Biogas from AD

BIOEXELL Training Manual

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NOTE: This manual was compiled based on the working papers and other materials used at the biogas training actions, carried out by the national partners of the BIOEXELL project. The editor apologise for the cases where references are missing.

Summary

What is biogas from anaerobic digestion?

ANAEROBIC DIGESTION - A natural process

Anaerobic digestion (AD) is indigenous to natural anaerobic ecosystems and represents the microbiological conversion of organic matter to methane in the absence of oxygen. The process is also known as the biogas process and has been widely utilised by modern society for stabilising primary and secondary sludge in wastewater treatment plants. AD is commonly used for the treatment of animal manure, organic waste from urban areas and food industries (co-digestion), more often associated with energy recovery and recycling of the digested substrate (digestate) as fertiliser to the agricultural sector.

Anaerobic digestion (AD) is a natural process during which bacteria break down the carbon in organic material. This process produces a mixture of methane and carbon dioxide, a mixture called biogas. The process occurs only in the absence of oxygen, hence the term "anaerobic" (literally meaning "without air"). Anaerobic digestion occurs naturally in the sediments at the bottom of lakes and ponds, in bogs and in the intestines of ruminant animals such as cows.


Figure 1: Examples of a German Farm Scale Plant (left) and a Danish Centralised co-digestion Plant (right)

This ability of bacteria to produce methane from organic material has been harnessed in specially constructed anaerobic digestion plants. At the core of these plants is the digester tank - an airtight tank in which digestion takes place. The digester is fed with organic matter and produces biogas. The digested substrate is called digestate. The digestate consists principally of nutrient rich liquid and undigested fibres. The digestate can be passed through a separator, which separates a fibre fraction from the liquid. The liquid fraction is a fertiliser containing the valuable nutrient nitrogen and some of the phosphorus and potassium, in a form that is more available for the crops than in undigested slurry. The fibre-fraction, reach in phosphorus, can be composted to produce a high quality soil conditioner, with similar properties to peat in horticultural products. The biogas can be used to produce heat in a gas boiler, or electricity and heat using an engine and a generator or it can be purified and used as vehicle fuel. Latest research shows possibilities to use biogas for fuel-cells and hydrogen production.

Thus, an anaerobic digestion plant has three main products:

- Biogas, for energy production
- Liquid fertiliser
- Fibre for compost

Anaerobic digestion plants can be constructed to operate at any scale. On-farm digestion plants are generally small and treat only slurry produced on the farm. Biogas is usually burned in a boiler to supplement farm and home heating requirements. Large-scale anaerobic digesters to which organic matter from a variety of sources is brought are called centralised biogas plants. Biogas from such plants is generally passed through a Combined Heat and Power plant (CHP). The electricity generated is fed to the national grid, while heat is used locally.

BIOCHEMICAL BASICS

The anaerobic digestion process occurs in the following four steps:

1. ***Hydrolysis***: large polymers are broken down by enzymes.
2. ***Acidogenesis***: acidogenetic fermentations are most important, acetate is the main end product. Volatile fatty acids are also produced along with carbon dioxide and hydrogen.
3. ***Acetogenesis***: Breakdown of volatile acids to acetate and hydrogen.
4. ***Methanogenesis***: Acetate, hydrogen are converted to methane and carbon dioxide.

PROCESS DESIGN AND TECHNIQUE

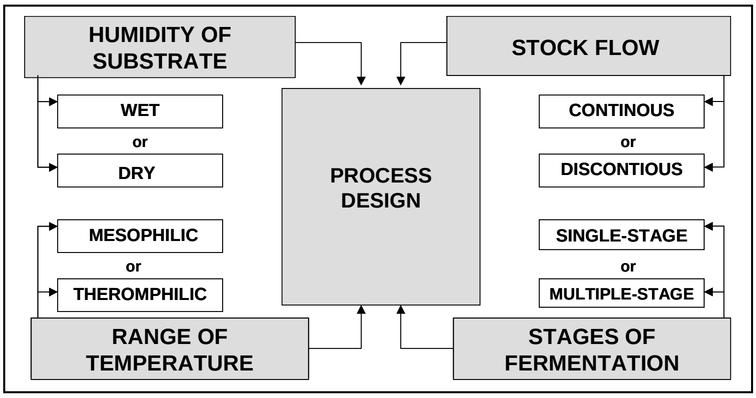

Figure 2: The four principles of AD process design

In the fermentation processes two different temperature ranges are distinguished:

- mesophilic temperature from 25 °C to 35 °
- thermophilic temperature from 49 °C to 60 °

The majority of the agricultural biogas plants are operated at mesophilic temperatures. Thermophilic temperatures are applied mainly in large-scale centralised biogas plants with co-digestion, where more stringent sanitation requirements are required [1].

The mode of feeding can be continuous or discontinuous. In discontinuous batch systems the fresh substrate is fed together with an inoculation of digested material into a reaction vessel. During one or two days the material is aerated in order to increase the temperature. During the following two or three weeks the substrate is anaerobically degraded, at first with an increasing daily gas production. After having reached a maximum after approximately 10 to

14 days, gas production decreases again to reach a plateau of about half the maximum production. To compensate for the unsteady gas formation three to four batch digesters are operated in parallel but filled at different times. Batch systems until recently are not very common for agricultural biogas plants [1].

Another form of the discontinuous process design is the storage systems. They combine digester tanks and retention tanks in one and the same tank. The combined fermentation and holding tank is slowly filled with fresh manure depending on the produced amount. The advantage of this system is the low costs. However problems may arise from high heat losses and unsteady gas formation rates [3].

Accumulation continuous flow (ACF)-systems are the most popular digester design in farm scale biogas sites. The fresh manure flows into the digester as it is produced. The digested manure is removed occasionally, when it is needed for fertilisation. When no fertilizer is needed, the full digester overflows into a holding tank, which is covered by a rubber membrane serving as a gas storage.

Another popular system is the continuous flow tank reactor. Here the raw waste is pumped regularly into the digester, displacing an equal volume of digested material. The volume in the digester remains constant. Most of the smaller systems are fed once or twice a day. The larger digesters are operated more continuously with feeding intervals of less than one hour [1]. There are several types of digester designs and mixing systems as shown in figure 4.

A biogas plant involves more than just a gas tight manure pit or a digestion vessel, it is usually built up of four elements (figure 3):

- The production unit, which includes the anaerobic digester, possibly a holding tank and/or a sanitation unit and the manure removal system.
- The gas storage and gas upgrading system
- The equipment for gas and manure utilization

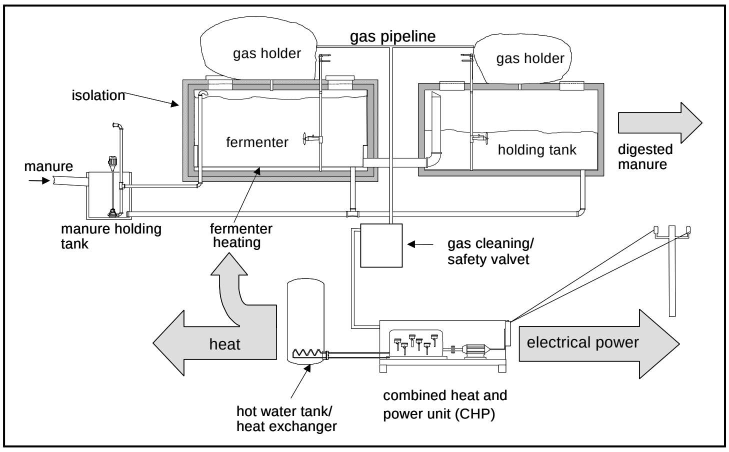

Figure 3: Biogas Plant: accumulation continuous flow (ACF)-system [2]

There are countless types of designs for each of the four elements. Some of the more widespread designs are highlighted in the following text.

The digester can be designed horizontally or vertically. The horizontal design has the following advantages: efficient and energy-saving mixers can be used. In horizontal digesters the fresh substrate is not mixed with the digested substrate at the other end of the digester (plug-flow). In this way high gas yields are achieved. For technical and economical reasons horizontal digesters are only built up to a maximum volume of 200-300 m³.

For Biogas plants with reactor volumes over 300 m³ usually digesters with vertical design are used. They are usually built of concrete with a round cross-section for structural reasons. Compared to the vertical design, the vertical digesters have the advantage of a better ratio of surface to volume. Thus material requirements and thermal losses are reduced. A key disadvantage is the fact that plug flow cannot be achieved [4].

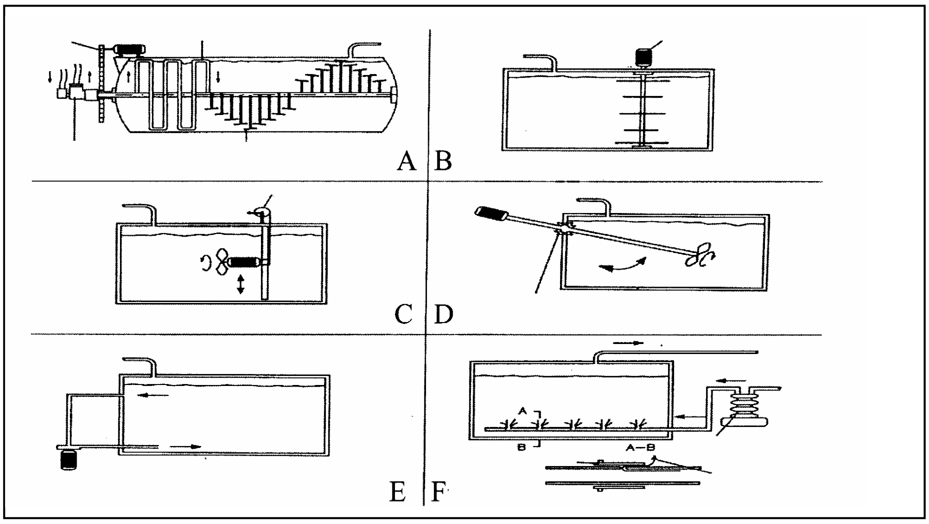

Figure 4: Different types of digesters and mixing systems [8].

A: Horizontal digester with horizontal paddle stirrer.
B: Vertical digester with vertical paddle stirrer.
C: Vertical digester with adjustable propeller stirrer.
D: Vertical digester with propeller mixer on a swivel arm.
E: Vertical digester with hydraulic mixing.
F: Vertical air lift digester.

The substrate in an agricultural biogas digester is usually mixed for the following reasons:

- Inoculation of the fresh substrate with digestate
- Distribution of heat to achieve an even temperature through out the digester
- Avoid or disrupt scum and sediment formation
- Release of biogas bubbles trapped in the substrate

If the substrate is not mechanically mixed it tends to separate, i.e. it forms a sediment and a solid scum. The scum is particularly difficult to remove after it has dried out through continuous gas production. The different types of stirrers are shown in figure 4.

In larger digesters usually two to three mixers are applied in different depths of the digester. In small size plants only one stirrer is installed for economical reasons. It is therefore important that it is adjustable for the mixing of a possible scum and sediment formation.

For all mixing purposes mentioned the speed of rotation is not important. Usually slowly rotating mixers are applied with rotations as low as 15-50 rpm. Again, not all types of stirrers are equally well adapted for all possible substrates. Hydraulic and pneumatic stirrers are restricted to dilute substrates such as pig manure with little potential for scum formation. A horizontal paddle stirrer on the other hand, is especially well designed for straw-rich cattle manure. However, it can also handle more dilute substrates. The most widely used stirrers are propeller mixers. They allow the most flexible application with respect to the substrate composition and the form and size of the digester. The only limit is the temperature for submerged motors. Above a digestion temperature of 40 °C there is not enough cooling [1].

