally-outstanding-and-profitable-performance/.](http://www.cstwastewater.com/oakey-beefs-spectacular-green-energy-orb-opens-the-way-to-environmentally-outstanding-and-profitable-performance/)

3. Austria

To meet the European Union 20-20-20 goals, Austria has to increase the amount of renewable energy to 34 % of total energy consumption. The Energy Strategy Austria envisages biogas to contribute to these targets by delivering electricity or biofuel. The focus lies on upgrading biogas to biomethane with two options. The first option is the addition of 20 % of biomethane to natural gas to reach 200,000 cars by 2020. The second option is increasing the amount of biogas produced to 10 % of the gas demand, which corresponds to 800 million Nm^3 biomethane annually in the country.

The renewable energy law foresees the construction of power plants to obtain an additional 100 MWe out of biomass by 2015. It must be mentioned that the energy strategy was set up in 2010 and is not an official statement of the current government. In the past few years prices for raw materials have increased tremendously and the plans to increase the amount of biogas plants have fallen behind schedule. Currently much effort is being invested to save existing biogas plants from bankruptcy. In November 2016 the prolongation of the feed-in tariffs had not been passed by the parliament. As a result, a certain number of plants are struggling to secure their future economic viability.

3.1 Production of biogas

Today the main production of biogas is derived from energy crops, sewage sludge and landfills (see Table 1). The annual biogas production corresponds to 1.5–2.5 TWh. Current trends are that high prices of biogas feedstock (e.g. maize) lead to severe difficulties to operate the plants economically. This has created a large interest to investigate the possibility to use alternative substrates. In total 368 biogas plants exist in Austria, but only 330 plants had a contract with OeMAG in 2015.

Table 1: Status of biogas production in Austria, contract with OeMAG (Ökostrombericht 2016)

Table 3.1: Status of biogas production in Austria, contract with OeMAG (data from 2013)

Plant type	Number of plants with electricity generation	Energy production (GWh/year)*
Waste water treatment plants and landfills	39	18.6
Agriculture and biowaste	291	558.9
Total	**330**	**570**

* = Produced energy as electricity excluding efficiency losses.
Source: Ökostrombericht 2016, Energie-Control Austria

3.2 Utilisation of biogas

In Austria biogas is utilised mainly for electricity and heat production. Even though the aim is to upgrade more biogas to biomethane for use as a vehicle fuel, this change is taking place rather slowly. There are around 10,000 natural gas vehicles (NGVs). The amount of NGVs in Austria increased from 2013 to 2014 by 12.5 % or 966 new vehicles. Now there are 172 compressed natural gas (CNG) filling stations. Three of the filling stations are situated at biogas upgrading plants.

Table 3.2: Utilisation of biogas in Austria (data from 2013)

Utilisation type	GWh
Electricity	570
Vehicle fuel	7 *
Flaring	13 *

* = installed capacity
Source: Ökostrombericht 2016; Franz Kirchmayr (Arge Kompost & Biogas)

There are 13 biogas upgrading units in operation. All commercial technologies are represented (amine scrubber, water scrubber, membrane and PSA). Most upgrading plants are rather small, 600-800 Nm^3/h, and have a combined capacity around 16.5 million Nm^3 biomethane annually.

3.3 Financial support systems

Support is provided for electricity production via the Green Electricity Law (Ökostromgesetz 2012).

Feed-in tariffs for 2013 are:

0.1950 EUR/kWh up to 250 kW_e,
0.1693 EUR/kWh from 250 - 500 kW_e
0.1334 EUR/kWh from 500 - 750 kW_e
0.1293EUR/kWh for higher than 750 kW_e
+ 0.02 EUR/kWh if biogas is upgraded
+ 0.02 EUR/kWh if heat is used efficiently

It is required that a minimum of 30% manure is used as a substrate to qualify for the feed-in tariff. If organic wastes are used, the feed-in tariff is reduced by 20%.

Older biogas plants, when subsidies are running out, can apply for an extended period of subsidies, up to a total of 20 years. Furthermore, a supportive measure for existing plants (built before 2009), of up to 0.04 EUR/kWh_e can be granted to assist with procurement of substrate.

Some investment grants exist, but they are dependent on local conditions.

Figure 3.1: Biogas plant in Strem nearby Güssing

3.4 Innovative biogas projects

IEE project FABbiogas – BIOGAS production from organic waste in the European Food And Beverage (FAB) industry

The European Food and Beverage Industry (FAB industry) is the second largest manufacturing sector in the EU 27 with a market share of 12.2% in value added terms. This sector generates a turnover of € 917 billion (14.5% of total manufacturing turnover) and employs 4.5 million workers (European Commission, 2009). The amount of residues generated in the manufacturing sector (FAB industry) is 5% of total food production (EUROSTAT 2006). The ongoing debate related to the Europe 2020 strategy about the availability of sustainable bio-energy resources and the food-or-fuel discussion have revealed the urgency of using untapped waste streams to produce energy. Anaerobic digestion of industrial waste provides a promising alternative to standard waste treatment. The motivation behind the project is to further expand supplies and trigger increases in the demand for biogas/bio-methane (CHP units, transport, grid injection) from the organic fraction of Food and Beverage (FAB) industry wastes. The EU project FABbiogas (Intelligent Energy Europe) project (from 04/2013-09/2015) aspires to change the mindsets of all stakeholders in the waste-to-energy chain by promoting residues from FAB industry as a new and renewable energy source for biogas production. Project outputs will support the diversification of energy sources within FAB companies, leading to wide-spread valorization and efficient integration of FAB residues into energy systems and boosting the realization of a growing number of biogas projects in Austria, Czech Republic, France, Germany, Italy and Poland.

Underground Sun Storage – storing energy from wind and solar power below ground

In most cases, energy from renewable sources lacks flexibility. Neither wind nor solar power can be controlled to meet actual energy demand. But the electricity grid cannot store energy, so grid operators have to adjust generation precisely to demand. If it were possible to store large amounts of power and inject it back into the grid when needed, generation would no longer be tied to demand. That is why huge energy storage facilities are essential in a world that relies on renewables. In nature, carbon and hydrogen have evolved as primary sources of energy, and the main substances in which energy is stored. Using electrolysis, excess energy generated from renewables is transformed into hydrogen, which can be stored in the natural gas network.

Storage of hydrogen produced using solar energy is being trialled at a small depleted gas reservoir in Pilsbach, Upper Austria. Energy from renewable sources that can be retained thanks to storage offers the only straight replacement for conventional energy – and Austria’s gas storage facilities provide the necessary infrastructure.

4. Brazil[5]

Brazil is recognised worldwide for the high share of renewable energy in its national energy matrix. In 2015, according to the national 10-Year Plan for Energy-2024, 42.5% of the internal energy supply originates from renewable sources, which includes hydro power, firewood and charcoal, by-products of sugar cane and other renewable sources (solar energy, wind power and biomass). According to estimates, this contribution is to increase to 45.2% of the internal energy supply by the year 2024, with the increase of other renewable energy sources from 4.8% to 8.1%.

Over past years various plants for the production and utilisation of biogas have been established in the country. In fact, this sector has been growing steadily. Helping this progress in the sector is the 2015 regulation for biomethane. It establishes a standard definition (a Normative Resolution) for biomethane produced from biodegradable materials originating from agroforestry and organic waste and the regulation applies to nationwide use of biomethane as a fuel for vehicles, commercial shipping and for residential use. The standard includes obligations regarding quality control to be met by the various economic agents who trade biomethane throughout Brazil.

In the COP 21, Brazil committed to reduce, by 2025, 37% of its greenhouse gas emissions, in relation to the levels of 2005. Subsequently Brazil agreed to reduce, by 2030, 43% of the greenhouse gas emissions, considering the same comparison basis. For such, the Energy Research Company/EPE (Empresa de Pesquisa Energética), an agency related to the Ministry of Mines and Energy, published a study called "Brazilian Commitment to Face Climate Changes: Energy Production and Use" frequently referring to biogas as one of the sources which jointly will achieve the mentioned goals. This represents one of the challenges of many sectors to include biogas in the Brazilian energy matrix.

4.1 Production of biogas

According to the Biogas National Registry (*Cadastro Nacional de Biogás*), maintained by the International Center on Renewable Energies – Biogás (CIBiogas), in the year 2015 there were 127 plants in operation in Brazil, with total biogas production of around 1.6 million Nm^3/day, or 3,835 GWh/year in terms of corresponding energy. The most utilised substrates were agriculture and industry residues, with percentages of 47% and 34%, respectively. However, the highest amount of biogas was produced in sanitary landfills, with 43% of the total.

*Table 4.1: Current biogas production in Brazil (data from 2015)**

Plant type	Number of plants	Energy production (GWh/year)*	%
Sewage sludge	7	199	5.2
Biowaste	8	32	0.8
Agriculture	60	1,096	28.6
Industrial	43	860	22.4
Landfills	9	1,648	43.0
Total	**127**	**3,835**	

* = Produced energy as electricity, heat, mechanical energy and vehicle gas, excluding efficiency losses.

[5] Report produced by: Leidiane Ferronato Mariani – PhD student at *Universidade Estadual de Campinas - Unicamp* and researcher at the International Center on Renewable Energies – Biogás; Marcelo Alves de Sousa – Manager of Institutional Relations of CIBiogas

The Energy Research Company - EPE (*Empresa de Pesquisa Energética*), an agency related to the Ministry of Mines and Energy of Brazil, has published studies regarding the technical potential of biogas in the country. In fact, estimated biomethane production for 2014 was approximately 18.5 million Nm^3/day, and 4,346 MW of installed electrical capacity (from only agricultural residues and urban solids). Another study referred to a projection of their economic potential (including sanitary sewage and industrial residues). It indicated that, considering the baseline scenario, the installed capacity of the biogas fuelled combined heat and power plants will amount to 458 MW in 2030 and 2,850 MW in 2050, or, in terms of corresponding biomethane, 2.33 million Nm^3/day and 15.25 million Nm^3/day, respectively. The estimated production of biomethane points to 5.78 million Nm^3/day in 2030 and 36 million Nm^3/day in 2050.

4.2 Utilisation of biogas

In 2015, 49% of the plants had heat generation as the main objective for biogas utilisation and 44% for electrical energy generation (Table 4.2). However, only around 31% of the total biogas produced in Brazil was utilised for heat generation, whereas electrical energy generation accounted for 65%. According to the Brazilian Electricity Regulatory Agency - ANEEL , in 2016 there were 29 biogas operated thermoelectrical power plants connected to the National Interconnected System - SIN (*Sistema Interligado Nacional)*, accounting for 118 MW.

The use of biogas for the generation of mechanical energy is widespread in Brazil due to the necessity for pumping the liquid slurry originated from the pig production facilities for the purpose of crop fertilisation, added to the availability of biogas from biodigesters installed in mid-2006 to provide for the Mechanism of Clean Development - a procedure contained in the Kyoto Protocol, but which was abandoned after the fall of the of carbon credit price. In 2015, besides the 6 plants that operated basically for such purpose, there were 19 other plants that applied part of their biogas production in the scheme. On the other hand, it has been estimated that there are hundreds of dispersed plants that still operate within the scope of the scheme; this creates difficulties in terms of data collection.

*Table 4.2: Utilisation of biogas in Brazil (data from 2015)**

Utilisation type	No. of plants	GWh**	%
Electricity	56	2,513	77
Heat	62	1,200	15
Mechanical	6	106	7
Vehicle fuel	3	16	< 1
Flaring	n.a.	n.d.	-

* = Categorized according to the main type of utilisation – a few cases of multiple applications
** = Calculated from the reported or estimated raw biogas production in volume (m3/y) and an assumption of 64 % CH_4 content.
Source: CIBiogas, 2015 (https://cibiogas.org/biogasmap)

There are 4 upgrading plants in operation in Brazil, 2 use scrubber upgrading techniques and 2 uses PSA. The biomethane produced is utilised to generate electricity and vehicle fuel. (Table 4.3)

There are two private filling stations for compressed biomethane, one in Parana and one in Rio Grande do Sul. There are 100 vehicles utilising biomethane in Brazil, 60 in Paraná and 40 in Rio Grande do Sul. The biomethane market in the country is still incipient, with some projects in planning or installation, but there is a great prospect of growth.

*Table 4.3: Biogas upgrading plants in Brazil (data from 2016)**

PLACE	SUBSTRATE	UTILISATION	CH4(%)	TECH-NOLOGY	PLANT CAPACITY (Nm3/h Raw gas)	IN OPERATION SINCE
Marechal Cândido Rondon, Paraná	Swine and dairy cattle wastewater	Electricity	> 96,5 %	Water scrubber	50	2009
Montenegro, Rio Grande do Sul	Codigestion - Laying hens wastewater; dairy, cellulose and citrus juices industry wastewater; and slaughterhouse wastewater	Vehicle fuel	0,97	PSA	500	2012
Santa Helena, Paraná	Codigestion - Laying hens and beef cattle wastewater	Vehicle fuel	> 96,5 %	PSA	42	2013
São Pedro da Aldeia, RJ	Landfill	Heat	97%	Water scrubber	1,200	2016

4.3 Financial support systems

The steady growth of biogas in Brazil results from a series of policies, research and initiatives directly or indirectly connected to this sector. They are described as follows:

Political grounds and Funding Sources

- **The National Policy on Solid Waste** points to the integrated management and the environmentally adequate management of solid wastes and ensures the adoption of initiatives related to biomass in energy production.
- **Sectoral Plan for the Mitigation and Adaptation to Climate Change for the Consolidation of a Low Carbon Emission Economy in Agriculture**: public policy that provides detailed descriptions of procedures for mitigation and similar activities in relation to climate change in the agricultural sector.
- **Normative Resolution n. 687/2015 that changes the Normative Resolution n. 482/2012 by the Brazilian Electricity Regulatory Agency – ANEEL:** establishes the general criteria for the access of micro and mini distributed generation to the systems of electrical energy distribution and the system of electrical energy compensation.
- **Resolution 08/2015 by the National Petroleum Agency - ANP**, which regulates the biomethane originated from organic agrisilvopastoral products and residues directed to vehicle application (CNG) and to residential and commercial facilities.
- **Program ABC - Program for Low Carbon Agriculture (*Programa Agricultura de Baixo Carbono*)**: Provides credit facilities for initiatives within the context of the Low Carbon Agriculture Plan, with resources for the treatment of animal wastes.
- **PRONAF Sustentável**: Credit facility for aspects concerning environmental sustainability for family agriculture with the application of credit resources from the National Program for Family Agriculture - PRONAF (*Programa Nacional para Agricultura Familiar*).
- **Auction A-5 ANEEL on electric energy:** For the first time a large-scale biogas project won an auction on energy generation, Auction A-5 (this means 5 years to start the operation), promoted by

ANEEL. The winner project is called Raízen, and trades 20.8 MW energy with the company Biogas Bonfim, representing BRL 251 per MWh. The substrate used to produce the biogas will be sugar cane industry effluent**.**

Actions by the private initiative, civil society and Research, Development and Innovation organizations

- **The Brazilian Association of Biogas and Biomethane – Abiogás:** (*Associação Brasileira do Biogás e Biometano*) was founded in 2013. It comprises public and private companies and institutions operating in different segments of the biogas chain. In 2015, ABiogas launched the proposal for a National Program of Biogas and Biomethane.
- **Biogas and Biomethane National Program – PNBB:** In the year 2015, the Brazilian Association for Biogas and Biomethane - ABIOGAS (*AssociaçãoBrasileira de Biogás e Biometano*) submitted the Proposal for a Biogas and Biomethane National Program - PNBB (*Programa Nacional de Biogás e Biometano*) for evaluation. The Plan aims at the creation of an institutional economic, normative and regulatory scenario that promotes the necessary favorable and stable conditions for the advancement of important projects for the sustainability of the Brazilian energy matrix.
- **The Brazilian Association of Biogas and Methane – ABBM:** (*Associação Brasileira de Biogás e Metano*) was established in 2013 and gathers together entrepreneurs, farmers, researchers and consultants. The pursuit of broader participation of biogas and biomethane in the energy matrix is one of its objectives.
- **Public Call 014/2012 - R&D by ANEEL:** Call for research and development projects on the biogas theme: "Strategic Project: Technical and Commercial Arrangements for the Insertion of Electrical Energy Generation with the use of Biogas originated from Residues and Liquid Effluents in the Brazilian Energy Matrix".
- **Rede BiogasFert** or Project "**Technologies for the production and utilisation of biogas and fertilizers with the treatment of animal manure within the scope of ABC Plan**" is a partnership undertaking involving EMBRAPA and ITAIPU. It gathers together researchers in the field of biogas and fertilizers from various universities and research institutions in the country.
- **CIBiogás-ER**, established in 2013, is an institution for research, development and innovation with the objective of transforming biogas knowledge into a product by means of the development of new business undertakings and their effective implementation in the Brazilian energy matrix.
- **Project Brazil-Germany for the Promotion of Biogas Energy Application in Brazil - PROBIOGAS:** The Brazilian Ministry of Cities (*Ministério das Cidades*) has implemented initiatives with the German Government, through GIZ (*Deutsche Gesellschaft für Internationale Zusammenarbeit*), for the application of biogas energy in Brazil. In 2016 this project made a publication on various studies compiling technical results obtained during its execution.
- **III Biogas Forum:** in October 2016 ABiogás organized an event with 336 participants registered to discuss the Brazilian biogas sector development. The event was considered the biggest one specifically on biogas in 2016**.**

4.4 Innovative biogas projects

CIBiogás/Itaipu Production Unit

The CIBiogás Demonstration Unit refers to the construction of an industrial complex for biomass treatment to produce biogas, which comprises: 10 m^3/day of Itaipu Binacional sewage, as well as 600 kg/day of their restaurants residues and about 1 tone of grass/daily. The biogas will be refined to produce biomethane to be used as gas to supply 20 kitchens in the Dam area, as well as to supply 63 cars in the ITAIPU Binacional vehicle fleet. The benefits are:

- Reduce costs with transportation and treatment of the kitchens organic residues;
- Reduce the sewage treatment station volume;

- Supply part the ITAIPU vehicle fleet with biomethane;
- Supply all the Dam area kitchens with about 30 m^3 of biomethane daily;
- Supply ITAIPU green areas with biofertilizers;
- Possibility to replicate the technology and offer data to universities research.

Besides the implementation CIBiogas will weekly monitor and follow up the power plant, with laboratory analysis. The power plant will be launched in February 2017.

Figure 4.1: Biomethane as a transport fuel (https://cibiogas.org/upcib)

There is a great potential to produce biogas with sugar cane effluents, such as vinasse and other residues. Nevertheless, by 2016 there were only 4 plants operating. In this context, the biogas plant erected in 2011 at the municipality of Tamboara, in Paraná state, is still considered innovative, since it is proving the technical and economic viability in this sector. The plant, that belongs to Geoenergética Company, uses 1,300 m^3/day of effluents, coming from Coopcana. In 2015 it produced 4,000 m^3/day of biogas, used to generate electricity to be sold to the free market. It has capacity to produce up to 4 MW, and is being improved, with R&D resources from Federal Government. The biodigester used is a circular one, made of concrete, with complete mixture.

Figure 4.2: *Geoenergética biogas facility* http://www.geoenergetica.com.br/

Entre Rios do Oeste

Entre Rios do Oeste is a municipality with 4,000 inhabitants, and 150,000 swine in its area. The swine residues became a big environmental problem, polluting ground, air and water. Facing this problem, CIBiogás presented a project to the Paraná Electricity Company/Copel, which decided to invest BRL 17 millions (equivalent to around U$ 5 millions) from R&D resources. The project will link 19 swine and poultry farms in the municipality through a 22-kilometer biogas pipeline, to guarantee the treatment of the animal waste by transforming it into biofertilizer and electricity, with the possibility of the producer to trade these products in order to generate additional income to the municipality. The project involves a partnership amongst Copel, CIBiogás and Itaipu Technology Park Foundation. The project execution started in August 2016, and will last 36 months.

5. Denmark

The "Green Growth" initiative, which formed the basis for a political agreement in June 2009, includes the objective that 50% of the livestock manure is to be used for green energy in 2020. This requires a significant acceleration of biogas deployment in Demark. In March 2012, the Danish Government entered a broad energy policy agreement, valid for the period 2012–2020. The agreement calls for a significant enhancement of the share of renewables in the Danish energy supply. The main aim is to make Denmark free from fossil fuels by 2050. Biogas is a key element in the 2012 energy agreement, which is dominated by wind energy.

5.1 Production of biogas

156 biogas plants were in operation in Denmark in 2015, corresponding to 6,4 PJ of energy (see table 5.1 and Figure 5.1 below). The increase is attributed to the breakthrough resulting from the Energy Agreement of 22 March 2012.

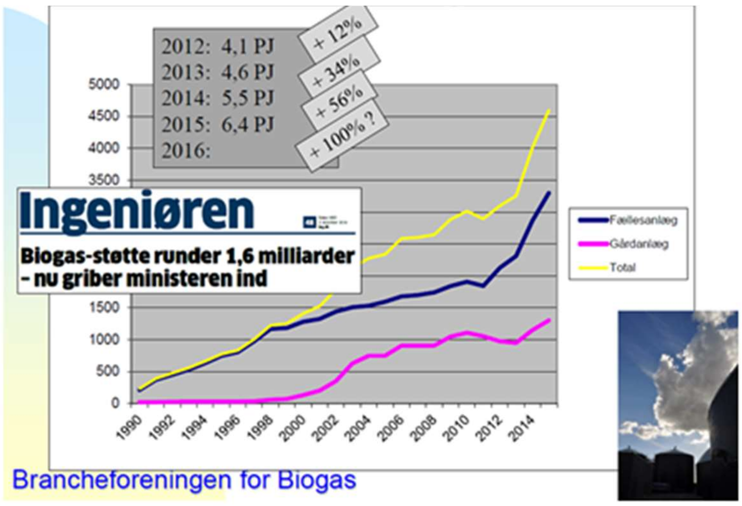


Figure 5.1: Biogas in Denmark 2015. Source: Sander, B., Danish Biogas Business Association, 2016

The most important role of biogas in the future Danish energy supply will be to balance the wind dominated electricity production. Furthermore, biogas will help convert the transport sector from fossil to "green" fuels.

Table 5.1: Current biogas production in Denmark (data from 2015)
Source: Danish Energy Agency/Personal correspondence with Søren Tafdrup, 2017

Substrate/Plant type	Number of plants	Production (GWh/year)
Sewage sludge	52	281
Biowaste	-	-
Agriculture	71	1367
Industrial	6	67
Landfills	27	48
Total	**156**	**1763***

* It is estimated that the Danish Biogas production has increased by 40-45 % during 2016-2017, compared to 2015. Gas up-grading is common for most of the plants (both new and old), with Amin wash as the dominating technology. The official statistics for 2016 will be available by the end of 2017.

A significant expansion of biogas capacity is a major challenge, as it requires finding suitable biomass feedstock, in sufficient amounts, to be co-digested with manure and slurry. This is because the available organic industrial waste is estimated to be depleted and that there are challenges with all other types of biomass, due to low potential, relatively high costs, or technological challenges to use in biogas plants. The potential of biomass to biogas is expected to be fairly stable until 2020. The amounts of manure and slurries are expected to decrease by approximately 5 %, while a slightly higher share of the total is expected to be supplied for biogas production. The available amounts of crop residues (straw, by-crops and crop silage) are also expected to increase. Co-substrates with high potential are deep litter, straw, source separated household waste, organic industrial waste and grass cover from natural areas. As stated above, the share of energy crops and by this their potential in the future deployment of biogas production in Denmark will be limited, due to sustainability considerations. The first priority will be to use the waste materials easily available, as pointed out by the Danish government in "Resource strategy - Denmark without waste" (2013).

Phosphorus limits – more environmental friendly consumption of phosphorus on the individual farms

It was noticed, that the current harmony rules lead to accumulation of 250 kg P / ha over 25 years. The rules were abolished from August 2017. The new rules give possibility of using a maximum of 170 kg N / ha from Livestock Manure (Nitrate Directive); Exemption for cattle farms with eco-friendly land use (230 kg N / ha from Livestock Manure). The new N-rules will worsen P-accumulation. The need to set up phosphorus limits for the supply of phosphorus by all kind of phosphorus fertilizers (commercial fertilizers, manure and other fertilizer types, such as sewage sludge) occurred. The new phosphorus limits vary between farms, depending on the type of farm, the crop rotation, the soil, the P- reserve on soils, the animal feeding practices etc. This means, that some farms will have higher limits than earlier, others will have lower. The exemption for the cattle farms means, that a specific farm can increase its harmonic demand from the normal 170 kg nitrogen per. hectare to 230 kg nitrogen per hectare, against the fact that the cattle breeder grows its fields more environmentally-friendly under certain strictly prescribed conditions. These conditions mean e.g. a crop rotation with a particularly high nitrogen uptake and a long growing season, for at least 70% of the farm's area. In addition, the farm must meet requirements of plowing down the nitrogen rich crops (leguminous) and of making laboratory tests of nitrogen and phosphorus content of the soil, every 4 years.

Table 5.2: New P-regulation from 2017

	2015	2017		2020		2022		2027	
	Gældende Harmonikrav	Generelt 76 pct.	Skærpet 24 pct.	Generelt 76 pct.	Skærpet 24 pct.	Generelt x pct.	Skærpet y pct.	Generelt w pct.	Skærpet z pct.
Fjerkræ / mink	45-55 / 43	45 43	30	40	30				
Slagtesvin	33,5	40 39	30	35	30				
Søer og smågrise	34 / 37	35	30	35	30				
Kvæg/får/geder	27 (kvæg)	30	30	30	30				
Undtagelsesbrug	36	35	35	35	35				
Organisk affald	30	30	30	30	30				
Overført husdyrgødning = biogasfællesanlæg	(1,4 DE)	Vægtet gennemsnit	30	Vægtet gennemsnit	30				
Gennemsnit	32,3	[36,3]	[30,7]	[34,8]	[30,7]				
Beskyttelses niveau	31,9	35,6 kg P/ha		34,3 kg P/ha		32 - 33 kg P/ha		30-31 kg P/ha	

Source: Sander, B., Danish Biogas Business Association, 2016

The main aim of the new P-regulation is to achieve an average decreasing P accumulation in soil (protection level) on long term (see Table 5.2 /*Beskyttelses niveau*):

5.2 Utilisation of biogas

In 2015 biogas was mainly used for power (66%) production. 17% was upgraded, and 16 % was used for heat production in Denmark.

The use of biogas as a transport fuel is growing rapidly, as there are environmental (air quality) and economic (cheaper than imported diesel) incentives. The number of filling stations increased to 16 in 2017 (+ 1 under construction). In 2017 there are 123 city buses, 115 heavy duty vehicles and 223 light vehicles, using CNG as fuel. There is no LNG used for transport in Denmark.

Table 5.3: Utilisation of biogas in Denmark (data from 2015)

Utilisation type	GWh	%
Electricity*	1,150	66
Heat	288	16
Upgraded	308	17
Flaring	<17	< 1

* = including heat losses
Source: Danish Energy Agency/Personal correspondence with Søren Tafdrup, 2017

5.3 Financial support systems

An improved financial support package for the biogas sector was adopted and approved by the EC in 2013. Removal of the restriction that the support cannot be given for both investments and operation was also approved by the EC in 2014.This consolidated the confidence in the future of biogas and consequently boosted the deployment of biogas in Denmark. The main elements of the Danish support system for biogas are:

- 0.056 EUR/kWh for biogas used in a CHP unit or injected into the grid (115 DKK/GJ).
- 0.037 EUR/kWh for direct usage for transport or industrial purposes (75 DKK/GJ)

These tariffs include natural gas price compensation of maximum 3.5 EUR/GJ (26 DKK/GJ) and temporary support of 1.34 EUR/GJ (10 DKK/GJ) up to 2016. It is also possible to apply for investment grants for plants digesting mainly manure. Support for upgraded biogas supplied to the natural gas network in calendar year 2013 was 111.6 DKK per. GJ. The support is payable to both upgraded biogas supplied to the natural gas grid and to purified biogas entering a town gas grid. This support is provided with effect from 1 December 2013. In the energy agreement, new support frames for biogas to transport and other applications were also agreed.

- 10.6 EUR/GJ in basis subsidy for combined heat and power heating (direct and indirect subsidies)
- 10.6 EUR/GJ in basis subsidy for upgrading and distribution via the natural gas grid
- 5.2 EUR/GJ in basis subsidy for industrial processes and transport

In addition:

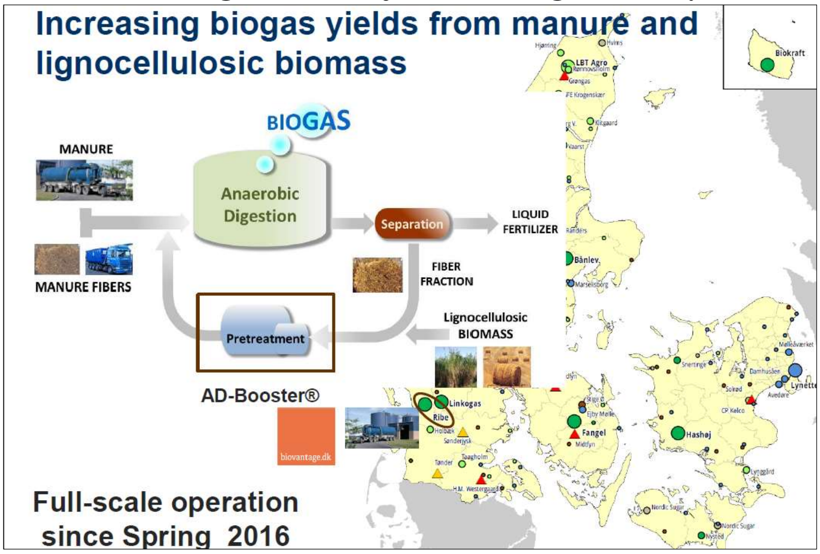
- 3.5 EUR/GJ for all applications – scaled down with increasing price of natural gas. If the natural gas price the year before is higher than a basis price of 7.1 EUR/GJ the subsidy is reduced accordingly.
- 1.34 EUR/GJ for all applications – scaled down linearly every year from 2016 to 2020 when the subsidy expires.