Once the digester is working properly the quality of the produced biogas has to be improved. Usually sulphur removal is necessary to avoid corrosion, which can damage the CHP unit and lead to high sulphur dioxide emissions after combustion. In on-farm biogas sites the biological method to remove hydrogen sulphide from the gas is applied in many cases. This system uses the ability of sulphide oxidising autographic microorganisms like Thiobacillus oxidants to convert H_2S to elementary sulphur and sulphate. For this microbiological oxidation air has to be added to the biogas. Usually the required air is added directly to the digester or in some cases also to the gas holding tank or to a special gas-cleaning unit. The amount of air needed for the process ranges between 2 % and 6 % of the biogas, depending on the H_2S concentration. For large digesters (e.g. in centralized AD plants) external biological scrubber columns or chemical adsorber columns are often applied [2].

The most common utilisation of biogas is in combined heat and power engines (CHP) or, in the case that electricity injection into the grid is not possible, heat production by burning in a boiler. For smaller biogas plants CHP units with double fuel diesel engines are mainly used if the installed electrical capacity is less than 100 kW_{el}. These engines need the injection of approximately 8-10 % of diesel fuel for ignition and are therefore able to handle a variation in quality of the used biogas. Applications with higher biogas yield are suitable to use gas-otto engines, which do not need the addition of liquid fuel and show a higher electric efficiency. In future fuel cells may be a commercial option and depending on local legislation the injection of biogas into the national gas grid are possible alternatives for the use of biogas (figure 5).

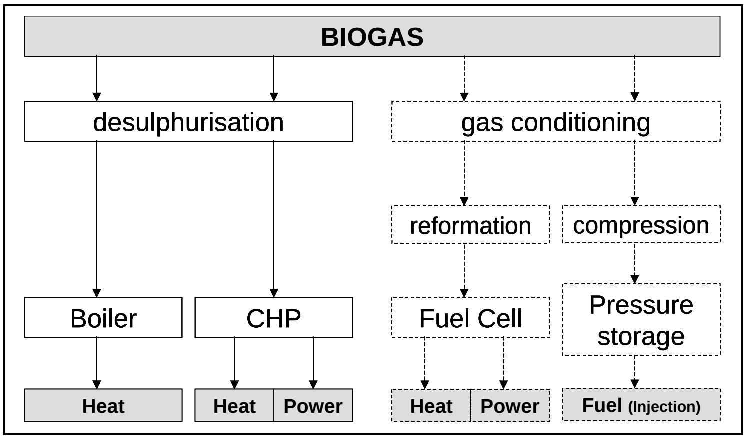

Figure 5: Scheme of different possibilities to use biogas.

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European legislation affecting the biogas sector

Anaerobic digestion (AD), together with composting, represents a sustainable, natural route of treatment & recycling of wastes of biological origin and a wide range of useful industrial organic by-products.

Caused by a steadily increasing biowaste collection, treatment and recovery, numerous EC-regulations and guidelines have been issued in this area, or are currently under development. Most of these regulations profoundly influence the technological developments and practical applications of AD. The most important pieces of legislation are now presented.

1. COUNCIL DIRECTIVE 75/442/EEC OF 15 JULY 1975 ON WASTE

Directive 75/442/EEC contains definition of wastes, together with guidelines for waste classification as well exclusion of specific wastes (e.g. radioactive materials, animal carcases, waste waters). Member States shall take the necessary measures to ensure that waste is disposed of without endangering human health and without harming the environment. In article 3 member states are requested to take appropriate steps to encourage the prevention, recycling and processing of waste, the extraction of raw materials and possibly of energy there from and any other process for the re-use of waste.

2. THE SEWAGE SLUDGE DIRECTIVE 1986/278/EEC

The directive 1986/278/EEC "Protection of Environment and Soil at the Utilization of Sewage Sludge in Agriculture" defines limiting values for heavy metals, organic trace compounds and defines hygienic requirements for handling and application of sewage sludge on agricultural soils. In addition the Regulation on Organic Farming 2092/91/EWG defines heavy metal limiting values for compost derived from source separate collection of municipal biowaste.

3. THE WATER FRAMEWORK DIRECTIVE 2000/60/EC

The water framework directive affects water industry, agriculture, development and construction industry and all businesses that have discharge consents, trade effluent licences or abstraction licences. The aim of the 72 pages Directive is to establish a framework for the protection of waters. As its name suggests, the Directive sets out a framework for action rather than imposing a set of rules.

4. COUNCIL DIRECTIVE 1999/31/EC ON THE LANDFILL OF WASTE

The EC directive on the landfill of waste defines the goals of organic waste reduction in landfills (based on the year 1975) as follows: Reduction to 75 % by the year 2006, reduction to 50 % by 2009 and to 35 % by the year 2016.

5. TOWARDS A THEMATIC STRATEGY FOR SOIL PROTECTION – COM(2002) 179 FINAL

The Commission will present a thematic strategy on soil protection in 2004. The strategy is one of seven 'thematic strategies' foreseen under the EU's 6th Environment Action Programme. It will consist of legislation on community information and monitoring system on soil, as well as a set of detailed recommendations for future measures and actions. The monitoring system will build on existing information systems and databases and ensure a harmonised way of establishing the prevailing soil conditions across Europe. By the end of 2004 a directive on compost and other biowaste will be prepared with the aim to control potential soil contamination and to encourage the use of certified compost.

6. DIRECTIVE 2001/77/EC ON THE PROMOTION OF ELECTRICITY PRODUCED FROM RENEWABLE ENERGY SOURCES IN THE INTERNAL ELECTRICITY MARKET

The document states, that the exploitation of renewable energy sources is underused in the Community at the moment. For this reason the directive aims to promote an increase in the contribution of renewable energy sources to electricity production in the internal market for electricity and to create a basis for a future Community framework thereof. To ensure increased penetration of electricity produced from renewable resources, the member states are requested to set appropriate national indicative targets. The EC "White Paper" indicative target of 12 % by the year 2010 provides a useful guidance. Biogas is one of the possible renewable alternatives and its broader penetration, as an energy source should therefore well benefit from these efforts.

7. WORKING DOCUMENT BIOLOGICAL TREATMENT OF BIOWASTE

Currently the second draft version of the forthcoming regulation "Biological Treatment of Biowaste" is available. The current version has to be harmonised with the recently published Animal By-product Regulation (EC) No 1774/2002. Furthermore it has to be adopted to the EC "Thematic Strategy for Soil Protection" – COM (2002) 179 final.
A revised third version of "Biological Treatment of Biowaste" has been announced for the year 2004.

The forthcoming regulation will contain:

- a list of allowable wastes for bio-treatment,
- directives for waste collection, handling and treatment,
- approval of treatment plants and allowable processing emissions,
- quality classes for bio-treatment residues and compost,
- control and analysis of end-products and
- application standards for the end-products.

In the current version, hygienisation of the bio-waste has to be guaranteed by a

- minimum temperature of 55 °C for at least 24 hours, at an average hydraulic dwell time in the reactor of at least 20 days.

If that is not guaranteed than a

- pre-treatment at 70 °C for 1 hour or a
- post-treatment of the solid digestate at 70 °C for 1 hour or
- Composting of the solid digestate is required.

Concerning quality standards, 3 categories of solid end product (compost) respectively stabilised waste have been defined. According to category 1 and 2 compost qualities, land application quantities will be regulated.

8. ANIMAL BY-PRODUCTS REGULATION (EC) NO 1774/2002

The Regulation (EC) No 1774/2002 of the European Parliament and the Council from 3 October 2002 laying down health rules concerning animal by-products not intended for human consumption (ABP, Animal By-Products Regulation) has to be applied in all Member States since May, 1st 2003.

Animal by-products (ABP) are defined as all animals or parts of animals not intended for human consumption. This includes dead on farm animals, animal manure and catering waste. Catering waste means all waste food including used cooking oils originating in restaurants, catering facilities and kitchens, including central kitchens and household kitchens.

Since inappropriate processing standards and the use of rendered products and catering waste are believed to be the main reason for major pandemic outbreaks of BSE (Bovine Spongiform Encephalopathy) and FMD (Foot and Mouth Disease), consequently rigorous measures had to be taken. The new regulation will require major changes in processing procedures by both waste producers and waste managers. In this Regulation 3 "risk – categories" are classified and new rules for the collection, treatment and disposal of animal by-products, including animal manure and catering waste (kitchen waste, restaurant waste etc.) are introduced.

8.1 Classification of animal by-products in 3 categories

Based on their potential risk to the public, to animals, or to the environment the Regulation (EC) No 1774/2002 (ABP regulation) classifies all animal by-products and their processed products and wastes into three categories and defines the corresponded treatment and utilisation possibilities.

Category 1 materials
Category 1 concentrates on animal by-products presenting the highest risk to the environment, animals or humans. This category contains, with others, the following materials:

- Animals or materials suspected or being infected by TSEs (Transmissible Spongiform Encephalopathies: BSE, MSE, FSE etc.)
- The SRM (specified risk materials) representing the material of (healthy) animals having the highest potential of containing the TSE pathogen such as the scull of 12 months old sheep and cattle and the intestines of cattle of all ages.
- Animals or parts of them with exceeding residues of environmental contaminants (e.g. dioxins, PCBs).
- Catering waste originating from international means of transport.
- Animal Waste collected in the wastewater stream of category 1 processing plants with a particle size > 6mm. Category 1 processing facilities have to apply a wastewater pre-treatment system removing all animal material with a particle size of more than 6 mm.

Category 2 materials
This category includes the following materials:

- Animals, or parts of them, representing a risk of being contaminated or transmitting any animal diseases (e.g. animals which die on farm or are killed in the context of disease control measures).
- Animal by-products with exceeding values of veterinary drugs.
- Animal Waste collected in the wastewater stream of slaughtering facilities (category 2 processing plants), with a particle size > 6mm (fat scraper contents, sand trap contents,

oil- and sludge residues). Category 2 processing facilities have to apply a wastewater pre-treatment system removing all animal material with a particle size of > 6 mm.

- Animal manure, contents of gut, stomach and intestines (separated from the intestines), milk and colostrums from animals not suspected to spread any diseases.

Category 3 materials
Category 3 contains:

- All animal materials derived from healthy animals slaughtered for human consumption, which are not intended for human consumption because of being rejected as unfit for human consumption or simply because of commercial reasons.
- Catering waste (with the exception of wastes from international means of transport which is classified as category 1) is also declared as category 3 materials.

8.2 Compulsory animal by-product treatment & recovery processes

The ABP regulation (EC) No 1774/2002 assigns to each ABP a compulsory treatment procedure and the corresponding utilisation possibilities according to the 3 categories previously described.

Category 1 Materials

Category 1 materials have to be collected without delay and marked (if possible with smell) or sterilised (50mm, 133°C, 3 bar, 20 min) and marked, followed by incineration in approved incineration plants. With the exception of TSE contaminated- or suspected materials, category 1 materials may also be sterilized (50mm, 133°C, 3 bar, 20 min), marked and buried in approved landfills. Catering wastes from international transportation may be sterilized and buried in approved landfills. Category 1 material may also be processed with other processes to be approved by the scientific committee.

Category 2 materials

Category 2 materials may be incinerated directly, sterilised and incinerated, or may be processed for uses other than animal feedings after sterilisation. For example processing in a biogas, composting or oleo-chemical plant and use as fertilizer, soil conditioner, and for technical products (except medical products). In case of no risk of infectious diseases unprocessed manure, rumen, gut and intestine contents, milk and colostrum may be applied on land, used in an approved pet food plant or used as unprocessed raw material in approved biogas and composting plants. Category 2 materials may also be processed with other processes to be approved by the scientific committee.