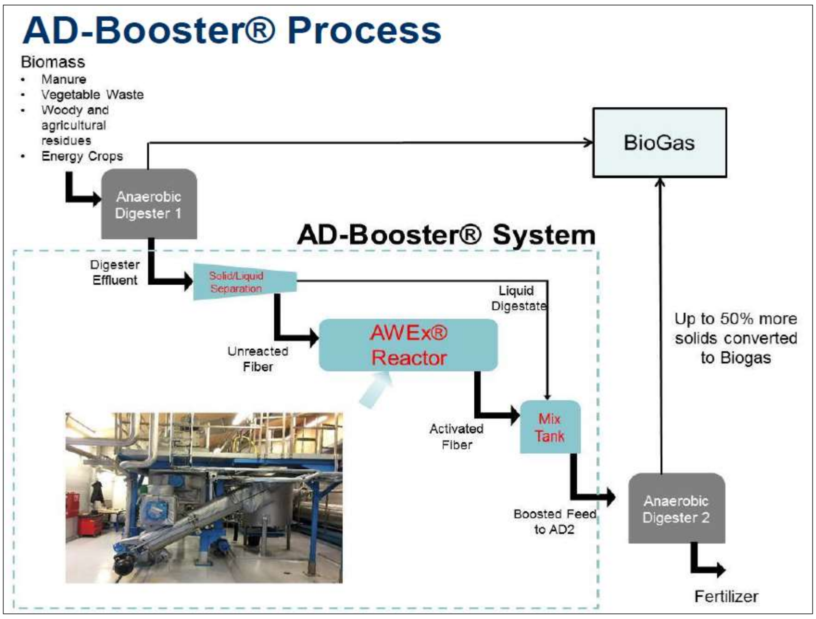
5.4 Innovative biogas projects

Demonstration of AD Booster system for enhanced biogas production

Source: Aalborg University: http://vbn.aau.dk/en/projects/demonstration-af-ad-booster-systemet-for-oeget-biogasproduktion(1039b817-8123-450d-b6bd-2d8c121bc97c).html

A demonstration project at commercial scale is on-going at Ribe Biogas Plant in Ribe, Denmark, aiming to prove enhanced biogas production by means of the AD Booster technology. The demonstration project is supported by private investors and by a grant from the EUDP Energy Technology Development and Demonstration Program. The involved partners are BioVantage, Ribe Biogas, Grontmij, and Aalborg University.





Source of pictures: Ullendahl, 2017

The primary focus of the technology demonstration is to confirm the laboratory and pilot results of the AD Booster process at a commercial scale, thereby opening the door to commercial application of the technology. The AD Booster system is operated in parallel with the existing biogas process, allowing direct comparison of process performance with and without the AD Booster system. The testing will confirm the process flow sheet, operating conditions, product yields, and overall operability of the system, thereby providing at-scale data for cost and performance modelling of commercial projects. Additional testing will be performed to demonstrate the ability of the AD Booster technology to increase methane yields from materials which traditionally have a low biogas yield due to the presence of high concentration of lignocellulosic polymers. This will be all from of straw, husk, woody waste as well as green waste. Success in this stage of the demonstration will open the door to economical biogas production using only lower-value feedstock, eliminating the need for food processing wastes and/or energy crops that are more costly and potentially limited in supply.

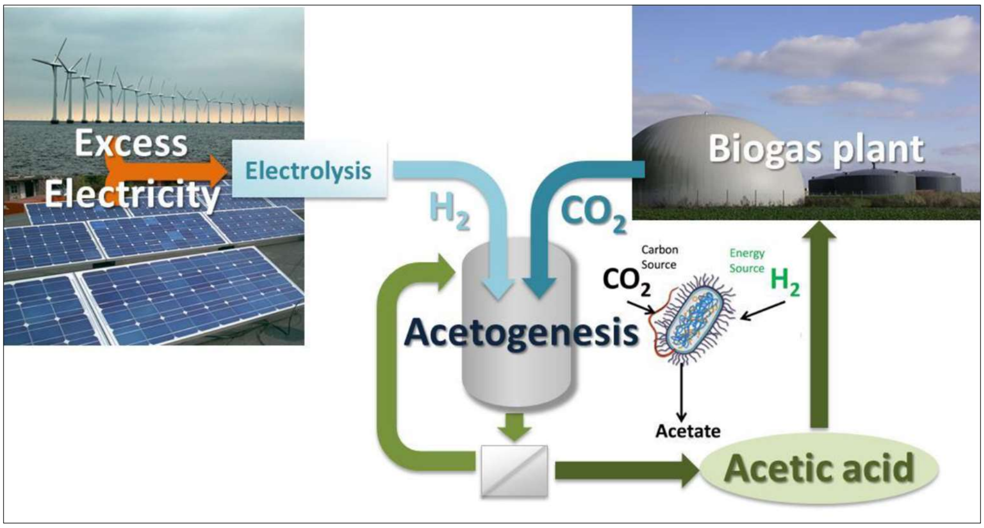
For more information about AD Booster, see also: https://energiforskning.dk/en/node/8347

XEL2Gas - Acetic acid as a storage molecule for excess electricity and its further conversion to biogas –proof of concept *Source: Energiforskning.dk* *https://energiforskning.dk/en/node/8419*

The XEL2Gas project aims at developing a smart, integrated, and robust biorefinery concept for long-term storage of surplus renewable electricity in the form of acetic acid. The energy storage involves biological conversion of hydrogen and carbon dioxide into acetic acid, which can be either stored or used as booster for biogas production.

Efficient conversion of electrolytically produced hydrogen into acetic acid and biogas can accommodate a significant amount of excess and fluctuating electricity, thus counterbalancing the unfavorable economy of peak production which is characteristic for contemporary wind and solar energy production. To ensure the lowest costs of converting surplus renewable electricity into acetic acid, integration with excess CO2 production from a biogas plant is proposed, aiming to also add economic benefits for the biogas plant.

The biological conversion of hydrogen and carbon dioxide into acetic acid is performed in a novel process using tailored microorganisms in an innovative modular bioreactor. The use of acetic acid as instant booster of biogas production will contribute to place biogas production as key technology for balancing fluctuating renewable energy production in the future.



Source of picture: Ullendahl, 2017

XEL2Gas develops long-term storage of excess renewable electricity by a biorefinery concept integrated with excess CO2 production. The concept involves biological conversion of hydrogen and carbon dioxide into acetic acid using tailored microorganisms and utilization of acetic acid for instant biogas production when needed

6. Finland

The government target in Finland is that about 10 % of gas used will be from biomass based gas, mainly SNG, by 2025.

6.1 Production of biogas

In 2015 the total recovered energy production from biogas was 630GWh from 84 different biogas production sites. Biogas production has slightly (ca 1.5 %) decreased since 2014. Although the production of biogas decreased, the utilization increased from 84.5 % to 86 %. Landfills continued to be the major gas producers.

Table 6.1: Status of biogas production in Finland (data from 2015)

Plant type	Number of plants	Energy production* (GWh/year)
Sewage sludge, municipal	16	148
Biowaste,codigestion	14	197
Agriculture	11	5
Industrial wastewater	3	4
Landfills	40	277
Total	**84**	**630**

* = Produced energy as electricity and heat excluding efficiency losses. [a]Vehicle fuel production 98 GWh should be added to total energy production. Source: Huttunen and Kuittinen, 2016, Suomen biokaasulaitosrekisteri n:o 19, University of Eastern Finland

It has been estimated that theoretically up to 4–6 TWh/year biogas could be produced from waste and manure, but there are no official targets for biogas production. The biogas yield from grass silage is about the same amount, but present use is negligible and there are no major investment plans for crop digesters. In 2015, about 20 co-digestion plants were under construction or in the planning phase. In addition, wood based bio-SNG production by gasification could significantly add to the gas supply in the future.

6.2 Utilisation of biogas

Biogas is mainly used for heat and electricity production in CHP plants located at the biogas production sites, or transported by pipelines for use in industrial processes. There are nine biogas upgrading units, and upgraded biogas is used as vehicle fuel or injected into the natural gas grid. The usage of biogas as an automotive fuel has increased 35 % compared to 2014.

Table 6.2: Utilisation of biogas in Finland (data from 2015)

Utilisation type	GWh	%
Electricity*	147	18
Heat	483	59
Vehicle fuel**	98	12
Flaring**	91	11

* = excluding efficiency losses; **not included in Table 6.1
Source: Huttunen and Kuittinen, 2016, Suomen biokaasulaitosrekisteri n:o 19, University of Eastern Finland

The ten operational upgrading plants are in most cases using water scrubbing technology, except two, one using membrane technology, and the newest one using PSA technology. There are 24 public filling stations for biomethane/CNG and three private fuelling stations in operation, mainly in the southern part of Finland. A few biogas upgrading and filling stations also exist outside the grid. The share of biomethane in the methane/CNG mix sold for transportation was approximately 30 % in 2015. In total about 1,900 gas vehicles were in operation in August 2015. Liquefied biomethane (LBG) is not used in transportation in Finland, but some LBG is exported. The first public LNG stations are under planning review in four locations in Finland. On energy basis, the price of biomethane is about half that of petrol.

6.3 Financial support systems

The Energy Market Authority of Finland supports new biogas plants, which produce more than 100 kVA, with a feed-in tariff. It guarantees a minimum price of 83.5 EUR/MWh for electricity, but when the combined capacity of the generators exceeds 19 MVA no subsidy is paid. If the generated heat is utilised, 50 EUR/MWh heat premium on top of basic subsidy is paid, provided that the total efficiency is at least 50% or at least 75% if nominal generator capacity exceeds 1 MVA. In the feed-in tariff system, an electricity producer whose power plant is approved in the system will receive a subsidy (feed-in tariff) for a maximum of twelve years. The subsidy varies on the basis of a three-month electricity market price or the market price of emission allowances. These subsidies are paid up to the amount confirmed in the acceptance decision. When the price of electricity is below 30 EUR/MWh, the subsidy to be paid amounts to the target price less 30 EUR/MWh. A subsidy is not paid when the price of electricity is negative.

Feed-in-tariffs have been applied since March 2011 and since then 170,000 EUR has been paid for biogas production (two plants) while during the same period 84.4 million EUR has been used for wood based bioenergy and 56.5 million EUR for wind energy.

Investment grants are paid by the Ministry of Employment and Economy to biogas plants which produce energy and do not meet the requirements of feed-in tariffs, but this kind of grant is not meant for residential buildings, farms or plants connected to the above-mentioned installations. A maximum of 30% of acceptable investment costs are supported provided that there is still money available in the budget for the investment year. The Ministry of Agriculture and Forestry supports biogas plants built on farms aiming at producing their own electricity and heat. More than half of biomass must be from their own farm and more than 50 % of the energy produced must be used by the farm. Part of the support is money and part of it is loan.

Finally, there is no excise tax on biogas.

6.4 Innovative biogas projects

Kalmari biogas plant has been in continuously running since 1998. Plant has been updated during the years and the capacity has been increased. Since 2015 main energy has come from dry fermentation plant (batch process) which uses grass, silage, straw, horse manure and wood chips as biogas raw-material (Figure 6.1).

Figure 6.1. Dry fermentation process at Kalmari farm.

7. France

The vision of the French Environment and Energy Management Agency is to produce 70 TWh biogas annually by 2030 and that 600 biogas plants will be built every year. 50% of the biogas produced shall be injected into the grid, 30% shall be used to generate electricity and the remaining 20% shall be used to produce heat. In 2050, the aim is to produce 100 TWh.

7.1 Production of biogas

In France there are almost 450 biogas plants and 240 landfills. Only 113 of the 240 landfills are valorising the biogas (see Table 7.1). The number of farm AD plants is expected to double or triple by the end of 2020.

Table 7.1: Status of biogas production in France (data from 2015)

Plant type	Number of plants	Electricity production (GWh/year)	Heat production (GWh/year)	Biomethane (GWh/year)
Sewage sludge	88	41	401	
Biowaste from MSW	16	67	22	
Industrial	80	7	350	
On-farm and centralized plants	267	624	545	
Landfills with biogas valorization*	113	953	294	
Total	**564**	**1,692**	**1,612**	**215****

* source ADEME : ITOM, les installations de traitement des ordures ménagères en France – Résultats 2010, octobre 2012; ** Le panorama du gaz renouvelable 2016, SER 2017.

A recent study financed by ADEME on *The estimation of feedstock for AD use* shows that the potential resources for AD will give a probable potential of 56 TWh by 2030. Based on its own calculation, an estimation of ADEME expects a theoretical production of 70 TWh by 2030.

7.2 Utilisation of biogas

In France there is a strong development of on-farm and centralized biogas plants and for landfills to recover biogas for electricity generation (today only 113 out of 240 landfills utilise biogas). Around 267 on-farms AD plants were built by the end of 2015 along with 31 centralized units. In addition, 88 WWT and 80 agrofood industry AD plants are currently operating. 16 MSW AD plants were in operation in 2015.

Regarding Table 7.1, 49% of the energy recovered is transformed into electricity, 43% into heat and close to 8% into biomethane.

At the end of 2016, 29 upgrading plants were in operation, whereof 26 injecting biomethane into the natural gas grid, producing 215 GWh of green gas, for a total power of 400 GWh/y. Today, all the biomethane produced is injected into the natural gas grid or sold in the compressed state as automotive fuel. There are more than 400 applications for injecting biomethane into the natural gas grid, which indicate a significant increase of the number of upgrading plants soon. The French gas operators are expecting an additional 170 new projects over the next five years, producing 4 TWh at a capacity of 46,000 Nm^3/h injected into the grid. The governmental plurennial energy programming (PPE) speaks of 8 TWh of biomethane injected into the natural gas grid by 2023.

There are more than 13,500 vehicles, including 3,500 trucks, in use in France (265,000 Nm^3/day consumption). There are 60 public filling stations[6] and around 130 private filling stations (2012 data). Most of public stations offer now bioGNC (biométhane fuel) by using the system of guarantees of origin.

7.3 Financial support systems

In France and its overseas territories, there is a feed-in-tariff system for electricity produced from biogas with the following properties (energy efficiency bonus and manure bonus included, tariffs revised yearly, values of 2015):

0.8652 to 0.11422 EUR/kWh_e for landfills
0.1192 to 0.227 EUR/kWh_e for AD plants

There are also upgrading tariffs as follows:

45 to 95 EUR/MWh for biomethane from landfills (depending of volume, values of 2011)
65 to 134 EUR/MWh for biomethane from WWTP sludge (depending of the volume injected and the age of the WWTP); a specific tariff has been published in June 2014);
69 to 125 EUR/MWh for upgrading the biogas to biomethane from AD plants (depending of volume and the nature of the feedstock, values of 2011)

Some subsidies are possible via the French Agency for Environment and Energy Management through two financial funds: the Waste Fund and the Renewable Heat Fund. So the subsidies depend on the nature of the investment and limited in amount or by the percentage of aid.

Other subsidies can also be applied, including regional (Regional Councils) or European (FEDER) funds.

Figure 7.1: Biogas unit in Sourdun, France, owned by Létang Biogaz Co. The plant produces biomethane from energy crops and agricultural wastes. The biomethane is injected into the local NG grid.

[6] source https://gnv-grtgaz.opendatasoft.com/pages/dashboard_v3/?headless=true#carte, 2017

Figure 7.2: Biomethane unit in Chaumes en Brie, France, owned by Bioénergie de la Brie Co. The plant use various products from agro food biowastes and manures. The grid injected biomethane supplies 5 nearby communities

8. Germany

The share of renewable energies in total energy generation is to be raised to 40-45% by 2025, to 55-60% by 2035, and to 80% by 2050. The reform of the Renewable Energy Sources Act (EEG) should play a key role in the success of the energy reforms. The introduction of specific growth targets for different technologies is a new development for the German renewables support scheme. The annual growth of biomass including biogas is limited to a maximum of 150 MW compared to 2,500 MW for onshore wind and solar power. The overall system is about to change and will be carried out in the future in the form of an auction model.