Category 3 materials

Category 3 materials may directly be incinerated, may be sterilised, marked and incinerated or buried in an approved landfill. Alternatively, category 3 material may be processed to pet food, pharmaceutical and cosmetic products following appropriate treatment in approved processing plants. Category 3 materials may be further processed in approved biogas and composting plants or in alternative processes approved by the scientific committee. Catering wastes (with the exception of category 1 catering wastes from international means of transport) may be processed in an approved biogas or composting plant according to national legislation.

8.3 Animal by-products permitted for bio-treatment

The ABP regulation (EC) No 1774/2002 permits biogas recovery or composting for a variety of animal by-products (table 1). Whether bio-treatment will be applied or not will be determined by the demands of pretreatment, process equipment requirements and allowable use of the end product digestate (compost). Consequently the treatment costs resulting will decide the appropriate allowable process selection.

In principle bio-treatment is not possible for all category 1 materials. As described earlier, only incineration or in some cases burial in an approved landfill are allowed.

All category 2 materials are allowed for bio-treatment provided the animal by-products have been sterilized, marked (smell) and the biogas plant applied has been approved according to article 15, (EC) No 1774/2002. The category 2 materials manure, stomach- and gut contents, milk and colostrum are exempted from the above requirements, provided absence of infectious diseases can be evidenced and the respective biogas plant has been approved according to national legislation.

Furthermore all category 3 materials are allowed for bio-treatment, provided the biogas plant has been approved according to article 15, (EC) No 1774/2002. Category 3 catering wastes are exempted from this approval and may be applied for bio-treatment in biogas plants according to national legislation based on the requirements of the ABP regulation.

Table 1: Allowable animal by-products to be processed in biogas plants, according. The ABP regulation EC 1774/2002

Category	***Animal By-product***	**Requirements**
1	Not envisaged	
2	Manure, stomach- and gut contents, milk, colostrum, all without any pretreatment	Absence of infectious diseases; Biogas plant approved according to National legislation
	All other category 2 materials	Sterilization (133°C, 3 bars, 20 min) and marking; Biogas plant approved according to (EC) No 1774/2002, article 15
3	All category 3 materials	Biogas plant approved according to (EC) No 1774/2002, article 15
	Catering waste except category 1 catering wastes	Biogas plant approved according to national legislation (according to (EC) No 1774/2002)

8.4 Practical approach with allowable category 2 and 3 materials

Manure, stomach and intestine contents, milk and colostrum are classified in category 2. These materials or mixtures of them with other biogenic wastes or raw materials (energy crops, silage) not covered by the ABP regulation, may be processed in biogas plants without pretreatment. The fermentation end product is classified as “manure” and may be used and applied on farm or pasture land like unprocessed manure without having to meet any requirements from this regulation.

To prevent unwanted uptake by ruminants, with the exception of manure (or manure derived digestate), all organic fertilizers are prohibited for application on pasture land (Article 22 [1], (EC) No 1774/2002).

A forthcoming new European Regulation, (SANCO/2380/2003) will lay down the pretreatment requirements for the application of manure and organic fertilizers (derived from ABP) on farm or pasture land.

As long as the manure (digestate) is not traded [1] or placed on the market [2], no further restrictions can be drawn from the ABP regulation.

If manure or manure-derived end products are placed on the market, the ABP regulation defines additional hygienic requirements. A heat treatment of 60 minutes at 70°C or an equivalent treatment according to article 33 (2) (EC) No 1774/2002 is obligatory. End products must be free from Salmonellae (absence in 25 g of end product) and Enterobacteriaceae (less than 1,000 colony forming units per g end – product).

As indicated earlier, catering waste is classified as category 3 materials in the ABP regulation.

Catering wastes are defined as waste food (including used cooking oil) originating from household kitchens, as well as catering services and restaurants. Catering wastes from international means of transport are classified as category 1 material and have to be disposed of.

Until the Commission decides to lay down other regulations, catering waste (category 3) or mixtures with manure may be processed in biogas or composting plants approved in accordance with national legislation. In this case the national authority may derogate from the requirements laid down in the Regulation (EC) No 1774/2002 if the process guarantees an equal reduction of pathogens.

The use of catering waste as swill for pig feeding is prohibited (Article 22, (EC) No 1774/2002). Only Germany and Austria may derogate there from until October 2006 under very strict treatment and control measures.

Anaerobic digestion of catering wastes may therefore possibly increase considerably.

8.5 Approval requirements for biogas plants according to article 15, Regulation (EC) No 1774/2002

Biogas or composting plants processing and converting animal by-products have to be approved in accordance with article 15 of the regulation (EC) No 1774/2002.
Biogas and composting plants treating only manure, stomach and intestine contents (separated from stomach and intestines), milk, colostrum (category 2) or catering waste and substrates not covered by the ABP-regulation may partly derogate from the requirements for the approval of the plant and the requirements for the corresponding fermentation end product.

Article15 demands 5 major conditions to be fulfilled for bio-treatment plants.

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[1] trade means: trade between Member States in goods within the meaning of Article 23(2) of the Treaty

[2] placing on the market means: any operation the purpose of which is to sell animal by-products, or products derived there from covered by this Regulation, to a third party in the Community or any other form of supply against payment or free of charge to such a third party or storage with a view to supply to such a third party

- *I.) meet the requirements for the approval of biogas or composting plants (Annex VI, Chapter II, Part A);*
- *II.) handle and transform animal by-products in accordance with the hygiene requirements and processing standards (Annex VI, Chapter II, Parts B and C);*
- *III.) be checked by the competent authority (in accordance with article 26);*
- *IV.) establish and implement methods of monitoring and checking the critical control points and*
- *V.) ensure the digestion residues and compost, as appropriate, comply with the microbial standards (Annex VI, Chapter II, Part D).*

These 5 major conditions requested are laid down in 15 paragraphs. Among these are most important:

1.) Biogas plants must be equipped with:

- *a.) a pasteurisation / hygienisation unit, which cannot be bypassed with:*
- *b.) adequate facilities for cleaning and disinfecting vehicles and containers on leaving the biogas plant.*

However a pasteurisation / hygienisation unit is not mandatory for biogas plants that transform only animal by-products that have undergone processing method 1 (i.e. steam sterilisation at 3 bars, 133^{0}C for 20 min).

2.) Each biogas plant must have its own laboratory, or make use of an external laboratory. The laboratory must be equipped to carry out the necessary analysis and approved by the competent authority.

3.) Only the following animal by-products may be transformed in a biogas or composting plant:

- *a.) Category 2 material when using processing method 1 (steam sterilisation: 50mm, 133°C, 3bar, 20 min) in a category 2 processing plant;*
- *b.) Manure and digestive tract content and*
- *c.) Category 3 material.*

4.) Animal by-products must be transformed as soon as possible after arrival. They must be stored properly and treated.

5.) Containers, receptacles and vehicles used for transporting untreated material must be cleaned in a designated area. This area must be situated or designed to prevent risk of contamination of treated products.

6.) Preventive measures against birds, rodents, insects or other vermin must be taken systematically. A documented pest control programme must be used for that purpose.

7.) Cleaning procedures must be documented and established for all parts of the premises. Suitable equipment and cleaning agents must be provided for cleaning.

8.) Hygiene control must include regular inspections of the environment and equipment. Inspection schedules and results must be documented.

9.) Installations and equipment must be kept in good state of repair and measuring equipment must be calibrated at regular intervals.

10.) Digestion residues must be handled and stored at the plant in such a way as to preclude recontamination.

11.) Category 3 material used as raw material in a biogas plant equipped with a pasteurisation/hygienisation unit must be submitted to the following minimum requirements:

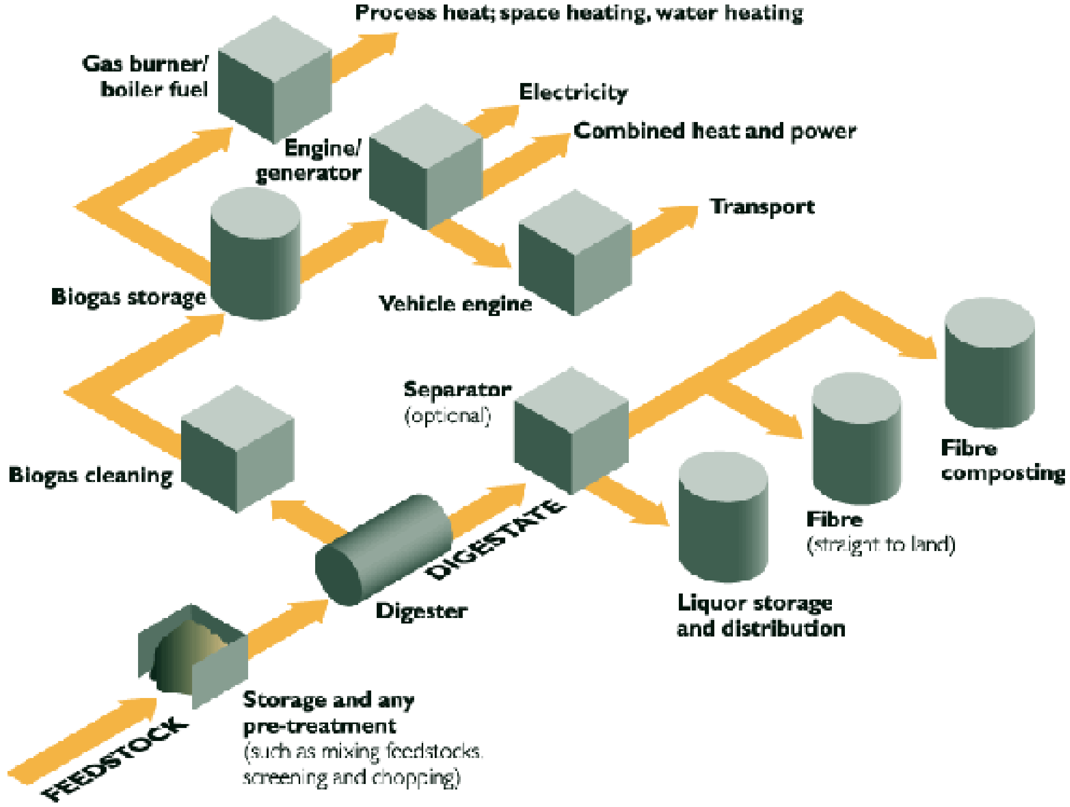
a.) maximum particle size before entering the unit: 12 mm

b.) minimum temperature in all material in the unit: 70^{0}C and

c.) minimum time in the unit without interruption: 60 minutes

Utilization of biogas – Present and future

Biogas is available from landfill sites, wastewater treatment plants, agricultural and livestock operations, food processing plants, gasified woody biomass, or other sources of organic waste. The combustible portion of the gas is methane (CH_4). Most of the rest is CO_2, with small amounts of nitrogen, oxygen, hydrogen, water (the biggest source of problems in biogas applications), hydrogen sulphide and trace elements.



* Source: British Biogen, AD good practice Guidelines

Figure 1: Overview of the AD Process /biogas utilization

BASIC TECHNOLOGIES FOR THE UTILIZATION OF BIOGAS ARE AS FOLLOWS:

1. Heat Production

Medium-calorific heating value- biogas can be used in a number of ways. (Domestic, Industry, Agriculture, district heating) Typically after condensate and particulate removal, the biogas is compressed, cooled, dehydrated and then be transported by pipeline to a nearby location for use as fuel for boiler or burners. Minor modifications are required to natural-gas-fired-burners when biogas is used because of its lower calorific heating value. Another alternative for biogas applications is to generate steam using a boiler onsite. The biogas, after condensate and particulate removal and compression, is burned in a boiler. The customer for this steam would need to be close to the site since high pressure steel insulated pipeline is expensive and heat is lost during transport. Heat production is the simplest and most common application for biogas. The combustion of biogas gives rise to low emissions of nitrogen oxides of about 35-50mg/MJ, which is around half the level for oil combustion.

2. Generation of Electric Power using reciprocating engines, gas turbines, steam turbines, Microturbine, and Fuel Cell

Electricity generated on-site using a reciprocating engine, steam turbine, or gas turbine, is being actively used. When a reciprocating engine is used, the biogas must have condensate and particulates removed. In order to move fuel gas into a gas turbine combustion chamber, the biogas must have most of the visible moisture and any particulates removed and then compressed. Using a steam turbine requires generating the steam first. Microturbine can be used to generate electricity at a capacity as small as 30 kW. However, issues exist in the high cost for biogas clean up and limited engine-running time when a Microturbine is applied. The microturbine technology has not been commercialised. High cost associated with biogas clean up is also an important issue for potential application of the fuel cell technology.

Fuel Cells are power-generating systems that produce DC electricity by combining fuel and oxygen (from the air) in the electrochemical reaction. In a first step the fuel is transformed into hydrogen either by a catalytic steam reforming conversion or by a (platinum) catalyst. The H_2 is converted to direct electrical current. The by-products of the reaction are water and CO_2. Conversion efficiency to electricity is expected to exceed 50%.

3. Combined Heat and Power Production (CHP)

The combined production of power and heat is commonly encountered alternative to heat production alone. The split between the amount of electricity and heat produced is determined by the design of the plant, but the normal value is about 35% electricity and 65% heat with a total efficiency of about 90%. In the case of CHP production, the biogas must be drained or dried, but in case, the soot emitted must be trapped and certain corrosive components, such as hydro-sulphuric acid and chlorinated hydrocarbons must be separated off

4. Vehicle fuel

The utilization of biogas as vehicle fuel uses the same engine and vehicle con-figuration as natural gas. However, the gas quality demands are strict. With respect to these demands the raw biogas from a digester or a landfill has to be upgraded. In practice this mean that carbon dioxide, hydrogen sulphide, ammonia, particles, trace components and water have to be removed so that the product gas for vehicle fuel use has a methane content above 95%. A number of biogas upgrading technologies, such as Selexol, Water Absorption, Chemical Absorption, and Pressure Swing Absorption (PSA) have been developed for the treatment of biogas. Using biogas in towns as a fuel for vehicles such as buses, taxis and communal vehicles can make economic sense and has evident environmental advantages.

5. Injection into an existing natural gas pipeline

Biogas can be upgraded into high- calorific heating value gas and injected into a natural gas pipeline. As compared with other power generation alternatives, the capital cost for sale of upgraded pipeline quality gas is high because treatment systems that are used to remove CO_2 and impurities are required. Also, upgraded gas needs a significant amount of compression to conform to the pipelines pressure at the interconnect point. However, the advantage of pipeline quality gas technology is that:

- the biogas is the only way to produce renewable natural gas,

- biogas may supply 10 to 30% of natural gas needs across Europe
- biogas can contribute to the security of gas supply in Europe
- biogas is also well distributed, so that the grid would be less vulnerable to any crisis
- it is easier to transport the energy into the cities than cities to the energy.

6. Conversion to other chemical forms

It is possible to convert the biogas to another form such as methanol, ammonia, or urea. Of these three options, conversion to methanol is the most economically feasible. In order to convert high methane content gas to methanol, water vapour and carbon dioxide must be removed. In addition, the gas must be compressed under high pressure, reformed, and catalytically converted. This tends to be an expensive process, which results in about 67 percent loss of available energy.

BIOGAS PERSPECTIVES FOR THE FUTURE

Gases are the fuels of the future. As sources of energy, gases have distinct advantages over liquid and solid fuels both technically and environmentally. In the ecologically sustainable society of the future, the greater part of waste products will be used for production. Natural gas forms an important bit in the puzzle of this development. That is why we are actively working with other gas fuel projects, both to develop biogas and the use of gas fuels. Apart from natural gas we can, to a limited extent today, offer our customers biogas.

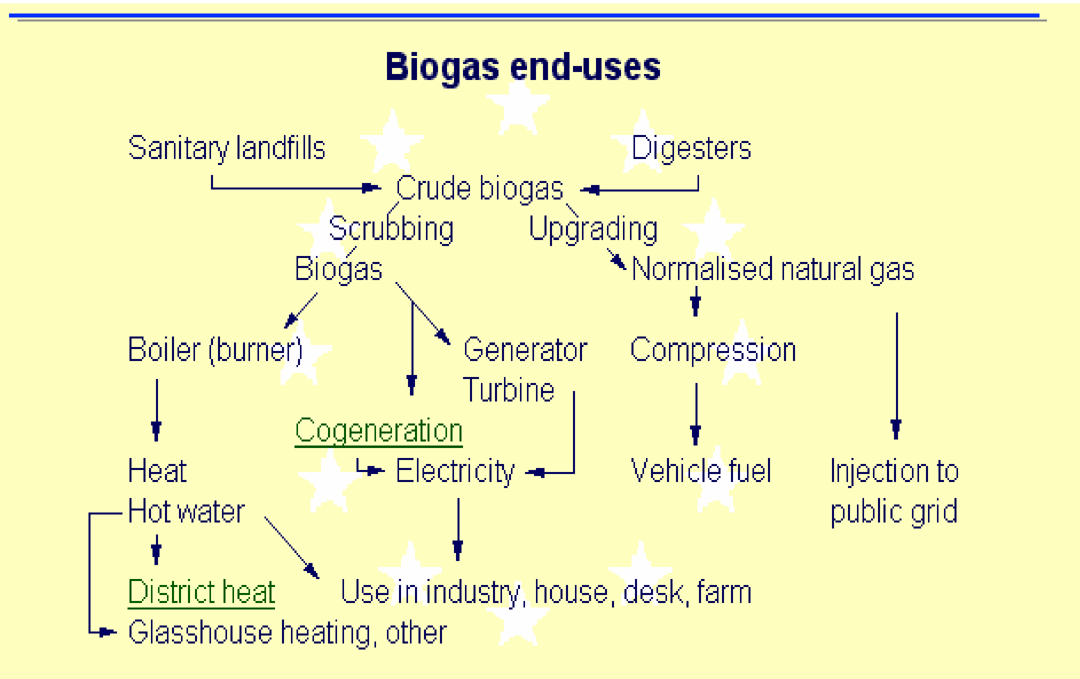


Figure 2: Biogas end-uses.

Development towards hydrogen (Source: SYDGAS)

Hydrogen is expected to be an important energy source in the future. It is produced from water and electricity made from biogas, wind power or solar energy.

Areas where hydrogen can be a significant carrier of energy are things like:

- vehicle fuel
- raw material and fuel for industry
- fuel for generation of electricity
- fuel for heating and cooling buildings

There are many indications that hydrogen will, in the long term, be the fuel that solves energy requirements in an environmentally viable way.

Quality management and safe recycling and of digestate

One of the main aims of today's waste management policies is to reduce the stream of organic waste going to landfills and to recycle the organic matter and the nutrients back to the soil, in a way that is safe for the environment, humans and animals. The modern technologies of manure and biogenic waste treatment and recycling must not result in new routes of pathogen and disease transmission between animals, humans and the environment or in organic and inorganic contamination of soil and water. Safe recycling of AD residues implies comprehensive quality management measures, implemented as an integrate part of national waste policies.

OUALITY MANAGEMENT OF DIGESTATE: THREE MAIN LEVELS

The quality management of digestate refers to the three main levels of the AD cycle (figure 1):

A: Quality management of feedstock
B: The AD process
C: Digestate declaration and optimal utilisation as fertiliser

The main issues of quality management are related to the control of chemical pollutants (organic and inorganic), breaking the chain of diseases transmission by inactivation of pathogens and other biological hazards, removal of physical impurities and nutrient declaration and recycling.

QUALITY MANAGEMENT OF FEEDSTOCK

This is one of the most important steps in ensuring a high quality end product (digestate), suitable for a safe recycling as fertiliser.

Most common categories of feedstock for anaerobic digestion are:

- Vegetable biomass from agriculture
- Animal manure and slurry
- Digestible organic wastes of vegetable and animal origin from food industries.
- Organic fraction of household waste / food remains, of vegetable and animal origin.
- Sewage sludge

Before being supplied to the AD plant, each type of biomass must be analysed and characterised concerning:

- Origin (the name and address of the company producing the waste), description of the process, the raw or processed materials the waste originates from, amounts available and the security of supply.
- In case of household waste, the area of collection, if source separated or not and the collection recipients (plastic bags, paper bags, bins, other).
- Declaration of the content of macro and micro- elements, heavy metals, persistent organic compounds, pH, dry matter etc.

- Organoleptic description (colour, texture, smell etc.).
- Eventual hazards related to handling or to the utilisation as soil fertiliser /soil conditioner.

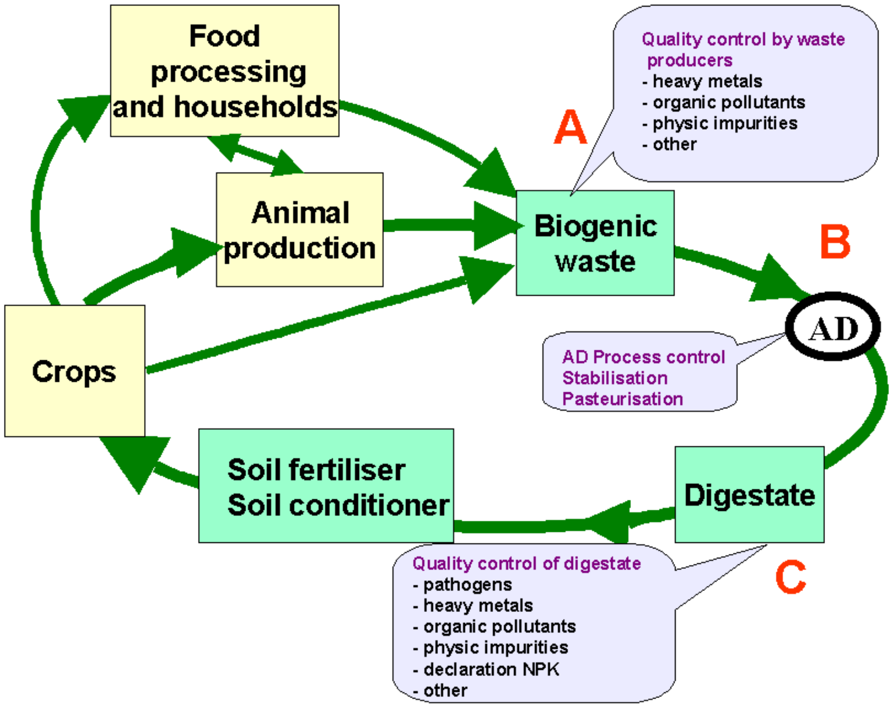


Figure 1: Schematic representation of the closed cycle of anaerobic digestion of biogenic waste and the three main steps (A, B and C) of the quality management of digestate.