Furthermore, the clean air guideline (TA LUFT) is about to get amended. Here regulations for open digestate storage and thresholds for methane and formaldehyde emissions from CHP units are the most important changes for biogas plants which are discussed.

Strategy papers released at the end of 2016 from the Ministries for Economic Affairs and Energy as well as the Ministry for the Environment, Nature Conservation, Building and Nuclear Safety state a clear shift for the biogas sector in regards of substrates and energy utilization beyond the period of the EEG (in particular beyond 2030). Substrates shall be mainly waste materials and by-products, the energy should be used increasingly in the transportation sector. However, until 2030 energy provision from CHP shall even increase slightly. Details for the management of the necessary transition are not given.

8.1 Production of biogas

Table 8.1: Status of biogas production in Germany (data from 2016, year of reference 2015)

Substrate/Plant type	No. of plants	Energy production [7]* (GWh/year)	
		Gross electricity**	Gross heat[8]
Sewage sludge	1,252[9]	1,389	2,022
Biowaste	333[10]	1,294	551
Agriculture	8,000	31,097	13,225
Biomethane	187 [11]	2,599	2,924[12]
Landfills	440[13]	396	129
Total	**10,212**	**36,775**	**18,851**

* = Fuel not included; ** = excluding efficiency losses

[7] Federal Ministry for Economic Affairs and Energy (BMWi): Development of Renewable Energy Sources in Germany based on the data of the Working Group of Renewable Energy Statistics (AGEE-Stat), December 2016. (http://www.erneuerbare-energien.de/EE/Redaktion/DE/Downloads/zeitreihen-zur-entwicklung-der-erneuerbaren-energien-in-deutschland-1990-2015.pdf?__blob=publicationFile&v=11, accessed on 21.01.2017)

[8] Heat utilization (external heat purposes excluding heat demand for biogas production); heat production from biogas and biomethane (without sewage sludge and landfills) in 2015 16.7 TWhth in total (AGEEstat 2017); from biomethane-CHP according BNETZA; heat from biogas according to ratio of waste/agricultural plants

[9] Federal Statistical Office (destatis): (https://www.destatis.de/DE/PresseService/Presse/Pressemitteilungen/2016/07/PD16_266_433pdf.pdf?__blob=publicationFile, accessed on 21.12.2016)

[10] Substrate input of 133 plants ≥ 90% of biowaste of the whole input amount per year (according to §27a EEG 2012, §45 EEG 2014); biowaste is defined as separate collected municipal waste (e.g. kitchen waste, green cut); about 200 co-fermentation plants with substrate input < 90% of biowaste including plants using agro-industrial waste.

[11] Biogas plants with upgrading technology to produce biomethane based on energy crops or energy crops in combination with manure.

[12] Heat production resp. heat utilization from biomethane CHP; electricity production from biomethane according to BNETZA; estimation heat production: electrical efficiency 40%, thermal efficiency 45%.

[13] Federal Statistical Office (destatis): (https://www.destatis.de/DE/ZahlenFakten/GesamtwirtschaftUmwelt/Umwelt/UmweltstatistischeErhebungen/Abfallwirtschaft/Tabellen/AE_Verwendung_Deponie_Biogas_2014.html, accessed on 21.12.2016)

The biogas production figures are roughly the same as given in the 2015 summary. However, because of the change to regulations within the 2014 and 2016 EEG, limitation of growth rate and the contribution of biogas in the energy supply will diminish. The 8,000 biogas plants in the agriculture sector make the biggest contribution to biogas production in 2015 with electricity and heat supplies of 31TWh/year and 13.2 TWh/year, respectively (Table 8.1).

In 2016 a total number of 196 biogas upgrading plants were in operation with a feed-in capacity to the gas grid of 115,400 m^3_{STP}/h biomethane (DBFZ, 2016) with a marginal increase in capacity of 3 % compared to the previous year, delivered by 9 new plants. It is evident that the negative trend suggested by the 2014 EEG reform started to manifest itself, which has consequences also for the sales markets for biomethane.

Based on data from the Fachagentur für Nachwachsende Rohstoffe e.V. (FNR) and the Deutsches Biomasseforschungszentrum (DBFZ), the technical primary energy potential for biogas production in 2020 (Status 2014) amounts to 123 TWh/year with the following proportions: biogas crops from arable land 94 TWh/year, animal manure 19 TWh/year, municipal wastes 7 TWh/year and industrial wastes 3 TWh/year. About 94 TWh/year (76%) of this potential was used in 2015.

8.2 Utilisation of biogas

According to information from the Federal Ministry for Economic Affairs and Energy (BMWi) , in 2015 most of the biogas was used for electricity and heat production, while biomethane utilisation as a vehicle fuel dropped by 9% in comparison to 2014 (Table 8.2). The share of energy consumption in Germany for electricity, heat and fuel amounted to 5.6%, 1.6% and 0.1%, respectively.

Table 8.2: Utilisation of biogas in Germany (data from 2016, year of reference 2015)

Utilisation type	GWh/year	%
Electricity*	36,775	61
Heat	18,851	31
Vehicle fuel	385	1
Flaring**	4,379	7

* = excluding efficiency losses

** = estimation, 5 % flaring losses for all types of production but landfill (10 %)

Source: Federal Ministry for Economic Affairs and Energy (BMWi), as to 08/2016

According to the 4th progress report of the Initiative for natural gas-based mobility[14], the number of filling stations offering biomethane (partly or up to 100%) declined from 293 to 251 in 2015 (data from 05/2016). The amount of biomethane is accounted for 0,46 TWh which corresponds to 20 % of the whole amount of natural gas sold in 2015 as a vehicle fuel.

8.3 Financial support systems

The amendment of the Renewable Energy Sources Act (EEG) 2017, which will enter into the force on 1.1.2017, stands for the switch from feed-in tariffs models as applied in the previous EEG versions 2000 – 2014 to the auction models for renewable energies. Beside on- and off-shore wind and PV facilities the newly built biogas plants with an installed electrical capacity of more than 150 kW_{el} as well as already existing biogas facilities can participate in auctions. The existing biogas plants can bid in order to receive the follow-up 10-years funding only by compliance with the flexible operation. The development corridor

[14] German Energy Agency (dena): Sustainable mobility based on natural gas and biomethane. Market development 2015/2016. Fourth progress report, 2016. (http://www.erdgasmobilitaet.info/service-und-aktuelles/downloads.html, accessed on 22.12.2016)

initially introduced within the EEG 2014 was further specified and is defined as following for two time periods:

- from 2017 till 2019 – 150 MW_{el} of the installed biomass capacities and
- from 2020 till 2022 – 200 MW_{el} of the installed biomass capacities can be auctioned each year.

Accordingly, plants have to participate successfully in tendering procedures to qualify for their funding in the scope of the EEG. The first tender for biomass will take place in September 2017. Outside of the tenders, small manure plants can additionally be built, because they kept their special role with their own tariff structure as determined by EEG 2014. Furthermore, plants with an installed capacity of up to 150 kWel are free to decide whether they will take part in the tenders or make use of the tariff.

Existing plants and recently installed plants can apply for tenders equally. There are no longer distinctions concerning the type of biomass used. This implies that biogas plants are directly competing with wood-fired CHP[15]. To further incentivize a flexible electricity generation, prospectively, not more than a half of the maximal possible rated power will be remunerated for biogas and biomethane plants. Thus, it is necessary to install at least a twofold CHP overcapacity in relation to the average rated power output.

Moreover, a cap for maize input is determined in the EEG 2017. The utilisation of maize silage and also of cereals is limited to maximal 50 % (mass based). The maize cap is going to be lowered further in the future; it will be decreased to 47 % in 2019 and to 44 % in 2021[16]. However, all other measures to steer the utilization of substrates (e.g. bonus for manure utilization, classification of substrates) or environmentally desired components (e.g. obligation for heat utilization) introduced in older versions of the EEG have been abandoned.

8.4 Innovative biogas projects

For reaching climate protection targets it is essential to quantify the emissions from greenhouse gas emitting sources. The results enable to determine the environmental impact of a technology and to gain knowledge of the value of emission mitigation strategies. Biogas plants emit methane. Known major sources are leakages, pressure relief vents, gas utilisation devices and open storage tanks. To date, no common European standard is established to measure the overall emission rates of methane from biogas plants. The objective of the project “European harmonisation of methods to quantify methane emissions from biogas plants (MetHarmo)” is to harmonise some first national approaches to quantify the emissions to a common procedure. The project started with a European workshop on methane emissions from biogas plants targeting at an overview on the state of the art. The second step is to perform two common measurement campaigns on a biogas plant with teams from all participating European countries. The evaluation of the results aims the evaluation of differences between the various techniques and further a harmonisation of similar methods or transferability of results between different methods. This shall result in a practical guideline recommending methods and giving assistance for the comparability and weighting of results gained with different techniques.

[15] Daniel-Gromke et al. 2017, Current Developments in Production and Utilization of Biogas and Biomethane in Germany, CIT accepted
[16] Daniel-Gromke et al. 2017, Current Developments in Production and Utilization of Biogas and Biomethane in Germany, CIT accepted

9. Norway

The main energy sources used in Norway are petroleum and hydropower. Close to 60% of the energy consumption in Norway is based on renewable sources, mainly hydropower and wood.

In a report to the Storting (Parliament) (St.meld. nr. 34 (2006-2007)) a national goal to increase the amount of energy from biomass has been set. Underlying this goal is the recognition that increased use of bioenergy will reduce the emissions of GHG and local pollution, and at the same time reduce the nation's dependency on petroleum and virgin sources of plant nutrients.

A national strategy on increased development of bioenergy was presented by The Ministry of Petroleum and Energy in 2008. This strategy suggests a conservative estimate of 14 TWh available bioenergy that can be realized annually by 2020.

Energi21 - A collective R&D strategy for the energy sector in Norway (www.energi21.no):
The Energi21 strategy sets out the desired course for research, development and demonstration of new technologies for the 21st century. The strategy has been revised at the request of the Ministry of Petroleum and Energy as part of the effort to boost value creation, facilitate energy restructuring with the development of new technology and to cultivate internationally competitive expertise.

According to the Report to the Storting No 39 (2008–2009), 30% (4–5 million tonne/year) of manure is to be used for biogas production together with 600,000 tonne of food waste (i.e. approximately 60% of available food waste) by 2020. The main incentive for this goal is to reduce emissions of GHG from agriculture by 500,000 tonnes of CO_2 equivalent. The Norwegian government presented a national sector-spanning biogas strategy in October 2014. The strategy claims that biogas is an instrument that will contribute to a national reduction of emissions by 2020 and to the objective that Norway shall be a low-emission society by 2050. A considerable technical potential for production and use of biogas has been identified, but high costs are challenging. To increase production and use of biogas, the government aims to stimulate technology development and reduce costs. The new biogas strategy presents instruments within:

- Research and development, and pilot plants
- Incentives for increased production and use of biogas
- Incentives to increase supply of feedstocks
- Incentives to ensure information dissemination

9.1 Production of biogas

Theoretical potentials: Sewage sludge (350 GWh), Food waste (635 GWh), Agriculture (2180 GWh based on manure), Industrial (no estimates, important industries are pulp and paper, fish farming and food industry). Fish farming is probably several thousand GWh; the first small plant was established in 2015. Landfilling of organic material is banned and thus the potential will be reduced.

The realistic potential for biogas production is estimated to be 2.3 TWh in 2020: 32% from manure, 22% from industry waste, 14% biowaste from households and 7% biowaste from catering and trade, 12% landfill, 7% straw, 6% waste water sludge. (The Norwegian Environment Agency, 2013. Report TA3020)

Table 9.1: Status of biogas production in Norway (data from 2015)

Substrate/Plant type	Number of plants	Production (GWh/year)*
Sewage sludge	26	222
Biowaste (food waste)	13	95
Agriculture	5 (1 larger)	43
Industrial	2	n.d.
Landfills	85	270
Total	**131**	**min. 630**

* = produced raw biogas expressed as its energy content from the different plant types

9.2 Utilisation of biogas

In Norway electricity prices are quite low and thus on economic grounds there is no incentive to generate electricity from biogas. Gas from landfills and smaller plants is usually used for heat production, and in only a few cases for the production of electricity. During recent years, in line with the Norwegian biogas strategy, almost all new plants upgrade the biogas to vehicle fuel quality. Statistical data on the utilisation is not complete, see table 9.2

Table 9.2: Utilisation of biogas in Norway (data from 2014)

Utilisation type	GWh	% (ca)
Electricity	42*	10
Heat	174*	30
Vehicle fuel	250	40
Flaring	-	

* = excluding utilisation in industry

In Norway there are 25 filling stations for compressed biomethane, 6 in the Stavanger region and 19 in the Oslo region. Some of these are combinations of CNG/biomethane. There are also plans to establish filling stations for biomethane in Trondheim and Bergen. Today, several buses use CNG in Trondheim and Bergen.

The market for biomethane use as vehicle fuel is expected to grow, but not so much as earlier expected due to more and more cars using electricity. Most of the increased biogas produced will be used as vehicle fuel.

Today almost 1,000 vehicles, including approximately 400 buses run on methane (NGVA Europe statistics 2013).

There are 8 upgrading plants in operation in Norway. Seven use scrubber upgrading techniques, one uses membrane (Dutch membrane producer). There is one that produce LBG. There could have been a more developed market for LNG powered heavy transport if the methane diesel technology (dual fuel) would have been commercially available.

Table 9.3: Norwegian upgrading plants

Plant	GWh delivered	Tech-nology	Year started	Substrate	Raw biogas treatment capacity
1	-	Amine	2010	Sludge	600
2	45 (planned)	Water (LBG)	2013	Food waste	1,100
3	20	Amine	2001 2008 2013	Sludge/ Food Waste	600
4	18	Membrane	2014	Food Waste	400
5	70 (planned)	Water	2015	Manure/ biowaste Food waste	1,200
6	25	Water	2015	Food waste	
7	17	Amine	2015	Sludge/ biowaste Food waste	700
8	60	Amine	2016	Sludge/ food waste	1,200

9.3 Financial support systems

The two most important incentives for increasing the supply of substrates are the landfill guidelines that banned landfilling of biodegradables from 2009, and that for each tonne wet weight of manure treated in a biogas plant a payment of NOK 60 (6.50 EUR) is made. The latter is an action taken to fulfil the Norwegian strategy (Storting No 39 2008 – 2009), with the goal to have 30% of Norway's manure treated by 2020.

To stimulate production of biogas, different schemes for investment aid are available, depending on plant size. Generally investment grants of about 30% are given, the limit accepted by EEA – The European Economic Area Agreement, but up to 50% is allowed in special pilot plant/research projects.

End-use of biogas as electricity is eligible for green certificate system, but the benefit is small and fluctuates since it is market-based, so together with the low electricity price this is not a real option for biogas producers. More interesting is upgrading the biogas and taking benefit of the tax exemption when used as automotive fuel. Natural gas use as vehicle fuel on the other hand will from 2016 no longer be exempt from tax.

9.4 Innovative biogas projects

Increased biogas yields through hyperthermophile hygienisation (The HTE-process)

Hyperthermics Energy AS[17], have established the first full scale biomass pretreatment unit at the biogas plant at Lindum in Drammen. The unit operates at 80 ºC and is incubated with H_2 producing hyperthermofilic organisms, for example strains of the *Thermotoga Maritima* family.

[17] http://www.hyperthermics.com/

Laboratory tests have shown significant increase in the energy yield obtained from organic waste and other biomass by introducing hyperthermophilic (HT) fermentation as pretreatment (hygienisation step) to a biogas process. In addition to H_2, the fermentation process produces organic acids and alcohols, all good substrates for the following biogas process.

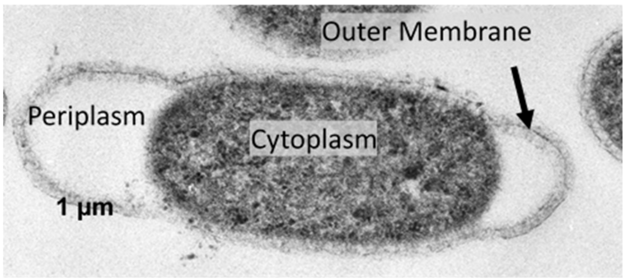


Figure 9.1: Thermotoga Maritima

The full scale plant has an annual design capacity of 10,000 tons of food waste and will be operational during the second half of 2016. In addition to regular production, the installation will be used as a full scale research infrastructure to test different substrates as well as biohydrogen production.

Biokraft Skogn (http://www.biokraft.no/)
This new industrial biogas plant will use bi-products from Norwegian marine industries combined with waste from the pulp and paper industry at Skogn, as well as other industrial wastes and bi-products.

Groundwork commenced on Biokraft Skogn biogas plant in the autumn of 2015 and the build has been finished during 2016, but will first be ready for production late in 2017. The plant will initially produce 12.5 million Nm^3 of LBG. However, the plant will be prepared for a doubling of capacity up to 25 million Nm^3. The plant's location at Skogn gives logistical advantages, being reachable directly by road, rail and boat.

Figure 9.2: Biokraft Skogn, new biogas plant with LBG production

Biokraft AS has a significant R&D initiative supported by the Norwegian Research Council that aims to develop innovative solutions for recycling of nutrients from biogas production and complete exploitation of resources and biological CO_2 capture and reutilisation. The primary shareholders in Biokraft AS are Scandinavian Biogas Fuels AB and TrønderEnergi.

10. Republic of Ireland

The biogas industry has not yet taken off in the Republic of Ireland. There are a number of reasons for this, including the relatively low level of renewable energy feed-in tariff (REFIT) as compared to that available across the border in neighbouring Northern Ireland. This has led to a situation whereby biogas developments are more profitable north of the border and as such developers are more likely to be based north of the border.

A Government Bioenergy Strategy is due to be released. It is hoped (and expected) that this will include targets or strategies for increased biogas production, for biomethane grid injection and for use of biomethane as a transport fuel.

10.1 Production of biogas

The exact number of biogas plants in the Republic of Ireland is hard to access in detail. Many wastewater treatment facilities have digesters but as they are in private ownership the data is somewhat hard to collate. The main use of biogas produced in waste water treatment plants is the production of heat and electricity in onsite CHP units, and the thermal drying of dewatered digestate to produce a high grade biofertiliser. There are approximately 8 landfill gas projects and 14 industrial facilities including those for wastewater sludge treatment. The Irish Bioenergy Association (IrBEA) state that there are numerous other facilities at an advanced state of desktop development. Cre (Composting and Anaerobic Digestion Association of Ireland) provided the data on landfill and wastewater facilities in Table 10.1.

Table 10.1: Biogas production in the Republic of Ireland (data from 2015)

Plant type	Number of plants	Installed capacity
Sewage sludge	14	n.d.
Biowaste		
Agriculture	9	3.9 MW_e
Industrial	4	
Landfills	8	29 MW_e
Total	**35**	

Source: Cre and IrBEA, according to latest available data

The facilities at present are dominated by provision of electricity and/or heat. This is reflective of the REFIT scheme. However there is a viewpoint that if the biogas industry is to take off in the country it is likely to require gas grid injection to facilitate better returns on the biogas produced. The biofuel obligation certificate (BOC) system operated by the National Oil Reserve Agency (NORA) allows for payment of three certificates to producers of gaseous biofuel with an energy value in excess of 35 MJ/Nm^3 if produced from residues or from second or third generation substrates and used for transport fuel. The certificates trade at a price that reflects the difference between 1L of diesel and 1L of biodiesel. It is very likely that the return on biogas as a transport fuel is superior to the return on electricity from biogas.

A decision paper by the Commission for Energy Regulation (CER) in Ireland has granted Gas Networks Ireland (GNI), the operator of the Irish gas network, funding of €12.8m to install 13 CNG service stations in Ireland to reduce emissions from transport and facilitate gas grid injection of biomethane[18]. A total network of 70 Compressed Natural Gas (CNG) filling stations, distributed on sites around the country,

[18] http://www.cer.ie/docs/001107/CER16313%20GNI%20CNG%20Funding%20Request%20CER%20Decision%20Paper.pdf

has been proposed by GNI. As many as 20,000 HGVs and 12,000 buses are being targeted to switch. Each station would be developed at a cost of around €1m each. Six CNG service stations are due to be built by the end of 2017. GNI in a 2015 publication "Network Development Plan: assessing future demand and supply position" (http://www.gasnetworks.ie/) proposes a target of 5% substitution of natural gas in the grid with green gas by 2020, rising to 20% by 2030. This reflects interest from large users of natural gas in sourcing green gas to be used as a source of renewable heat and as a renewable transport fuel[19].

A Bord Gais report[20] suggests that a realistic biogas industry could be based on 5% of cattle, pig and sheep slurry, 75% of poultry slurry, 50% of slaughter waste, 25% of food waste and 100,000 ha of grass land (2.2% of agricultural land). The report suggests that biogas should be upgraded to biomethane and gas grid injected. This would require approximately 180 rural digesters, 4 slaughter waste digesters and 4 municipal digesters; all at a scale of 50,000 tonnes/year of substrate. The investment cost was estimated at ca. 1,400 million EUR. This scale of investment could facilitate substitution of 7.5% of current natural gas demand and provide for ca. 5% of energy in transport (Singh et al. (2010) Renewable and Sustainable Energy Reviews 14(1) 277-288).

There is one biogas upgrading plant in Ireland under construction complete with a gas grid injection point.

In the last three years a number of companies have invested in natural gas vehicles (NGVs). Initial trials by Bus Eireann in Cork and Celtic Linen have been very positive. This industry is expected to grow rapidly. A market for gaseous transport fuel initially based on natural gas will facilitate gas grid injection of biomethane.

10.2 Financial support systems

Support to biogas in the Republic of Ireland includes:

- A landfill levy of 75 EUR/tonne is in place as of July 2013. Also as of July 2013 there is a requirement to provide collection of source segregated food waste for population centres in excess of 25,000 persons. By July 2015, this will be required for populations of 500 persons. These regulations provide an incentive to digest the organic fraction of municipal solid waste.
- REFIT for biogas to CHP was 7.2 Euro cent/kWh_e in 2007 and was raised to 12 Euro cent/kWh_e in 2008.

As of May 2010, the tariffs are indexed and offered on a 15-year basis and include:

- AD CHP equal to or less than 500 kW: 15 Euro cent /kWh_e
- AD CHP greater than 500 kW: 13 Euro cent/kWh_e
- AD (non CHP) equal to or less than 500 kW: 11 Euro cent/kWh_e
- AD (non CHP) greater than 500 kW: 10 Euro cent/kWh_e

[19] http://www.cer.ie/docs/001107/CER16318%20Diageo%20CNG%20Consultation%20Response.pdf; http://www.cer.ie/docs/001107/CER16324%20Glanbia%20CNG%20Consultation%20Response.pdf.

[20] http://www.gasnetworks.ie/Global/About%20Us/About%20Us%20documents/The%20Furture%20of%20Renewable%20Gas%20in%20Ireland.pdf

Figure 10.1: Biogas plant McDonnell Farms Limited. Primary Digester and first covered storage digester. David McDonnell milks 300 dairy cows in Limerick and also operates a free range poultry farm. In 2009/2010 he installed the most modern farm digester in Ireland which has a capacity of 250 kW_e. (Source: SEAI (Sustainable Energy Authority of Ireland) Anaerobic Digestion: A case study – McDonnell Farms Biogas Limited, Shanagolden, Co. Limerick))

10.3 Innovative biogas projects

Science Foundation Ireland (SFI) MaREI centre for Marine and Renewable Energy

The SFI MaREI Centre (http://marei.ie/) is a cluster of key university and industrial partners dedicated to solving the main scientific, technological and socio-economic challenges related to marine and renewable energy. These challenges will require innovative solutions to reduce time to market and reduce costs to a competitive level. They cover all aspects of technology development and require solutions to the engineering problems, energy conversion and storage transmission and integration as well as the enabling ICT technologies and environmental aspects. MaREI includes for a number of research areas including for Bioenergy. The objectives of the bioenergy research include:

- Assessment of the financially feasible green gas resource in Ireland including for biogas production from organic residues and from grass.
- Evaluation of the biomethane potential from various types of seaweed harvested at different times of year
- Interrogation of the optimum methods of generating biomethane from seaweed including co-digestion with suitable substrates
- Examination of cogeneration of hydrogen and methane from macro- and micro-algae
- Investigation of microbial ecology of algae digesters
- Design and fabrication of "in –situ" and "ex –situ" biomethanation processes
- Optimal applications of Power to Gas systems

Advanced technologies for biogas efficiency sustainability and transport (ATBEST)

The ATBEST initial training network (http://www.atbest.eu/) develops innovative research and training for the biogas industry in Europe. Twelve early stage researchers and 2 experienced researchers have been recruited from ten countries (Poland, Italy, Spain, India, Germany, Greece, Lebanon, China, the UK and Slovenia). These fellows are based in eight different training sites. ATBEST is a multidisciplinary collaboration between internationally-renowned research teams and industrial partners. The aim is to establish long-term collaborations and develop structured research and training relevant to industry and academia along the biogas supply chain. ATBEST is led by Queens University Belfast and has three partners from the Republic of Ireland.

The Animal & Grassland Research and Innovation Centre Teagasc, Ireland are investigating synergies from co-digestion of grass silage with other feedstocks. Their objectives are to: identify the optimal growth stages of grass and legume silages and the optimal mixture with cattle slurry for biomethane production; identify the optimal slurry type and the optimal mixture with grass silages harvested at different growth stages for biomethane production; undertake a full cost analysis of biogas/biomethane production system.

The Environmental Research Institute (ERI) in University College Cork (UCC) Ireland is evaluating innovative biomethane systems with life cycle assessment. The main focus in its evaluation lies in efficient digestion systems and upgrading of biogas with external hydrogen from surplus electricity. In this scenario, the storage capability of biogas functions as a "battery" of the electricity grid.

Gas Networks Ireland (The Irish Gas Grid) is investigating the optimal model for rolling out a biomethane industry in Ireland incorporating novel innovative technologies and novel biogas substrates.

11. Korea

Total energy production has been steadily increased over recent years; renewable energy accounted for 3.5% (9.9 MTOE, million tonnes of oil equivalent = 115 TWh) in 2012 of which 1.6 MTOE was bioenergy (8.9% from biogas plants and 6.2% from landfill gas). Landfill gas utilisation has dominated biogas production over the last decade while biogas plants have started to make a significant contribution only since 2010. The "Bioenergy Strategy 2030" targets bioenergy production to increase by a factor of more than 4.

Total energy production has steadily increased over recent years; renewable energy accounted for 4.32% (12.3MTOE, million tons of oil equivalent = 143TWh) in 2015 of which 2.8 MTOE was bioenergy (3.6% from biogas plants and 1.3% from landfill gas). Landfill gas utilization has dominated biogas production over the last decade while biogas plants have started to make a significant contribution only since 2010. The "Bioenergy Strategy 2030" targets bioenergy production to increase by a factor of more than 4.

11.1 Production of biogas

A total of 109 biogas plants are now in operation and produce almost 2,270 GWh per year. Landfill gas (LFG) contributes 18.9 % (428GWh/yr), biogas from sewage sludge 59.3%, and biowaste 21.4%. Biowaste mainly consists of food waste, food waste leachate, and digestible co-substrates. Table 11.1 shows Korean biogas production from different types of plants.

Table 11.1: Status of biogas production in Korea (data from 2015)

Substrate/Plant type	Number of plants	Production* (GWh/year)
Sewage sludge	62	1,346
Biowaste (co-digestion)	20	485
Agriculture	6	11
Industrial	-	-
Landfills	21	428
Total	**92**	**2,270**

* produced raw biogas expressed as its energy content from the different plant types

Electricity generation from biogas plants amounted to only 145 GWh in 2015. There are 15 new biogas plants under construction to treat 4,764 tons of food waste and food waste leachate daily to produce 454 GWh biogas by 2017. The electricity generated from LFG reached 247 GWh in 2015. The electricity production is expected to increase to 1,937 GWh in 2020.

11.2 Utilisation of biogas

About 31% (707 GWh) of the biogas is utilized for electricity production. The main part (35.1%, 796GWh) of the remaining biogas is used for heat generation. This part is decreasing every year to meet the increasing demand for biogas sale. Flaring biogas is still significant and increased, compared to the previous year (18.9%). The utilisation of biogas as vehicle fuel was only 5.1% of the total biogas production. The utilisation of biogas in Korea is summarized in Table 11.2.

The number of buses using CNG as a vehicle fuel reached 39,528 and the number of gas filling stations reached 201, including 6 biomethane filling stations. However, these biomethane filling stations only supply 0.2% of the total number of buses.

Table 11.2: Utilisation of biogas in Korea (data from 2015)

Utilisation type	GWh	%
Electricity*	707	31.1
Heat	796	35.1
Vehicle fuel	115	5.1
Flaring	428	18.9
Biogas sale	224	9.9
Total	2,270	100

* = including efficiency losses.

Biogas upgrading is carried out by water scrubbing, PSA and membrane at 5 wastewater treatment plants and 5 food waste leachate plants. One other food waste AD plant of biogas upgrading is now under construction. The biomethane is used mainly in city buses and municipal vehicles and grid injection. The standard for vehicle fuel and grid injection is similar to Swedish standards.

11.3 Financial support systems

There are no tariffs or subsidies for biogas. However, 10% VAT (Value Added Tax) and a 2% tariff will be charged when the mixture of CNG and biomethane is sold. A feed-in tariff system was implemented until 2011.

However the RPS (Renewable Portfolio Standard) system has been enforced since 2012, requiring all power plants generating over 500 MW electricity to supply also a certain share of renewable energy. As "Mandatory Supply Quantity (MSQ)", 2% of the total power generation should be supplied using an appropriate kind of renewable energy. There is a governmental target to increase MSQ up to 10% of the total power generation in 2022. The REC price (general) has been around KRW 131,125/MWh (106 EUR/MWh) in July 2016.

11.4 Innovative biogas projects

Animal Manure to Biogas Project

- The Ministry of Agriculture, Food, and Rural Affairs has financially supported enterprisers with 60% of the total construction cost of AD plants treating 70-100 m^3 of manure per day.
- 7 AD plants are now under construction and 11 more AD plants will be built by 2020.

Organic Wastes to Energy Project

- The Ministry of Environment (MOE) established a center for Organic Wastes to Energy.
- The total budget for the research project 2013-2020 (7 years) is 74 million US Dollars (MOE $56.5 million and Private $17.5 million) and the following research results are expected;
    - Construction of an AD plant for food waste with a volume of 1,800 m^3. Research on biogas upgrading, system development for odour control, O/M manual development for the AD plant and application of digestate.