MANAGEMENT OF CHEMICAL CONTAMINANTS

1. Inorganic contaminants/ heavy metals

Heavy metals are elements having atomic weights between 63 and 200. When inappropriately managed, digestate applied as fertiliser may transport dissolved heavy metals to agricultural fields. The presence of heavy metals in digestate occurs from natural and anthropogenic sources. Of particular concern for digestate are: cadmium (Cd), chromium (Cr), mercury (Hg), lead (Pb), copper (Cu), nickel (Ni), zinc (Zn). Cadmium e.g. may be incorporated into plant tissue. Accumulation usually occurs in plant roots, but may also occur throughout the plant.

Excess metal levels in soils, surface and ground water may represent a health risk, by direct or indirect toxicity, cause eco-toxicity and environmental accumulation. The toxic effect depends on concentration, biological availability and varies with species differences. Slightly elevated metal levels in natural waters for example may cause sub-lethal effects in aquatic organisms such as: histological or morphological change in tissues, suppression of growth and development, changes in circulation, enzyme activity and blood chemistry, change in behaviour and reproduction etc [3].

<u>Table 1:</u> Example of concentrations limits of heavy metals in sewage sludge (mg/kg DM) for application on farmland in different European countries.

Country/ Region	Cd	Pb	Hg	Ni	Zn	Cu	Cr
EU, recommend.	20	750	16	300	2500	1000	1000
EU, maximum	40	1200	25	400	4000	1750	1500
Austria	4	500	4	100	1000	400	150
Belgium	6	300	5	50	900	375	250
Denmark	0.8	120	0.8	30	4000	1000	100
Finland	1,5	100	1	100	150	600	300
France	20	800	10	200	3000	1000	3000
Germany	10	900	8	200	2500	800	900
Ireland	20	750	16	300	2500	1000	1000
Italy	20	750	10	300	2500	1000	-
Luxemburg rec.	20	750	16	300	2500	1000	1000
Luxemburg max.	40	1200	25	400	4000	1750	1750
Norway	4	100	5	80	1500	1000	125
Spain (pH< 7)	20	750	16	300	2500	1000	1000
Spain (pH> 7)	40	1200	25	400	4000	1750	1200
Sweden	2	100	2.5	50	800	600	100
Switzerland	5	500	5	80	2000	600	500
The Netherlands	1,25	100	0,75	30	300	75	75
United Kingdom	-	1200	-	-	-	-	-

Source: [1], [2]

2. Persistent organic contaminants (organic xenobiotic substances)

The persistent organic compounds of xenobiotic origin represent a hazard to humans, environment and plants due to their toxicity and other environmental adverse effect. Numerous xenobiotic organic compounds are known to have estrogenic effect on vertebrates (xenoestrogens) or to be endocrine disruptors and are considered to be responsible for decline in human male reproductive health as well as for a number of forms of cancer in humans. The hazard effect is related to their volatility, mobility and water solubility, persistence/low biodegradability and bio-availability.

AD residues, composted materials and waste derived products can contain persistent organic contaminants according to the origin of their base ingredients. Agricultural wastes can contain pesticide rests, antibiotics and other medicaments. Industrial organic waste, sewage sludge and household waste can contain aromatic, aliphatic and halogenated hydrocarbons, organo-chlorine pesticides, PCBs, PAHs etc. Some of the most frequent organic contaminants are:

- PAH (Polycyclic aromatic hydrocarbons). Mainly found in smoke from incineration and the exhaust fumes from vehicles. They deposits on roofs and road surfaces, from where they are flushed into the sewage sludge systems by rainwater.
- DEPH (Di (2-ethylhexyl) phthalate). The compounds are primarily used as plastic softeners, especially of PVC (e.g. tarpaulins, toys, cars and vinyl flooring). By washing, the substance ends up in the sewage system.
- LAS (Linear alkyl benzene sulphonates). Primarily used as surfactants in detergents and cleaning agents.
- NP and NPE **(**Nonylphenol and nonylphe-nolethoxylates with 1-2 etoxy groups). Typically used as surfactants in detergents, cleaning agents, cosmetic products and vehicle care products. They find their way into the sewage system via wastewater from laundries and vehicle workshops and from cosmetics in household waste and sewage.

Table 2: Example of limit values for persistent organic pollutants in Denmark, valid from July 2000.

	Mg/Kg Dry Matter
LAS	1300
PAH's	3
NPE	10
DEPH	50

Source: [4]

The problem related to the control and management of the organic contaminants in digestate is that it is difficult to perform a screening of such a broad spectrum of contaminants at a reasonable cost. The most feasible way to deal with the problem is the feedstock quality control. Combined aerobic-anaerobic treatment of substrate is also largely utilised today in composting systems and in some cases in AD systems, as a post-treatment step.

Laboratory trials on the four groups of organic contaminants listed above show that a certain reduction of some of the persistent organic contaminants can occur during the anaerobic digestion [5]. Some conditions must be fulfilled: the presence of a relevant micro flora (bacteria populations), optimal life conditions for the relevant micro flora, the accessibility of persistent organic compounds to bacteria population, an adaptation period and a rather constant supply of the organic matter to the reactor. The reduction of LAS and NPE seems to be more effective than the reduction of DEHP and PAH's. The issue still requires further research based on full-scale trials.

3. Management of physical impurities

Physical impurities are considered all the non-digestible materials as well as the digestible and low–digestible materials, due to their particle size. Physical impurities are likely to be present in all kinds of biomass feedstock, but most frequently in household wastes, food waste, garden waste, straw, solid manure and other solid types or waste. The most common physical impurities are: plastic and rubber, glass, metal, stones, sand, larger particle size of digestible materials (roots, wood, bark etc.), other physical contaminants. Their presence in feedstock can cause fouling, obstruction and heavy wear of the plant components, disturb the operational stability and cause economic losses while their presence in digestate can cause aesthetic damage, pollution and trauma to the environment (PVC and other plastics, glass and metal etc.) [6].

The removal of physical impurities increases the public acceptance of the digestate as fertiliser and is mainly a matter of ensuring a high physical quality of the feedstock. This can be done either by source sorting or by on site separation (mechanically, magnetically or other). The feedstock can be collected through public or private systems of collection. The separation of the digestible fraction can be done already in the collection phase or it can be done later, using the known waste separation technologies.

3.1 Source sorting

The separate collection and source sorting is the method that gives a good feedstock quality and excludes contamination from other materials. Separate collection can be done in recyclable paper bags or in plastic bags (biodegradable or not). The collection in non-degradable plastic bags requires on site separation step, for the removal of the rests of plastic bags and lost of biodegradable matter, removed together with the plastic impurities.

3.2 On site separation

The extent of the on site separation depends of the waste collection method (separate or bulk) and the purity and the type of the collected waste. On site separation does not provide the same waste quality as the source sorted separate collection and can be more costly. It usually is part of a pre-treatment process.

MANAGEMENT OF BIOLOGICAL CONTAMINATION

The main biologic contaminants in AD substrates are various types of bacteria, viruses, intestinal parasites, prions and other contaminants. The modern technologies of manure and biogenic waste treatment should not result in new routes of pathogens and diseases transmission between animals, humans and the environment. Some main measures would contribute to ensuring a veterinary safe recycling of digestate:

- Livestock health control. No animal manure and slurries will be supplied from any livestock with health problems.
- Feedstock selection and control. Hazardous biomass types are excluded from anaerobic digestion and canalised towards suitable, safe disposal methods (table 3).
- Pre-treatment/sanitation of feedstock [7]

- Pressure sterilisation: 133^{0}C, 3 bar, for 20 minutes.
- Pasteurisation: 70^{0}C, for 1 hour.

- Regularly control of the efficiency of pathogen reduction measures in digestate [8].

EUROPEAN HEALTH RULES CONCERNING ANIMAL BY-PRODUCTS NOT INTENDED FOR HUMAN CONSUMPTION

Many countries enforced national veterinary legislation regarding pathogen control in digestate, but in order to ensure an unique European legislation and by this the same safety measures and quality standards all over Europe, a common EU regulation was adopted “laying down the health rules concerning animal by-products not intended for human consumption”[7].

The document outlines the methods and sanitary measures regarding the treatment of animal waste and the criteria for the future regulation of this area. Apart from this, a second draft of a working document concerning the biological treatment of biowaste, regulating the treatment and utilisation of all kinds of organic waste is about to be elaborated by the Commission.

The aim of these documents is to promote the biological treatment of organic waste by harmonising the national organic waste management measures, to prevent any negative impact on the environment and to ensure that the use of treated and untreated organic waste results in benefits for the agriculture and ecological improvement, to ensure the functioning of the internal market and to avoid obstacles to trade and distortion and restrictions of competition.

Table 3: Health rules concerning animal by-products not intended for human consumption

Category and description	Rules for utilisation
1. Animals suspected to be infected with TSE, specific risk material. - Animals, other than farm and wild animals, spec. pets, zoo and circus animals. - Catering waste from means of transport operating internationally	Always destruction incineration
2. Manure from all species and digestive tract content from mammalians. - All animal materials collected when treating wastewater from slaughterhouses or from category 2 processing plants, except from cat.1 slaughterhouse wastewater treatment plants. - Products of animal origin, containing residues of veterinary drugs. Dead animals, others than ruminants.	For AD must be pressure sterilised, for 20 minutes at 133^{0}C and 3 bars. NB: Manure and digestive tract content can be used for AD without pre-treatment.
3. All parts of slaughtered animals, declared fit for human consumption, or not affected by any signs of diseases. - Hides, skins,	For AD must be sanitised in separate tanks for 1hour at 70 ^{0}C.

Source: [7]

UTILISATION OF DIGESTATE AS FERTILISER AND NUTRIENT MANAGEMENT

Sampling, analysing and product declaration of digestate

To be recycled as fertiliser, digestate must have a defined content of macronutrients. Average samples of digestate must also be analysed for heavy metals and persistent organic contaminants, making sure that these are not exceeding the detection limits permitted by law.

Nutrient load per hectare

The application of digestate must be done on the basis of a fertiliser plan, elaborated for each agricultural field. The experience shows that an environmental and economic suitable application of digestate fulfils the phosphorus requirements of the crops and completes the nitrogen requirements from mineral fertiliser.

Inappropriate handling, storage and application of digestate as fertiliser can cause ammonia emissions, nitrate leaching and overloading of phosphorus. The nutrient loading on farmland is various regulated in different countries (table 4). The EU nitrate-directive (91/676/EEC nitrate) regulates the input of nitrate on farmland, aiming to protect the ground and surface water environment from nitrate pollution.

Table 4: Example of national regulations of the nutrient loading on farmland

	Maximum nutrient load (Kg N/ha y)	Required storage capacity	Compulsory season for spreading
Austria	100	6 months	28/2-25/10
Denmark	Until 2003 230-210 (cattle) 140-170 (pig) From 2003 170 (cattle) 140 (pig)	9 months	1/2-harvest
Italy	170-500	90-180 days	1/2- 1/12
Sweden	Based on livestock units	6-10 months	1/2- 1/12
UK	250-500	4 months	-

Source: [2]

CONCLUSIONS

The quality management of the anaerobic digestion residues implies quality control of the three main chains of the AD cycle: the feedstock, the digestion process, and the digestate. This is done by some main measures:

- Selection/excluding from AD of the unsuitable waste types / loads, based on the complete declaration of each load: origin, content of heavy metals, persistent organic compounds, pathogen contamination, other potential hazards etc.
- Source sorting and separate collection of digestible wastes, preferably in biodegradable recipients.
- Periodical sampling and analysing of the biomass feedstock.
- Extensive pre-treatment/on site separation (especially for unsorted waste).
- Pre-treatment for safe veterinary recycling
- Process control (temperature, retention time etc.) to obtain a stabilised end product.
- Periodical sampling, analysing and declaration of digestate.
- Handling, storage and application of digestate after a fertilisation plan throughout “good agricultural practice”.

SAFE RECYCLING OF DIGESTATE

Good agricultural practice - experience from Denmark

- Source sorting and separate collection of digestible wastes, preferably in biodegradable recipients.
- Selection / excluding from AD of the unsuitable waste types / loads, based on the complete declaration of each load: origin, content of heavy metals and persistent organic compounds, pathogen contamination, other potential hazards etc.
- Periodical sampling and analysing of the biomass feedstock.
- Extensive pre-treatment/on site separation (especially for unsorted waste).
- Process control (temperature, retention time etc.) to obtain a stabilised end product.
- Pasteurisation / controlled sanitation for effective pathogen reduction.
- Periodical sampling, analysing and declaration of digestate.
- Including digestate in the fertiliser plan of the farm and using a "good agricultural practice" for application of digestate on farmland.

Guidelines for optimum use of digestate

Example from Ribe Co-digestion Plant, in Denmark.

The guidelines are based on several years' field trials and experience achieved by advising the many farmers, who used digested slurry from Ribe Biogas Plant in Denmark.

- As a principal rule, digestate should only be applied at the start of the growing season, in March and April, and later on, only in vegetative growing crops.

- By the establishment of spring-sown crops, the digestate must be incorporated into the soil immediately after it has been applied. The time from application to incorporation must be as short as possible, to minimise ammonia volatilisation. The best thing to do is to simultaneously spread and incorporate the digestate.

- In over wintering crops, the crop must be started with one third of the total N-requirement in mineral fertiliser. The best utilisation of the digestate in over wintering crops is achieved in the period mid spring to early summer, when the crops are in vigorous vegetative growth. To make the digestate infiltrate quickly into the soil, dragging hose-equipment must be used. The most suitable crops for digestate utilisation are: Winter wheat, winter barley, winter rye and winter rape. Digestate can supply 50-70% of their N-requirement.

- The risks of ammonia volatilisation from digestate is rather high and can be reduced by using the right equipment - dragging hoses - and by taking the weather into consideration. During storage, handling and spreading it is important to take the ammonia volatilisation into consideration.

In figure 2 is shown a model calculation of the NH_3- and NH_4^+-concentration in Europe. The dark areas on the maps show high ammonia concentrations and are correlated with the areas with high animal production. Besides the environmental pollution, losses of nitrogen due to ammonia volatilisation are also an economic loss for the farmers.

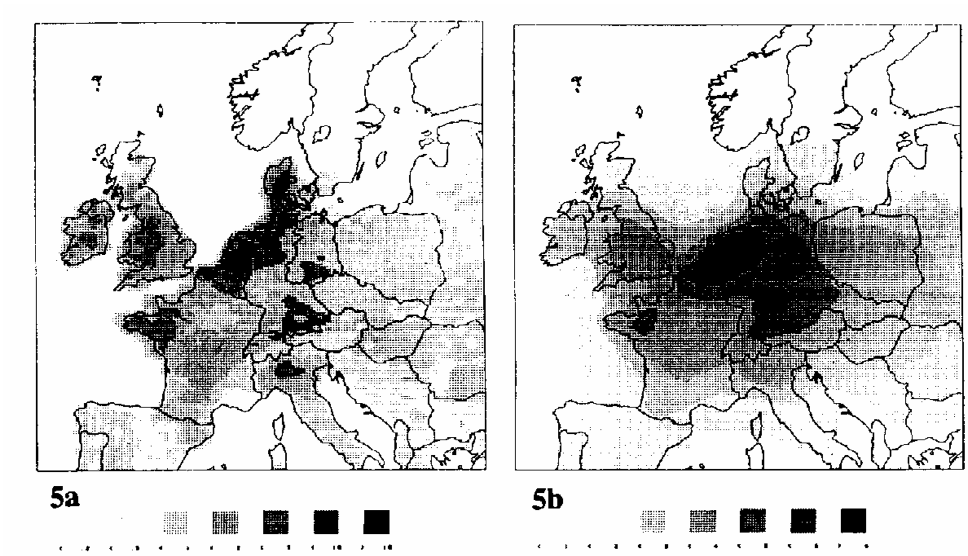


Figure 2: The calculated geographic distribution of the NH_3- and NH_4+-concentration in Europe (ug/m^3). Source: Holm-Nielsen, Halberg, Huttingford and Al Seadi, 1997.

The potential loss of ammonia from digestate during storage, under different conditions is shown in figure 3. In case of covered tank (not shown on the figure), the loss of ammonia is practically zero.

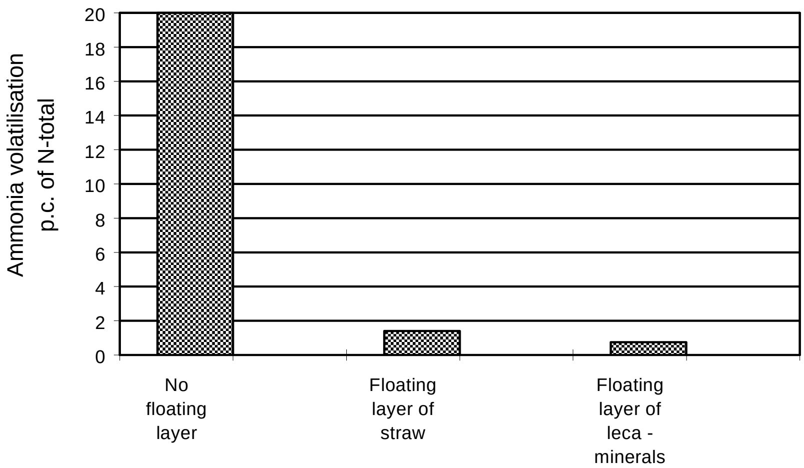


Figure 3: Ammonia volatilisation from storage tanks. Source: Holm-Nielsen, Halberg, Huttingford and Al Seadi, 1997.

To minimise the ammonia volatilisation, during the storage and spreading of digestate, some general guidelines should be followed:

- Always have a covered or a floating layer on the storage tank.
- Avoid stirring by always pumping from the bottom of the tank.
- The digestate should only be stirred just before application.
- Place storage tank where they are sheltered from wind and.
- Inject or incorporate the digestate in the topsoil immediately after application.
- Use dragging hoses when digestate is applied in growing crops (figure 4)
- Apply digestate only under optimum weather conditions: cool, humid and no wind.

There is a possibility to acidify the digestate when applied. This decreases the pH-value and thereby the liability of ammonia to volatilise.

Figure 4: Dragging hoses for the application of digestate, Source : BioPress

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Practical guidelines for planning a biogas plant

(Source: NIRAS and SDU)

KEY PRECONDITIONS FOR DEVELOPMENT

The main precondition for building a biogas plant is the existence of accessible, digestible biomass feedstock. This means that the biogas plant must be located in areas with high livestock density and easy access to industrial organic waste. The second most important precondition is to have a market for energy sale.

Some of the indispensable elements of the decision process are:

- The identification and the evaluation of the amount and the security of supply of digestible biomass resources in the area and the elaboration of a plan for biomass supplying.
- The existence and the evaluation of the potential market for energy sale (heat and electricity).
- Possibilities to get a favourable financing scheme (long term, low interest loans, grants etc).
- Careful evaluation of the environmental and socio-economic impacts (increased transport, odours, employment etc.) and of the public acceptance of the biogas plant.
- A general outline of the operational budget (main costs and income sources).

THE PLANNING ACTORS

The actors involved in planning a biogas plant are usually the farmers as slurry suppliers, the organic waste suppliers, the energy consumers, local authorities and decision makers, biogas planners and consultancy companies, biogas plant suppliers companies, financing companies, investment companies etc.

ORGANIZATION AND FINANCING

It is highly important that the planning phase does not exclusively concern the technical assessment but also focuses on the organisation and financing of the project. In connection with the assessment of the organisation, decisions should be made concerning the organisation both in the initial phase and in the operating phase. In the initial phase the choice roughly lies between two types of organisations:

I. The biogas plant can be bought by single contractor. The builder (builder’s consultant) invites tenders for the whole contract from either domestic or international contractors. The advantage is that the project is bought at a fixed price but the disadvantage is that it is difficult to determine how the plant is constructed and to calculate the impact on local employment.

II. The biogas plant can alternatively be established as an ordinary building project. This means that builder’s consultant designs the plant in detail and afterwards tenders are invited for part contracts. The advantage is that the builder gets a comprehensive insight into the construction of the plant and that the local impact on employment can be affected. Normally this method of calling in tenders results in cheaper plants. The disadvantage can be some uncertainty about the price.

In the building phase the definition of organisation can be postponed until the closing of a contract on consultancy. The plant can be owned and operated by an existing organisation (e.g. a larger company, power companies or public authorities). Usually it will be necessary to form a new organisation consisting of the involved parties. The organisation must observe the following objectives:

- achieve sufficient security for the economy of the company
- secure coherence between assumption of risk and the profit potentials
- secure coherence between influence on decisions in the organisation and profit potentials.

The chosen organisation, participants and especially the financial commitment of the participants in the project are of considerable importance for achieving satisfactory financial arrangements.

If the project is established and operated by a large well-consolidated company, the company will provide the required security. If the organisation is formed with the explicit purpose to establish and operate the plant, it may some times be difficult to establish the required security. In this case the measures are:

- invested capital from the participants
- sum guaranteed
- public guarantees secured because of the socio-economic, local economic and environmental advantages of the project.

The financing will usually be divided into two principal items:

- Grants (national or international)
- Loans

In connection with the assessment of the project it is of course necessary in the business plan to include the costs for financing (interests and repayment). The biogas plant is characterized by very large investments (extensive capital costs) compared to the operating costs. It is therefore necessary to procure financing, which is:

- Long-term (minimum maturity of 10-15 years)
- Loans with as low interests as possible.

As receipts derive sale of energy and possibly manure on ordinary market terms, which must (as a minimum) be expected to follow the ordinary price development, there will not be any risks involved in financing the plant with index regulated loans. Figure 1 shows the key elements of the economy of a biogas plant in Denmark.

KEY ELEMENTS OF CONSTRUCTION

Regardless the supplied types of biomass, any biogas plant will consist of the following main components:

Pre-storage/Receiving equipment: The biomass is received at the plant in pre-storage tank(s) and/or other equipment from which it will be admitted into the digesters. The purpose of the receiving equipments is to facilitate unloading and mixing procedures and to prepare the biomass for admission into the digesters. The pre-storage/receiving equipment must have a capacity which will prevent bottleneck situations from occurring and allow the plant to operate for a few days without further supplies (e.g. in connection with holidays).

Digesters: The capacity and process temperature of the digesters should allow a stable and efficient process. The tanks should always be heated and insulated so that the temperature can be controlled. In addition to this the digester must be provided with a stirrer, which will secure efficient mixing of the biomass.

Post -storage tanks: The purpose of the tanks is to operate as buffer tanks so that the plant can maintain production without removing biomass. In addition to this it is possible to extract gas (after digestion).

Pipe systems with pumps and valves: The total pipe system required for moving biomass, gas, process heat, etc.

Gas storage: Usually it will be an advantage to have some gas storage capacity before the gas reaches the place of consumption in order to compensate for fluctuations in the gas production. If the settling price of power differs between night and day, a possibility would be establish a storage which allows utilization of gas when the power price is at its highest. The gas storage should be constructed as a low-pressure storage.

Gas utilization: The gas is best utilized in a gas engine (power and possibly heat production). The power is sold to the mains. The heat can either be used as process heat or converted into cold in an absorption cooler. As an alternative the heat can be emitted.