Figure 11.1: Nonsan Biogas Power Plant that is producing 2.55GWh electricity (1,782,000Nm^3 biogas) annually. Source: Kyeryong-Nonsan Livestock Farming Cooperatives, Chungnam, Korea

12. Sweden

In Sweden there is a governmental aim to produce 50% of the energy from renewables by 2020 (this has already been reached), but there are no specific targets for biogas production. Sweden also has a governmental vision to have a fossil free transportation sector by 2050. The results of a Swedish Government Official Report on the subject were published in 2013. The Swedish Energy Agency have been given the task to suggest a strategy to implement them, but with no set deadline and with no additional resources. The gas business in Sweden has in 2015 launched their own vision and strategy work, envisioning that 15 TWh of biogas could be produced by 2030, thereof 12 TWh to be used as vehicle fuel. Biomethane from gasification of forestry residues constitutes a major share of the envisioned potential.

12.1 Production of biogas

In Sweden the production of biogas has been stagnant or slowly climbing for several years. The main reason is the difficulties in showing a reasonable profit for new investments and new biogas plants. Biogas produced in new plants has been balanced by the steady decline in landfill gas production. Table 12.1 shows the Swedish biogas production from different types of plants.

Table 12.1: Biogas production in Sweden from different plants (data from 2015)

Plant type	Number of plants	Biogas production* (GWh/year)
Sewage sludge	140	697
Biowaste	35	854
Agriculture	40	50
Industrial	6	121
Landfills	60	187
Gasification	1	38
Sum	**282**	**1,947**

* = produced raw biogas expressed as its energy content from the different plant types
Source = Produktion och användning av biogas år 2015, Statens Energimyndighet 2016

The potential to produce biogas from anaerobic digestion and gasification up to 2030 has been evaluated (Dahlgren S (2013) "*Realiserbar biogaspotentiali i Sverige 2030 genom rötning och förgasning*", WSP). The potential depends mainly on the development of the financial support system, technical developments and the price of fossil fuels. The investigation was made for three scenarios with good, moderate or bad development of these parameters.

The potential to produce biogas from anaerobic digestion was shown to be 1–3 TWh in scenario 3 (poor development), 58 TWh in scenario 2 (moderate development) and 5–10 TWh in scenario 1 (good development). Today, almost 60% of the biogas produced is upgraded to biomethane and this proportion is expected to increase even more in the period to 2030.

12.2 Utilisation of biogas

In Sweden, almost 60% of the biogas is used as vehicle gas. This part has been increasing every year to meet the growing demand of the gas powered automotive market. However, recently the market trend has become more stagnant. The biomethane share has continued to increase. The main part of the remaining biogas is used for heat production. The entire utilisation of biogas in Sweden is summarized in Table 12.2 below.

Table 12.2: Utilisation of biogas in Sweden (data from 2015)

Utilisation type	GWh	%
Electricity*	62	3
Heat**	387	20
Automotive fuel	1,219	63
Industrial	49	3
Other use***	19	1
Flaring	198	10

* = excluding efficiency losses.
** = including heat losses, e.g. during electricity production, and heat used by the biogas plant.
Source = Produktion och användning av biogas år 2015, Statens Energimyndighet 2016
*** = new utilisation category 2015, to avoid misfiling of non-categorized use

In Sweden, the bulk of the upgraded biogas is used as automotive fuel and designated "fordonsgas" (vehicle gas). The biomethane (data from 2016) is produced in 62 biogas upgrading plants with various technologies (~70% water scrubbers, ~10% PSA, ~18% amine scrubbers, and two membrane based). In one plant, with a capacity of 60 GWh, the biomethane is liquefied and sold as LBG (Liquefied BioGas). During 2015 37 GWh of LBG was delivered. Of the 1,572 GWh of methane used as an automotive fuel, the renewable share was 73% on energy basis in 2016. It is used by 54,439 gas vehicles, including 2,331 buses and 821 heavy duty vehicles. There are 227 filling stations dispense vehicle gas, out of which 167 are public. Six of these offer liquefied vehicle gas (LNG/LBG).

12.3 Financial support systems

Sweden has no feed-in tariffs, but instead uses other support systems, mainly focused on increasing the use of biomethane as automotive fuel. The existing support system measures are:

- No carbon dioxide or energy tax on biogas until the end of 2020 (recently approved by the European Commission). Corresponding to around 74 EUR/MWh compared to petrol and 60 €/MWh compared to diesel, and of which 25 EUR/MWh is from the carbon dioxide relief and the remaining part is from the energy tax relief.

- 40% reduction of the fringe benefit tax for use of company NGVs until the end of 2016, up to a limit of 16,000 SEK (1,700 EUR). 2017-2019 extension has been capped lower, up to a limit of 10,000 SEK (1,070 EUR).

- Investment grants for marketing of new technologies and new solutions for biogas during the period 2010-2016. Maximum 45% or 25 MSEK (~3 M EUR) of investment cost, 90 MSEK per year.

- "Klimatklivet" – the climate leap, is the continuation of the former climate investments programmes benefitting the municipal sector. From 2015 to 2018 a total of 1,925 MSEK is available for applications on all measures which improves the fulfilment of Sweden's climate goals. Already in the first round of applications, biogas and NGV's have been greatly awarded. It is also open for companies.

- A joint electricity certificate marketed between Norway and Sweden. The producer receives one certificate for every MWh electricity produced from renewable resources and the electricity consumers must buy certificates in relation to their total use. Average price in 2014-2015 ranged between 140-192 SEK/MWh (15-20 EUR/MWh), with a declining trend.

- Maximum of 40 SEK/MWh (~EUR 4.3/MWh) for manure based biogas production to reduce methane emissions from manure. The total budget 10 year budget of 240 MSEK (2014-2023) has been increased for the period 2016-2019 by 120 MSEK.

12.4 Innovative biogas projects

Microbial community ability to adapt to altered temperature conditions influences operating stability in anaerobic digestion
doi: 10.1016/j.egypro.2017.03.408[21]
In a recent study, Swedish researchers at SLU took inoculums from two food waste treatment facilities, one mesophilic biogas plant in Jönköping, and one thermophilic biogas plant in Uppsala. The Jönköping plant wanted to know if it was possible to change the temperature in order to increase the loading rate, and also increase the hygienic action of the digestion. The Uppsala plant, fed a co-substrate consisting of slaughterhouse waste, wanted to see if changing to mesophilic temperatures could alleviate their current issue with ammonia inhibition, leading to process instability.

The researchers from SLU designed a laboratory trial where they decreased and increased the temperature incrementally, respectively, going from mesophilic to thermophilic with the Jönköping inoculum, and going from thermophilic to mesophilic with the Uppsala inoculum. They monitored the changes in specific methane production, carbon dioxide content and VFA content, and also observed the changes in the microbial community. In both cases, there was a disturbance in the interval of 40-42 °C, see figure 12.1.

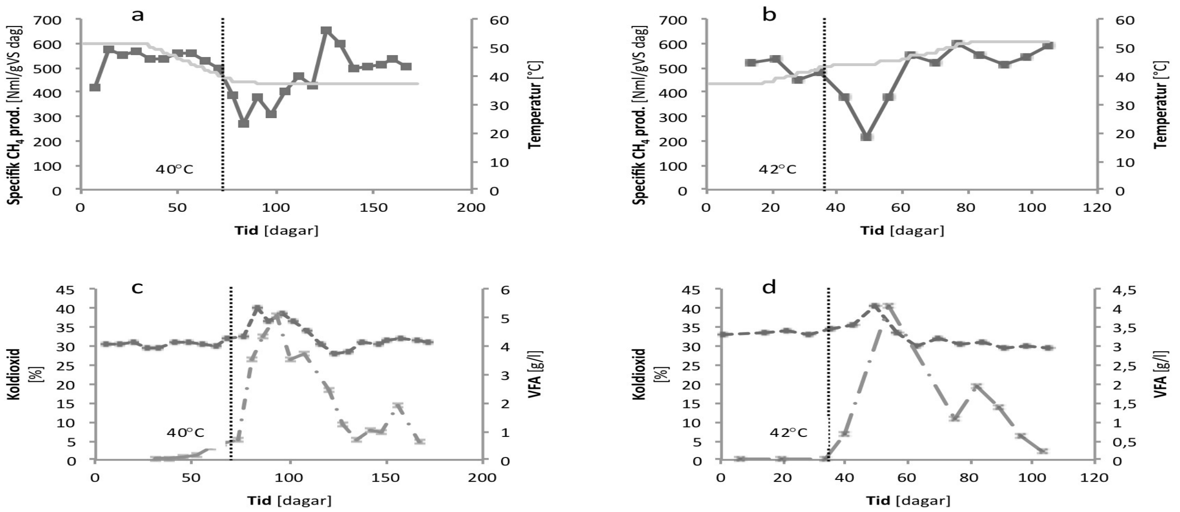


Figure 12.1: The perturbation in the process parameters is clearly detected in both setups around the temperature of 40-42 °C. Koldioxid = Carbon dioxide. a/ and c/: Thermophilic-to-mesophilic (Uppsala); b/ and d/: Mesophilic-to-thermophilic (Jönköping).

After the change, the load was increased gradually from the initial 3 to 7 g VS/l/day. The originally thermophilic inoculum failed at 6 g VS/l/day. Microbial studies showed that the thermophilic-to-mesophilic digester did alter its composition in line with the originally mesophilic one. However, certain

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21 https://www.researchgate.net/publication/317310035_Microbial_Community_Ability_to_Adapt_to_Altered_Temperature_Conditions_Influences_Operating_Stability_in_Anaerobic_Digestion

populations found in the original mesophilic inoculum could not be found in the thermophilic-to-mesophilic digester. More details in the open access article, and also in the 2016 country report.

13. Switzerland

After adaptation of the energy strategy 2050 by the Swiss Federal Council, which aims at phasing out nuclear power and on more strongly promoting hydropower and new renewables (among them biogas and biomethane), a first set of measures hat been defined. FIT is further on financed by a network supplement payed by consumers. With respect to bioenergy the current maximum amount of 15 CHF/MWh of this network supplement shall be increased to 23 CHF/MWh in order to further secure the FIT. Subsidies for new installations are granted for up to five years after the coming into force of the new law.

13.1 Production of biogas

Only a slow growth in numbers of biogas installations treating biowaste or agricultural residues took place in 2015. This growth is outbalanced by a slight decrease in installations treating sewage sludge and in landfill gas installations. The state of the current biogas production in Switzerland including the shares of biomethane upgrading installations and biogas which is fed to the national gas grid presented in the table below.

Table 13.1: Status of biogas production in Switzerland (data from 2015)

Plant type	Number of plants	Biogas production* (GWh/year)
Sewage sludge	463 (15)	583 (115)
Biowaste (co-digestion)	26 (10)	308 (103)
Agriculture	99 (3)	297 (8)
Industrial waste water	23 (3)	71 (11)
Landfills	4 (0)	6 (0)
Total	**615 (31)**	**1,265 (237)**

* = produced raw biogas expressed as its energy content from the different plant types
Numbers in (parentheses) indicate share of plants and biogas grid injection, respectively

The number of installations for sewage sludge digestion will continue to show a moderate decrease due to decommissioning of small WWTP digesters and centralization of sludge digestion. The net biogas production from sewage sludge digestion will most probably increase over the next decade, mainly attributed to more efficient digester operation. The actual production in 2015 (583 GWh/y) represents 73% of the estimated sustainable potential (800 GWh/y) or 29% of the theoretical potential (2’000 GWh/y) from sewage sludges respectively.

The number of AD installations for biowaste treatment is expected to increase over the next decade due to an almost full coverage of source separation of OFMSW. The actual production (308 GWh/y) represents 56% of the estimated sustainable potential (550 GWh/y) from biowastes.

The largest potential for biogas production can be located in agricultural residues, mainly in liquid and solid manure. Due to legal restrictions there is currently no biogas produced from energy crops, a situation which will not change during the near future. The number of agricultural AD installations is expected to grow considerably, highly depending on the tendency towards small and decentralized or rather large and centralized installations. The actual production (297 GWh/y) represents 7 - 9% of the estimated sustainable potential (3’300 – 4’000 GWh/y) from agricultural residues and manure.

Anaerobic digesters for the treatment of industrial wastewaters are not expected to grow considerably in numbers nor in biogas production in the near future. The actual production (71 GWh/y) covers more than 90% of the estimated sustainable potential from industrial wastewaters.

Due to the complete ban for landfilling of organic waste since 2000 there will be a full phase out of landfill biogas during the next decades. The already low production is expected to disappear within two decades.

In total the actual production of biogas (1'265 GWh/y) represents some 24% of the estimated sustainable potential (5'300 GWh/y) or 3% of the theoretical potential (39'000 GWh/y).

13.2 Utilisation of biogas

With respect to its end use biogas is still mainly used to produce electricity (sewage sludge, agricultural and biowaste installations) and heat (sewage sludge, industrial wastewater). There is however a growing demand for biomethane upgrading and grid injection for domestic heating and CHP. Biomethane utilization as an automotive fuel still plays a minor role with only about 20% of upgraded biomethane going to the transport sector. Table 13.2 gives an overview over biogas utilisation in 2015.

Table 13.2: Utilisation of biogas in Switzerland (data from 2015)

Utilisation type	GWh/yr	%
Electricity*	300	24
Heat	330	26
Grid injection	240	19
(thereof automotive fuel)	(50)	(4)
Parasitic (heat, electr.)	380	30
Flaring	n.d.	<1

* = excluding efficiency losses

With a total of 31 biomethane upgrading installations end of 2015, compared to 24 in 2014, there is a strong rise for this technology route which is expected to continue. PSA (12) and glycol (2) upgrading is not growing while amine wash (9) and membrane technologies (8) are on the rise. The total biomethane production equals 237 GWh/yr or 19% of the total biogas produced. An additional amount of 80 GWh/yr of biomethane from waste is imported from Germany to cover the growing demand. Out of the 31 biomethane upgrading installations 3 are operated off grid with independent vehicle fuelling stations. A total of 134 CNG filling stations are in use serving more than 12,000 vehicles and covering mostly the densely populated north-western area of Switzerland. On average vehicle gas contains 20% biomethane.

13.3 Financial support systems

The basic feed-in tariff system remained unchanged with a strong basic tariff and a gradation for size. Small agricultural installations are promoted through a bonus system. Table 13.3 below summarises the feedin-in tariff system of Switzerland.

Grid fed biomethane is excluded from the feed-in tariff system but promoted by a support program initiated by the Swiss Gas Association. Financial support depends on biomethane production capacity.