THE PLANNING TASK

Feasibility studies

The potentials of a biogas plant can be established in a geographically defined area. The biogas plan may typically consist of the following items:

- mapping of manure resources
- mapping of waste products
- energy production and application/sales of energy
- supply scenarios (alternatives)
- estimate of consequences for the plant
- utilization of the digested product as manure

As an alternative the potentials can be studied based on a specific project. The contents will more or less be identical but be adapted to specific conditions at the site and the required plant concept. Table 1 shows the average biogas potential of the most common AD substrates in Denmark.

Location of the plant

The projects can be established in connection with a biogas plan or based on knowledge about local conditions. The following conditions must be observed:

- Accessibility to biomass – manure and/or various type of waste
- Possibilities of selling power and possibly heat (either directly or as cooling through absorption coolers)
- Political readiness to establish the project
- Possibilities of financing.

High-rate conversion requires available resources of a minimum of 40 t of biomass/day and a part of the biomass must be procured as high-grade waste products, etc.

Transport of biomass is one of the important operation costs for the biogas plant. Aiming to have a sustainable economy for the plant, a thumb rule must be considered: the nutrient value of the digested biomass unit must be at least the same or bigger that the total costs of treatment, storage and transport of the same digested biomass unit. This aspect must be considered when planning the emplacement of the plant in the area as well as the location of the post storage tanks for digested biomass.

NB: When deciding upon the location of a biogas plant, a suitable distance between the plant and the residential areas must be considered as well as the direction of the main winds, in order to minimise traffic and odour nuisances.

Mapping of resources and energy sale

The resources are mapped either directly or indirectly. By direct mapping the specific qualities and quantities are examined. It is often possible in industries or other enterprises, which have already established a more or less organized handling of the biomass. Indirect mapping indicates that quantity etc. is estimated from standard figures such as e.g. manure production per cow, waste production per inhabitant, waste quantity per slaughtered animal. The method is particularly suited for mapping of manure and organic household waste. In practice the methods are combined.

The following information about the biomass is obligatory:

- quantity
- quality (content of dry matter and a rough identification of type)
- possible seasonal variations
- present use/disposal (possibly including price of disposal).

Organisation

Besides the technical assessments the feasibility study should also contain an assessment of the organisation of the project under establishment and under operating conditions. As biogas projects aim at meeting requirements and solving problems for individuals, companies, groups, etc. it is essential that all interested parties are involved from the first steps of the planning phase.

Based on the interests and potentials of the interested parties the future builder/management organisation can be formed. In some cases the existing organisation is able to handle this task but often a completely new organisation is required. The organisation must be described and plans for a possible formation of a new organisation must be started already in the initial phases of the planning.

Financing

Biogas plant projects are characterized by large investments and relatively low operational costs (in principle the fuel is free). The financing is therefore extremely essential and it is important in connection with the feasibility study to identify possible sources of financing so that the costs of funds are known.

Mostly financing of grants and loans. In addition to this there can be certain amounts of invested capital or capital adequacies involved, made by interested parties. The optimal financing for biogas plants consists of long-term schemes (in Denmark loans over 20 years) with low interests. In order to obtain low interests it is of utmost importance to procure a considerable guarantee from financially solid partners.

Planning tools

Important planning tools are:

- Model for calculation of the quantity of biomass
- Models for calculation of the potential gas production
- Models for calculation of the investments
- Standard business plan
- Models for calculation of environmental impact
- Models for calculation of optimal utilization of the digested biomass as manure.

And most important:

- Dialogue with the involved parties
- Local adaptation of solutions
- Assessment of political acceptance.

The appendix lists a number of key figures and directions to be used in the planning phase.

These tools and routines can of course be refined and specified into details as required. But it is essential that the planning process starts at an overall level. The first phase will focus on the overall possibilities of establishing the plant. The financial possibilities are often totally indicative for the implementation so a business plan for the plant should already be prepared at this stage – in the introductory phases mainly based on a number of conditions and outlining estimates.

If the investigations indicate that the project is viable, the estimates are calculated into details and the conditions are gradually exchanged with specific knowledge about actual conditions, agreements, etc.

<u>Table 1:</u> Estimated biogas potential of the most common AD substrates in Denmark

Biomass	**TS (%)**	**VS/TS** (%)	**VS** (%)	Specific methane potential $m^3CH_4/kgVS$	Specific methane production m^3CH_4/ton
Cattle manure	8.00	80.00	6.40	0.200	12.8
Pig manure	5.00	80.00	4.00	0.300	12.0
Poultry droppings	5.00	80.00	4.00	0.300	12.0
Mixed manure	6.50	80.00	5.20	0.250	13.0
Solid manure, cattle	20.00	80.00	16.00	0.200	32.0
Solid, manure, pigs	20.00	80.00	16.00	0.300	48.0
Solid manure, poultry	20.00	80.00	16.00	0.300	48.0
Liquid manure, cattle	3.00	80.00	2.40	0.200	4.8
Liquid manure, pigs	2.50	80.00	2.00	0.300	6.0
Stomach/intestinal content, cattle	12.00	80.00	9.60	0.400	38.4
Stomach/intestinal content, pigs	12.00	80.00	9.60	0.460	44.2
Flotation sludge	5.00	80.00	4.00	0.540	21.6
Fish sludge	4.00	80.00	3.20	0.250	8.0
Bleach clay	98.00	40.00	39.20	0.800	313.6
Fish oil	90.00	90.00	81.00	0.800	648.0
Whey	5.00	90.00	4.50	0.330	14.9
Whey concentrate	10.00	90.00	9.00	0.350	31.5
Size	15.00	80.00	12.00	0.400	48.0
Jam	15.00	85.00	12.75	0.330	42.1
Soya bean oil/ margarine	95.00	90.00	85.50	0.800	684.0
Alcohol	40.00	95.00	38.00	0.400	152.0
Waste water sludge	5.00	75.00	3.75	0.400	15.0
Conc. waste water sludge	10.00	75.00	7.50	0.400	30.0
Refuse	30.00	85.00	25.50	0,400	102.0

Source: DTU, Denmark

AD = anaerobic digestion
TS = total solids
VS = volatile solids

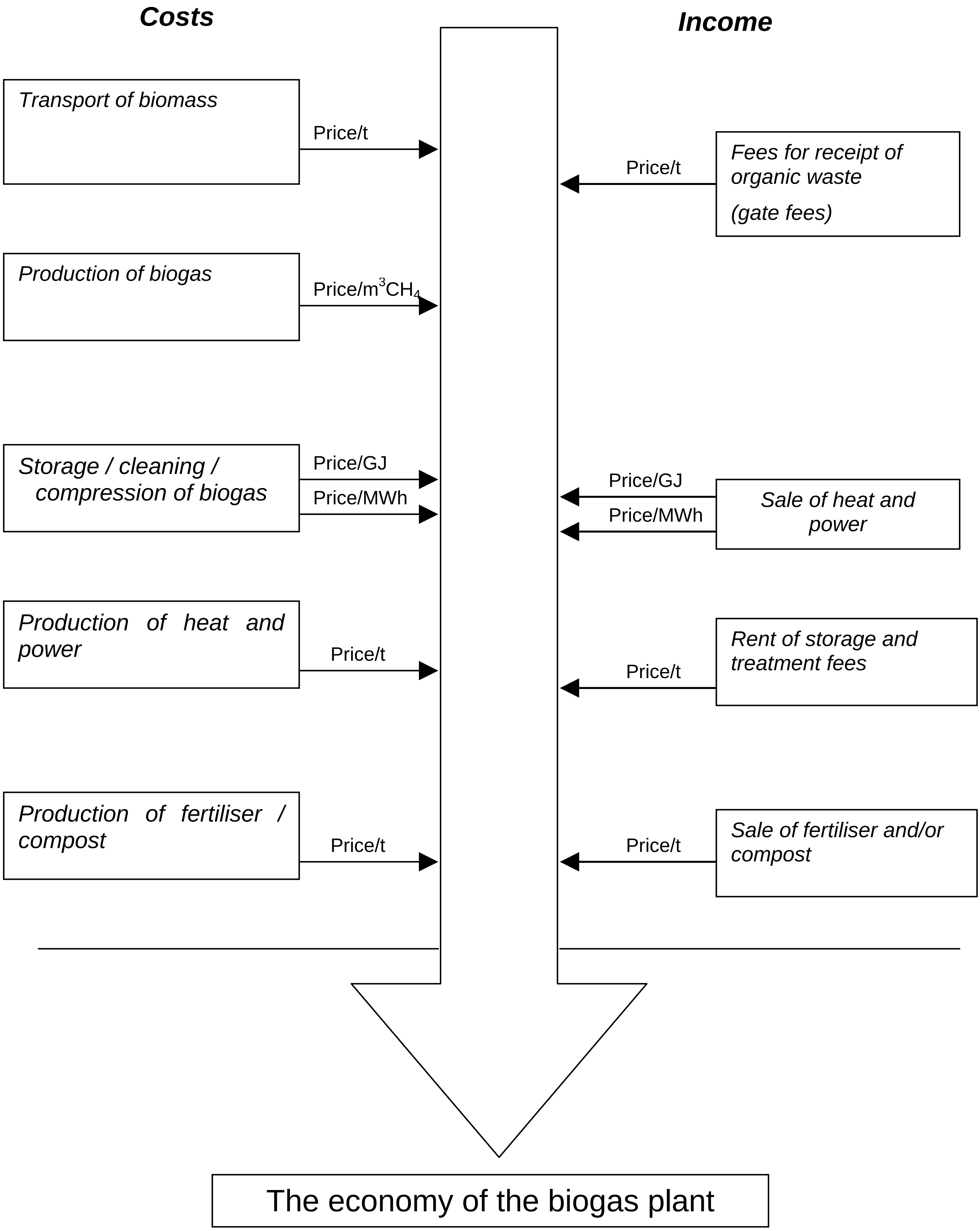

Figure 1: the key elements of the economy of a biogas plant
Source K. H. Gregersen, FOI Denmark

ADDITIONAL SOURCES OF INFORMATION ON PRACTICAL GUIDELINES

There are a variety of different practical guidelines available on the World Wide Web. The following web addresses provide guidelines, which can be downloaded:

International Energy Agency IAE – Bioenergy Task 24:
Good practice in Quality Management of AD residues from biogas production, Teodorita Al Seadi, 32p.
Download: http://www.iea.org/

Biogas and More – Systems and Markets Overview of Anaerobic Digestion, July 2001, 20p
Download: http://www.iea.org/

AD-Nett:
Ortenblad, H. (Editor): Anaerobic Digestion: Making Energy And Solving Modern Waste Problems, AD-Nett Report,
Download: www.ad-nett.org

Germany:
Rules and Regulations for Safety of Biogas sites, German Version available: www.Biogas.org
English version available via Mail: German Biogas Association, Angerbrunnenstrasse 12, D-85356 –Freising, e-Mil: info@biogas.org

U.K.:
Document: "Anaerobic Digestion of farm and food processing residues" – Good practice guidlines. PDF document, 57p
http://www.britishbiogen.co.uk/

United States:
Feasibility Study of Anaerobic Digestion Options from Perry, NY, Msword document, 27p
Download: http://www.cce.cornell.edu/wyoming/Anaerobic Digestion/anaerobic_digestion.htm

Dairy Waste Anaerobic Digestion Handbook, Options for Recovering Beneficial Products From Dairy Manure, by Dennis A. Burke P.E., June 2001, 57p
Download: www.makingenergy.com

Biogas in Europe - Selected country profiles and biogas case studies

AUSTRIA

About 500 million tonnes of methane, mainly from natural sources, are worldwide released annually to the troposphere (IPCC, 1992). Landfills contribute between 11-33 million tonnes (Thornloe et al, 2000), wastewater lagoons and sludge treatment contribute 12–38 million tonnes (Orlich, 1990), while ruminants cause 20-35 million tonnes methane emissions (Safley et al, 1992). An overall yearly increase of the emission rate of 1 % has been estimated (Khalil, 2000).