Table 13.3: Feed-in tariff for heat and electricity in Switzerland in Swiss currency (CHF).*

Power class	≤ 50 kW_e	≤ 100 kW_e	≤ 500 kW_e	≤ 5 MW_e	> 5 MW_e
Basic tariff [CHF/kWh]	0.28	0.25	0.22	0.185	0.175
Agricultural bonus [CHF/kWh]	0.18	0.16	0.13	0.045	0
Heat bonus [CHF/kWh]	0.025	0.025	0.025	0.025	0.025
Maximum [CHF/kWh]	0.485	0.435	0.375	0.255	0.20

* 1 EUR = 1.07 CHF

13.4 Innovative biogas projects

Off-grid Biomethane upgrading Schoenenwerd
In June 2016 the first fully off-grid biomethane upgrading and public filling station for biogas from anaerobic sludge digestion opened in the Swiss city of Schoenenwerd. The demonstration project is based on the BlueBonsai membrane treatment and can deliver up to 6 m3/h of high-purity biomethane at a cost of approx. € 170/MWh. The project is intended to act as a proof-of-concept demonstrator for two years to allow for multiplication and further market penetration.

www.apex.ch, BlueBonsai membrane technology provider

Figure 13.1: Membrane Biogas Upgrading WWTP Schoenenwerd (www.ee-news.ch)

Valbroye Biogas, Henniez
In June 2016 one of the largest agricultural biogas installations got in operation in the city of Henniez in western Switzerland. With a total annual capacity of 23‘000 tons of manure, collected from 27 farms in the vicinity and an additional amount of 3‘800 tons of spent coffee from Nespresso und Nescafé manufacturing the installation will produce some 4.5 GWh/a of renewable electricity and an equal amount of renewable heat which is partly used in a nearby bottling plant.

www.greenwatt.ch, Biogaz Valbroye
www.nestle.com, Media

Figure 13.2: Valbroye Biogas plant (www.greenwatt.ch)

Swiss Competence Centre for Energy Research BIOSWEET Biomass for Swiss Energy Future

The SCCER BIOSWEET was established in 2014 as a national network of 16 Partners from 10 Academic Institutions and more than 30 Cooperation Partners from public and private sector organizations. The SCCER BIOSWEET develops and implements biomass valorization technologies to make the Swiss energy turnaround happen. For 2050, the Federal Energy Strategy foresees a contribution of 100 PJ from bioenergy to the final energy consumption. To meet this goal the current energy production from biomass needs to be doubled. For the 2nd Phase of the BIOSWEET network, lasting from 2017 – 2020 a total amount of 11.6 million CHF (equaling 10.8 Mio €) has been granted. With respect to biogas the activities will focus on increased efficiency of wet digestion (biowaste, manure), strengthening the coverage of manure digestion, both centralized and decentralized (farm scale) as well as integration of power to gas technologies into new and existing AD concepts.

14. The Netherlands

To meet the European Union 20-20-20 goals, the Netherlands has to increase the amount of renewable energy to 14 %, which can be compared to 2% achieved in 2005. The ambitions of the Netherlands to increase the amount of renewable energy are expressed in the National Renewable Energy Action Plan. There it can be seen that the expected amount of energy from the feed-in of biomethane into the natural gas grid will increase to 6.7 TWh in 2020 if the required share of renewable energy should be reached.

14.1 Production of biogas

In the Netherlands there are 252 biogas plants producing around 4 TWh of biogas (data from 2013). Installed capacity is given for production of heat, electricity and upgraded biogas in Table 14.1 to give an indication how the production is distributed. For electricity and heat production are available, see Table 14.2. Biogas upgrading to biomethane with subsequent gas grid injection is included in the figures, corresponding to approx. 900 GWh.

Table 14.1: Status of biogas production in The Netherlands (data from 2015)

Plant type	Number of plants		Installed electricity capacity (MWe)	Upgrading capacity (Nm3 biomethane /h)
Sewage sludge	80			
Biowaste + industrial	50 (biowaste and industrial together			
Agriculture	97			
Landfills	not reported			
Total	**268 (assuming 41 landfills)**		**133****	**10.000**

* a large installed heat capacity is also available from the CHP units installed for electricity production, which is not included in this column.
** average full load hours 4169/a for agricultural production plants

Table 14.2: Status of biogas final utilisation in The Netherlands (data from 2015)

Plant type	E-production (GWh/year)	Heat production (GWh/year)
Sewage sludge	206	335
Biowaste + industrial	346	849
Agriculture	550	622
Landfills	46	57
Total	**1148**	**1863**

The development of biogas in the Netherlands has not been very strong during recent years, mainly due to the increasing costs of feedstocks. The development has been focused on energy utilisation of industrial and municipal biowaste while the development in the agricultural sector has been very slow. Due to changes in the feed-in tariff system (more money available) it is expected that new projects will develop in agriculture in the future.

In the Green Gas Roadmap published in 2014, it is concluded that in 2020 digestion could potentially produce an estimated 1,200 million Nm^3 of biogas (63% CH_4 content), which corresponds to around

7 TWh. In 2030, this could potentially increase to 4,600 million Nm^3 biogas, which corresponds to almost 30 TWh. This will only be possible by developing several big gasification plants in the future.

14.2 Utilisation of biogas

In the Netherlands, 80 % of the produced biogas is utilised, corresponding to around 3.2 TWh delivered, as either heat, electricity or automotive fuel, as seen in Table 14.3.

Table 14.3: Utilisation of biogas in the Netherlands (data from 2014)

Utilisation type	GWh	%
Electricity*	1148	36%
Heat*	1863	58%
Automotive fuel	approx. 197	6%

* = excluding efficiency losses.

The gas grid requirement of 88% methane may seem to make the biogas upgrading cheaper and suitable for technologies and designs adapted for producing lower biomethane qualities, but due to wobbe index limitations this is not always the case. It may be necessary to upgrade further, and then dilute with nitrogen to also meet the calorific requirement. In 2012, the first biogas upgrading unit using cryogenic separation was taken into operation in the Netherlands. Data from May 2014 show that 7,500 vehicles were running on methane with 186 filling stations available[22].

14.3 Financial support systems

In the Netherlands is the SDE+ sceme the feedinntariff support system for renewable energy. The interesting concept of the scheme is that it forces all renewables to compete with one another. In a staged application process with closing dates set at 6 dates throughout the year (see Table 14.3) projects can apply when the tariff fits their business plan. Since the tariff gradually increases during the year the scheme favours large scale facilities, unless the small facilities can demonstrate that heat is utilised. In Table 14.3 the tariffs are guaranteed minimum income, which means that the scheme only pays out if energy prices are lower than the prices in the the feed inn tariff for a certain category. In 2016 was 9BEUR available in this system. In 2017 the available budget is 12 BEURA special category in it will support small scale manure digesters.

14.4 Innovative biogas projects

Mono-manure digestion is a new development in the Netherlands. The digester at Den Eelder was the first of its kind in the Netherlands.

At Den Eelder, the cows poo green electricity

The Den Eelder farm's website proudly boasts that 'our cows poo electricity and heat!' Just to clear the air: thanks to a closed circuit and a mono-digester, the farm runs on green energy produced from its own manure. However, owner Ernst van der Schans does not believe he has found the goose that lays the golden egg: "Don't expect this to make you wealthy."

In the early nineteen-eighties, Mr van der Schans started farming near Well-Ammerzoden, in the province of Gelderland. In 1990, he branched out to dairy processing, a rather energy-intensive process. He now has a relatively large dairy farm, with around 500 cows.

[22] http://www.ngvaeurope.eu/european-ngv-statistics

Mono-digestion or co-digestion: Soon, the idea of generating biogas sprang to mind. This was not just about using this renewable energy himself, the goal was also to reduce methane emissions. “In the beginning, we were not sure if we should use a mono-digestion technique - where it is only manure that is converted into biogas - or a co-digestion technique, in which other products are also fed into the digester.

Start small: In 2012, Ernst van der Schans finally decided to go for a Microferm mono-digestion system, with a 66 KWe cogeneration unit (CHP). “There were several reasons for this”, says Mr van der Schans. “We didn’t have to add a cost item to our books for the supply of co-products. We did not have to produce any additional manure for the digester, and we just wanted a simple, small-scale installation. So we started small, with 7,000 tons of manure every year.”

Closed cycle: Ernst van der Schans is happy that he opted for mono-digestion. “It suits our farm. We like using a closed-cycle system. In addition, we prefer not to have any external products or animals on our site. We also wanted a simple logistical process.”

Level floors: “We use manure shovels once an hour to remove manure from the animal enclosures. A small amount of this fresh manure is pumped into the digesters every five minutes. This is important. The fresher the manure, the more methane and gas is produced. By using fresh manure we also reduce methane emissions from the manure storage facilities, allowing us to make an additional contribution to climate policy.”

- Technique: mono-digestion
- Input (per year): 15,000 tons of fresh cow manure
- Capacity: 66 kW electricity / 700 kW heat
- Net output (per year): 500,000 kWh_e /yr and 1,500,000 kWh_h/yr

Figure 14.1: Den Eelder farm’s biogas plant

15. United Kingdom

The UK government is still supporting the rollout of AD in England and devolved administrations.

- In England, Defra set out in 2011 a vision for AD to generate 3-5 TWh of heat and electricity by 2020.
- Wales, as part of their 'One Wales Delivery Plan' has created a capital and revenue financial support package for local authorities who wish to adopt AD technology.
- Scotland has seen the introduction of food waste bans to landfill. This has driven up the AD capacity and this trend is expected to continue.
- Northern Ireland with its attractive government subsides (4 ROCs each worth approximately £43/MWe) for AD has seen an increase of farm fed (grass) facilities.

15.1 Production of biogas

Overall electrical capacity from biogas (sewage sludge and AD) equated to 630 MW in 2015.

As of the end of 2015, there were 87 AD plants treating food waste (176 MW_e) and 230 farm plants (198 MW_e). The number of new plants has increased rapidly since 2005, along with gas production, and is predicted to keep on rising rapidly. The electricity generation from AD in United Kingdom increased by 17% during the period 2013-15. These statistics have been compiled from various sources. No complete set of biogas production is collected by any organisation.

Table 15.1: Status of biogas production in the UK (data 2015 - Renewable electricity generation)

Substrate/Plant type	Number of plants	Electricity generation (GWh/year)	Capacity (MW_e)
Sewage sludge[1]	159	846	200
Biowaste	87[2]	707[1]	176[2]
Agriculture	230[2]	1,009[1]	198[1]
Industrial	34[1,2]	n.d.	57[1,3]
Landfills	442[1,3]	5,045[1]	1,051[1]
Total	**913**	**7,607**	**1,641**

Sources: [1]DUKES (2015)[23]; [2]National Biogas Portal, National Non Food Crops Foundation (NNFCC); [3]Anaerobic Digestion and Bioresources Association (ADBA)

15.2 Utilisation of biogas

The main use for biogas in the UK today is for electricity production with 2,770GWh produced in 2015 from sewage sludge and Anaerobic Digestion via CHP.

The production of heat from biogas is still yet to fully mature in the UK with only 4 biogas plants currently accredited to receive RHI (renewable heat incentive) payments. However, 28 GWh of biogas heat was generated between November 2011 and December 2015. Biomethane production is starting to grow within the UK. Between November 2011 and December 2015, approximately 709GWh of equivalent heat was generated by the gas produced by 30 installations receiving payment (38 accredited, 53 full applications). Progress into 2015 was very encouraging with the likes of the Minworth gas to grid facility opening. This plant, which is the biggest of its kind in the UK, will be able to convert 1,200

[23] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/450298/DUKES_2015_Chapter_6.pdf

Nm^3/h biogas into 750 Nm^3/h biomethane which will be injected into the National Gas Grid. Overall, by the end of 2015 there were 52 biomethane facilities operational which represents over 2.5 TWh per annum. These operations are not included in the statistics of this report. See figure 15.2 for details.

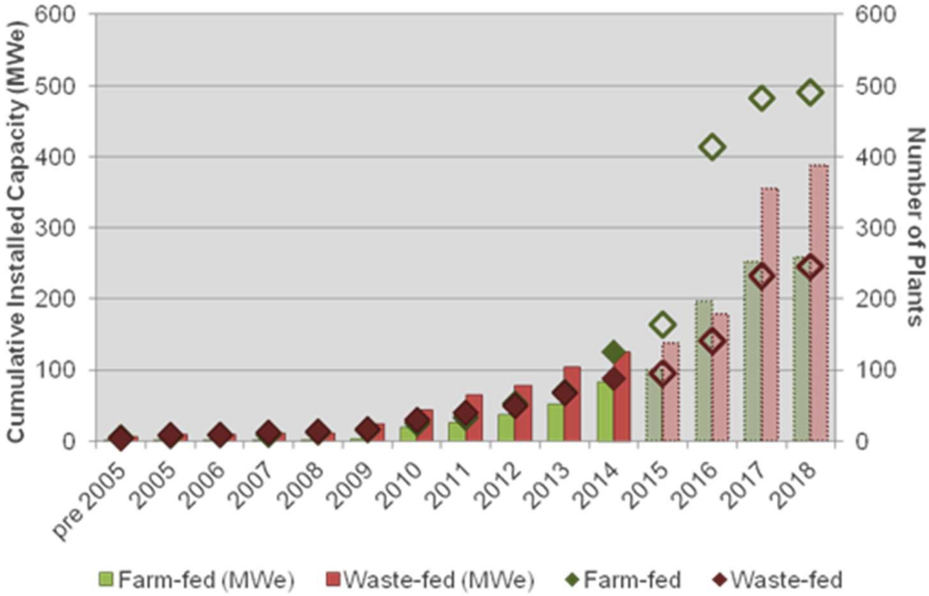


Figure 15.1: Growth of the UK's AD sector, both farm and waste fed (Source: Reproduced by courtesy of NNFCC (2014) © AD biogas in 2030 could be around 23 to 37 TWh (Analysis of Characteristics and Growth Assumptions Regarding AD Biogas. see link[24])

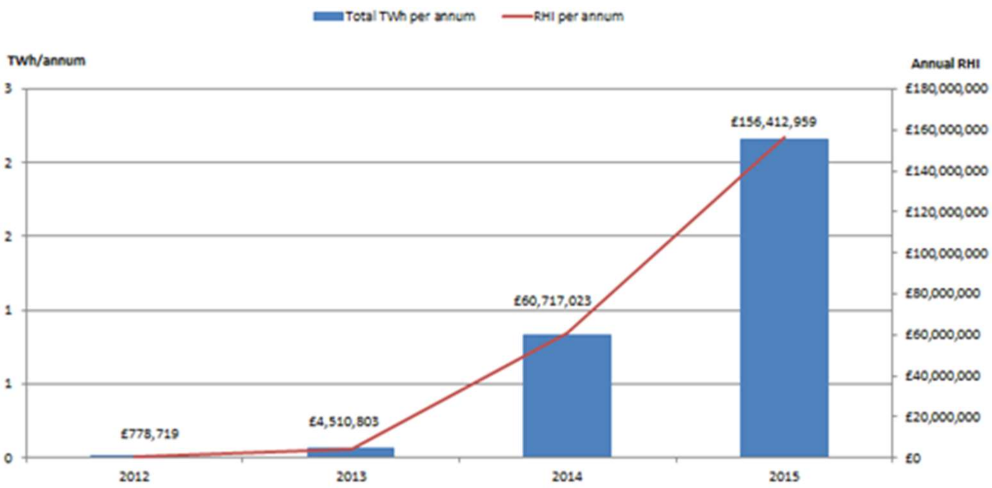


Figure 15.2: Annual Biomethane to Grid and RHI (Renewable Heat Incentive)

In terms of fuel, around 2 million litres were produced for vehicles by the biogas industry during the period Jan 2014 – May 2014. No more recent statistics are available. The Gasrec Albury site has closed down, so now there is no longer any production of liquefied biomethane in the UK (previously approximately 4,000 tonnes production per year).

[24] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/48166/2711-SKM-enviros-report-rhi.pdf

15.3 Financial support systems

In the UK a range of financial support systems are available for Anaerobic Digestion operators. The Feed in Tariffs (FIT) provide a guaranteed price for a fixed period to small-scale electricity generators. FITs are intended to encourage the provision of small-scale low carbon electricity. Only AD facilities with less than 5 MW capacity and completed after 15 July 2009 are eligible for FITs.

Table 15.2: The Feed in Tariff (pence/kWh) with guaranteed price for a fixed period

Description	Period in which Tariff Date falls	Tariff (p/kWh)
Anaerobic digestion with total installed capacity of 250kW or less	1 April 2014 to 30 September 2014	12.46
	1 October 2014 to 31 March 2015 1 April 2015 to 30 September 2015 1 October 2015 to 21 March 2016	11.21 10.13 9.12
Anaerobic digestion with total installed capacity greater than 250kW but not exceeding 500kW	1 April 2014 to 30 September 2014	11.52
	1 October 2014 to 31 March 2015 1April 2015 to 30th September 2015 1 October 2015 to 31st March 2016	10.57 10.13 9.12
Anaerobic digestion with total installed capacity greater than 500kW	1 April 2014 to 30 September 2014	9.49
	1 October 2014 to 31 March 2015 1April 2015 to 30th September 2015 1 October 2015 to 31st March 2016	9.02 8.68 8.68

Anaerobic digestion is among the technologies that receives additional support in the form of multiple Renewable Obligations Certificates (ROCs). An anaerobic digester will receive 2 ROCs/MWh until April 2015, this will then fall in line with DECC estimations of costs to 1.9 ROCs/MWh in 2015/16 and 1.8 ROCs/MWh in 2016/17. The value of ROCs varies are as follows: the upper limit is set by the buy-out price, which is the penalty suppliers need to pay for each missing ROC. During the 2015-16 obligation period the buy-out price is £44.33 per ROC.

The Renewable Heat Incentive (RHI) provides a fixed income (per kWh) to generators of renewable heat, and producers of renewable biogas and biomethane. From 1st July 2015 the RHI payment which was instrumental in the growth of biomethane production has been cut severely as shown in the Table below

Table 15.3: Renewable heat incentive (pence/kWh) for various sources. Increases due to inflation linkage

Tariff name	Eligible technology	Eligible sizes	Tariffs (p/kWh)
Biomethane injection	Biomethane until July 2015	biomethane all capacities	7.5
	Post July 2015	1st 40 GWh 2nd 40 GWh > 80 GWh	6.52 3.83 2.95
Small biogas combustion	Biogas combustion	Less than 200 kWth Post 1 July 2015	7.5 7.62
Medium biogas combustion (commissioned on or after 4 December 2013)		200 kWth and above & less than 600 kWth Post 1 July 2015	5.9 5.99
Large biogas combustion (commissioned on or after 4 December 2013)		600 kWth and above Post 1 July 2015	2.2 2.24

Renewable Transport Fuel Obligation (RTFO) is a requirement on transport fuel suppliers to ensure that 5% of all road vehicle fuel is supplied is from sustainable renewable sources by 2010. In January 2014 the certificates were worth an average of ~10 GBP/litre (~ € 12.5).

15.4 Innovative biogas projects

Wyke Farms Ltd

This 480 ha family-owned farm operates its business in such a way as to minimise its impact on the local environment and to create a truly agrobiotic relationship with the environment. It is a long established cheese making business, drawing its milk supply from its own two herds (2,500 cows) and 110 surrounding farms, processing 300 million litres of milk into 14,000 tonnes of organic Cheddar Cheese. The existing capacity of 15,000 tonnes can be scaled up to 40,000 tonnes per year. The aim is to create a wholly sustainable working farm for which the AD plant is key in the potential scaling up of the capacity (15,000 tonnes per year to 40,000). The purpose of the plant is to source all its electricity and gas needs from the biogas plant and subsequently also to include biomethane to fuel the fleet of milk tankers and other vehicles on the farm. Phase 1 involved the construction of 2 x 5,000 m^3 digesters and 2 x 500 kWe CHPs where one CHP sold the electricity to the grid distribution network and the other to the cheese processing plant. It has a throughput of 300 tonnes per day. This consist of a mix of pig and cow slurry, whey permeate and other milk products, bakery residues and any surplus grass and maize silage as well as rape seed straw. In phase 2, which is the situation as in 2015, 50% of the biogas used for electricity was diverted for upgrading to biomethane for injection into the gas grid. Phase 3 is scheduled to use the biomethane to fuel the farm's milk transport fleet and other vehicles.

Figure 15.3: Wyke Farm.

Cullompton Farm (David Parrish)

The digester is 3 years old and has a capacity of 700m^3 and the CHP 80kW_e. Unlike many digesters in the UK, the plant has a covered digestate store, illustrating best practice. Digestate is separated into a liquid and fibre fraction using a Murcott elevator belt press separator, which has also supplied the plant with their auto-degritting technology. The plant is fed on slurry from approximately 130 cows, plus chicken manure from their free range broiler house. The surplus heat is supposed to be used in their broiler houses.

16. Summary and Conclusions

Biogas production in the IEA Bioenergy Task 37 member countries is clearly dominated by Germany with more than 10,000 biogas plants. None of the other member countries have each more than 1,000 biogas plants (see Figure 16.1).

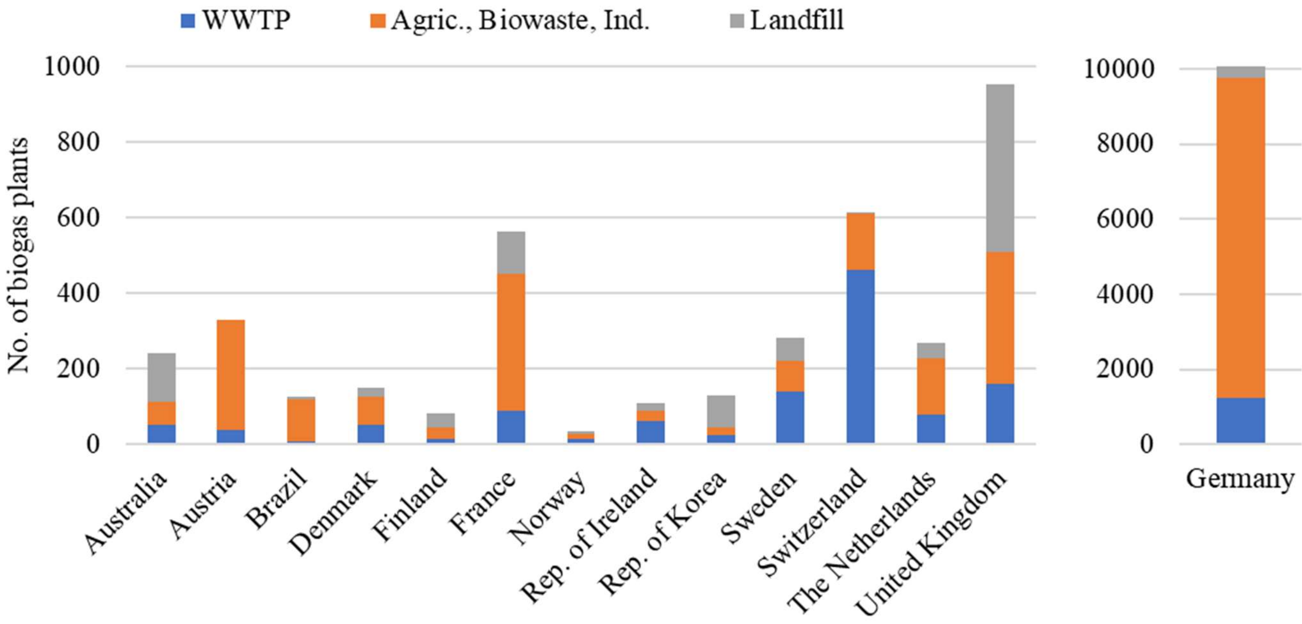
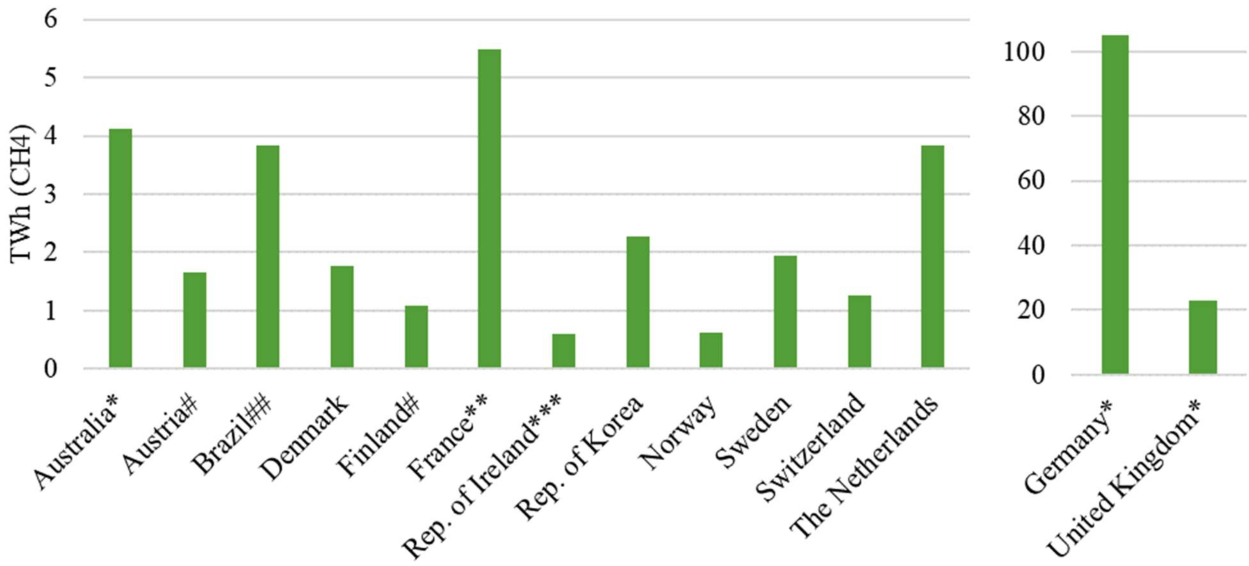


Figure 16.1: Number of biogas plants in operation in the IEA Bioenergy Task 37 member countries (2015).

The annual biogas production is around 100 TWh in Germany, 23 TWh in the UK[25], 5.5 in France, 4 TWh in Brazil and 4 TWh in the Netherlands. Remaining countries show production rates in the range of 0.5-2 TWh (see Figure 16.2). In countries like UK and South Korea, the biogas produced in landfills is the largest source, while the landfill gas is only a minor contributor in countries like Germany, Switzerland and Denmark, indicating the degree of landfilling of organic waste material. The actual biogas production is not reported in all countries, so in this report it has been calculated, based mostly on the electricity production with an assumed efficiency of 35%.

The biogas produced is in most countries mainly used for generation of heat and electricity, with the exception of Sweden where approximately half of the produced biogas is used as vehicle fuel. Germany is second in absolute numbers (460 GWh). Many other countries, such as France, The Netherlands, Denmark and South Korea, have emerging markets for biomethane as an automotive fuel.

[25] Only biogas for electricity generation, excluding biomethane plants (estimation production potential 2.5 TWh end 2015) and renewable heat (RHI, negligible amounts)



* = Calculated from the reported electricity production and an assumed efficiency of 35%.
** = Calculated from the reported electricity production an assumed efficiency of 35% for landfills, agricultural and biowaste based plants and from the sum of reported heat and electricity production for industrial and wastewater treatment plants.
*** = Calculated from 80% of the installed capacity for electricity production and an assumed efficiency of 35%
# = Calculated from the reported electricity production and an assumed efficiency of 35%, and from the sum of the other utilisation types
= Calculated from the reported or estimated raw biogas production in volume (m3/y) and an assumption of 64 % CH_4 content.

Figure 16.2: Annual biogas production in the IEA Bioenergy Task 37 member countries.

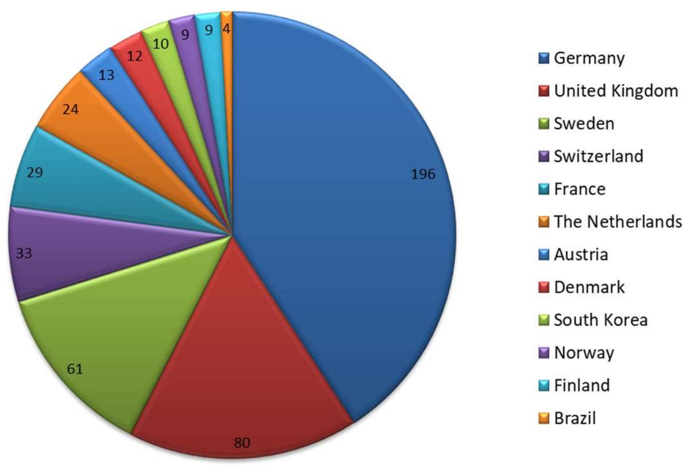


Figure 16.3a: The distribution of the reported operational biogas upgrading units in the IEA Bioenergy Task 37 member countries (end 2016). The labels are in the order from the largest to the smallest. Data for Korea is from 2015.

The amount of biomethane produced and the number of biogas upgrading plants is increasing. In Figure 16.3a the distribution of 480 biogas upgrading plants among the IEA Bioenergy Task 37 member countries is shown; the technologies used is indicated in Figure 16.3b.

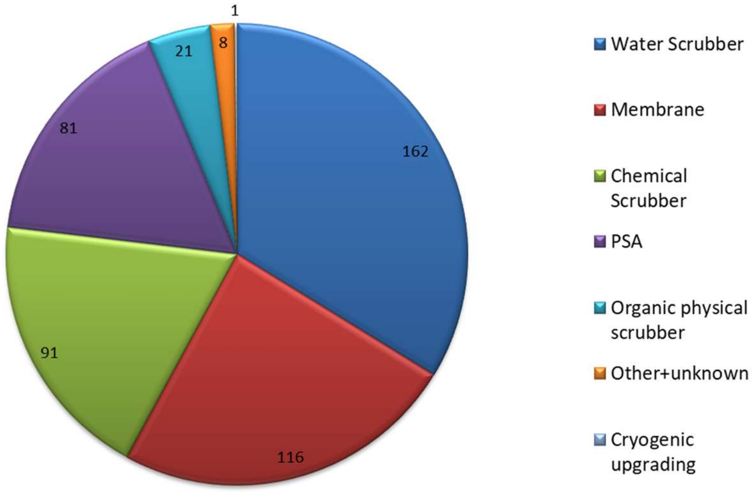


Figure 16.3b: The distribution of upgrading technologies for the reported operational biogas upgrading units in the IEA Bioenergy Task 37 member countries. The labels are in clockwise order from the largest Water Scrubbing (162) to the smallest.

The two countries in the top in last years report, Germany and Sweden, have stagnant markets. Thus UK has now taken over the second position from Sweden, with 30 new plants since last year. France and Switzerland are the only other countries with significant growth, the other countries more or less standing still. In the UK growth might soon stop because of major changes in the supporting policies.

Financial support systems are very different from country to country. Various systems with feed-in tariffs, investment grants and tax exemptions exist. A clear correlation between the financial support system and the way biogas is utilised is evident in the Task 37 member countries. In the UK and Germany with feed-in tariffs for electricity, this has led to most of the biogas being used to produce electricity, while the system with tax exemption in Sweden favours utilisation of the biogas as an automotive fuel. With benefits offered, gas grid injection will grow, as is the case in France, Denmark and the UK.

IEA BIOENERGY 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 work carried out by IEA Bioenergy Task 37: Energy from Biogas.

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