Recovery of methane in technical biogas plants was rapidly increasing during the last years. More than 4,500 installations (including landfill gas recovery) in Europe, corresponding to 3.3 million tonnes methane or 92 PJ / year, could be estimated in 2002. The total European potential has been estimated to 770 PJ (28 million tonnes methane) in year 2020 (Jönsson and Persson, 2003; Jönsson, 2004).

In Austria, the Biogas production increased steadily during the last years. Main driver was a supporting Bioenergy legislation (Ökostromgesetz BGBl. I Nr. 149/2002), resulting in favourable economic operational conditions for “Energy Crop” digestion plants. Energy crop digestion plants receive guaranteed fixed electricity tariffs, (for 13 years), ranging between 0.165 € (< 100 kW), 0.145 € (100-500 kW), 0.125 € (500-1,000kW) and 0.123 € (> 1,000 kW) electrical power. To receive these tariffs, solely energy crops and few selected agricultural by-products (e.g. crop residues, straw, residual feed, manure, stomach contents) are allowed for digestion.

The amount of agricultural plants raised from 119 (12 / 2003), 171 (07 / 2004), to 191 (0 /2005). Additional 23 plants are currently in planning. The overall electrical power can be estimated to about 100 MW. This corresponds to an annual biogas production (agricultural plants) of about 69-104 million m^3.
Future trends in biogas development are generally considered optimistic. The Austrian Agricultural Chamber (2003) expects 175 new biogas plants, each about 300 kW electrical power, until 2009. This could result in additional 60 million m^3 biogas in the near future.

Sources:

Austrian Agricultural Chamber (2003): Personal communication.
IPCC (1992): Climate change 1992. The supplementary report to the IPCC scientific assessment. Houghton, J.T.; Jenkins, G.J. und Ephraums, J.J. (Hrsg.). Verlag Cambridge University Press.
Jönsson, O. and Persson, M. (2003): Biogas as Transportation Fuel. Fachtagung 2003 des Fachverbandes Sonnennergie, Germany
Jönsson, O. (2004): Swedish Gas Center, 205 09 Malmö, Sweden
Khalil, M.A.K. (2000): Atmospheric Methane – It`s role in the global environment. Springer, Berlin.
Orlich, J. (1990): CH_4 emissions from landfill sites and wastewater lagoons. Proceedings of the International Workshop on CH_4 Emmissions from Natural Gas Systems, Coal Mining and Waste Mangement Systems, 9.-13. April 1990. US Environmental Protection Agency, Washington DC., USA.

Safley, L.M.; Casada, M.E.; Woodbury, J.W. and Roos, K.F. (1992): Global CH_4 emissions from livestock and poltry manure. EPA Report 400/1-91/048 US Environmental Protection Agency, Air and Radiation, Washington, DC:, USA.
Thorneloe, S.A.; Barlaz, M.A.; Peer, R.; Huff, L.C.; Davis, L. and Mangino, J. (2000): Waste Mangement. In: Atmospheric Methane S 234-262;, von Khalil, M.A.K. (Ed.); Springer (2000), Berlin.

Figure 1: Small Austrian farm scale energy crop co-digestion plant with digester (background), storage tank and silo

Table 1: Biogas Plants in Austria (July 2004)

Federal State	**Number of Plants**
Wien (2006)	1
Salzburg	13
Vorarlberg	26
Oberösterreich	39
Kärnten	15
Steiermark	28
Burgenland	4
Tirol	13
Niederösterreich	38
TOTAL	**177**

Table 2: Main data of a typical small farm-scale energy crop co – digestion plant

Parameter	
YEAR OF CONSTRUCTION	2000
IN OPERATION SINCE	2001
TOTAL DIGESTER VOLUME (m^3)	700
DIGESTER SYSTEM	2-step continuous stirred tank reactor
MEAN RESIDENCE TIME (d)	100
DIGESTION TEMPERATURE	37-38^{0}C
MAIN SUBSTRATE	Corn silage
OTHER SUBSTRATES	Sun flower, grass
Co – SUBSTRATES	Cow manure, fat scraper contents
BIOGAS USE	Electricity generation, 2 CHP, 150 $kW_{el.}$
USE OF DIGESTATE	Fertilizer, own farm land
INVESTMENT COSTS (€)	250,000
SUBSIDIES (€)	50,000
BIOGAS PRODUCTION (m^3/a)	490,000
ENERGY PROD. ELECTRICITY	757,000 kWh / a
ENERGY PRODUCTION HEAT	1,300,000 kWh / a
ENERGY YIELD / ha (kWh)	20,000 (Main substrate maize silage)
PROCESS ENERGY ELECTRICITY	7.9 %
PROCESS ENERGY HEAT	12.9 %
EFFICIENCY POWER GENERATION	31 %
ELECTRICITY RATES (€ cents / kWh)	10.23
TOTAL RUNNING COSTS (€ / a) Labour Maintenance Various	58,200 9,000 750 48,450
INCOME (Energy, € / a)	78,225
INCOME (Co - substrates)	0
TOTAL INCOME (€ / a)	78,225
NET MARGIN (€ / a)	**20,025**

DENMARK

Denmark is one of the front line countries of the world when it comes to the production of biogas from anaerobic co-digestion of animal slurries and suitable organic residues from industry and from the overall society.

Biogas from anaerobic digestion not only contributes to the reduction of CO2 emissions by substitution of fossil fuels; the anaerobic digestion of slurry reduces the emissions of methane from slurry storage tanks and of nitrous oxide from the soil and by this it doubles the positive climate effect. By anaerobic digestion a mineralising process is taking place, so the nitrogen from slurry is more accessible for the crops; the farmers get an improved value of nutrients in the applied slurry and the environmental risks of nitrogen leakage to the ground water is considerably diminished. Furthermore, application of digested slurry means a significant reduction of odour nuisance for the neighbourhood areas, compared with raw slurry.

Biogas is the cheapest Kyoto-instrument, that with a substitution price for CO2 of about 5.3 euro pr ton, is competitive with the trade of CO2 quotes, although their price is even expected to increase the coming years.

The development of the Danish biogas sector went through a period of stagnation the last couple of years, due uncertain electricity sale prices. In the meanwhile, the Danish Parliament has signalled that there is a wish to further develop the biogas sector, from the existing 3 PJ per year up to 8 PJ per year, by offering price guarantees for the electricity produced on biogas, up to the 8 PJ. Thus, it is expected that about 20 new biogas plants will be established the coming years, although the electricity price of 0.079 euro for the new established plants will be reduced to 0.053 euro after ten years.

On long term, reaching the target of eight TJ depends first of all on achieving a positive and interactive implication of the local communities in the respective biogas projects. It is of outmost importance as well to find the most suitable location for the biogas plants, so that not only the global climate, the quality ground water and the local resources preservation will benefit from it, but also a significant reduction of odours from the overall animal husbandry activities will occur in the countryside.

Separation of slurry

The interest for separation of slurry was increasing in Denmark during the last six months, after the Danish government informed that a change of law is under consideration for the farmers that separate their slurry, so they will be allowed to increase the nr LU on their farm without being obliged to buy the necessary land for the spreading of slurry. This requires documentation that all separated nutrients are declared and optimally utilised in crop production. The present limit is of 250 LU/ha. Separation of slurry has been on the agenda for many years and the main technique is taken from the industry sector and developed to be suitable for slurry.

Incentives for the farmers:

- less transport
- better nutrient utilisation
- less odour nuisance

- less soil damage by slurry application
- reduction of pathogen and weeds seeds

The question is whether it is also economically sustainable for farmers to separate their slurries. Less transport and better nutrient utilisation not always covers the costs of separation (5-10 DKK/t slurry), but what really could make a difference would be the possibility of expansion without purchasing extra land for slurry application.

Separation can take place without biogas production but trials at Bygholm Research Centre shows that it is a lot easier to separate digested slurry in a decanter centrifuge than untreated slurry. Several of the companies that work to develop separation technologies (Dansk Biogas, Green farm Energy, Bioscan) have the biogas extraction an integrated part of their treatment plant concept.
If a pre-separation step is chosen, the volume of the biomass that is going to be digested is reduced and this increases the capacity of the biogas plant. Ansager Staldrens Aps is working with this concept at present.

Barriers

- There is no market for the separated P-reach fibre fraction in DK.
- It is not yet clear which requirements are going to be made for the marketing and utilisation of the excess concentrate of nutrients. As an example, the phosphorus rich fibre fraction from decanter centrifuge has a potential fertiliser value of 150 DKK/t but so far the farmers prefer to use NPK mineral fertiliser adjusted to the plants needs or other organic fertilisers they get gate fees for.

Table 3: Biogas production in Denmark

Biogas production in Denmark 1997-2003							
	1997	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**
	PJ	PJ	PJ	PJ	PJ	PJ	PJ
Wastewater plants	0,721	0,775	0,797	0,857	0,857	0,867	**0,868**
Industrial plants	0,142	0,096	0,053	0,072	0,109	0,124	**0,142**
Landfill gas recovery	0,526	0,578	0,553	0,575	0,557	0,623	**0,436**
Large scale joint plants	0,973	1,166	1,183	1,279	1,345	1,403	**1,508**
Farm scale plants	0,032	0,056	0,070	0,129	0,179	0,344	**0,625**
Total	**2,394**	**2,670**	**2,656**	**2,912**	**3,047**	**3,362**	**3,578**

Visions for the Future

- Two types of biogas plants are under development:

  1. The large scale farm plant, co-digesting slurry from a large pig farm

2. The “star-plant”, established at a farm with high heat consumption (e.g a large pig farm) but processing the slurry from other 2-3 farms within a radius of max 5-8 km.

- Separation will be a common part of the biogas plant, often associated with evaporation

Slurry transport and application will take place by pumping via pipelines

Lemvig Biogas Plant

Figure 2: Lemvig Biogas Plant (Source: www.lemvigbiogas.dk)

The Lemvig Biogas plant is located in the central part of the Jutland peninsula, in one of most intensive animal breeding areas of Denmark. The plant processes and handles biological materials from farmers and different industries, suitable to be treated in a biogas plant, and with a significant biogas potential. All supplied biomasses are registered in the company’s electronic card index of goods.

Animal manure from farmers

The animal manure is transported into the vacuum tankers belonging to the biogas plant. The manure is unloaded in one of the unloading halls’ two funnels with the cars pump placed directly into the enclosed receiving tank/ mixed tank.

Vegetable biomass

The plant receives vegetable residues and other products such as rapeseed oil/ seeds, soybeans, grains and fruit- and vegetable waste etc. The solid and liquid products are delivered by external transport contractors and are unloaded in the unloading hall’s industry line, directly into the tank for the storage of industrial biomass and from there they are pumped into the reactors.

Slaughterhouse waste

Slaughterhouse waste is delivered by external transport contractors and unloaded in the unloading hall’s industry line, directly into the industry tank.

Other organic industrial waste

The plant receives other organic wastes as fish waste and flotation fat. The materials are transported in and are unloaded into the industry tank.

Digested biomass

After the retention time in the reactors and the sanitation tanks, the digested biomass is pumped through a pipe line to the post storage tanks, from where it is distributed by the vacuum tankers to the farmers' own storage tanks, most of them placed out in the fields, where the digested biomass is to be applied.

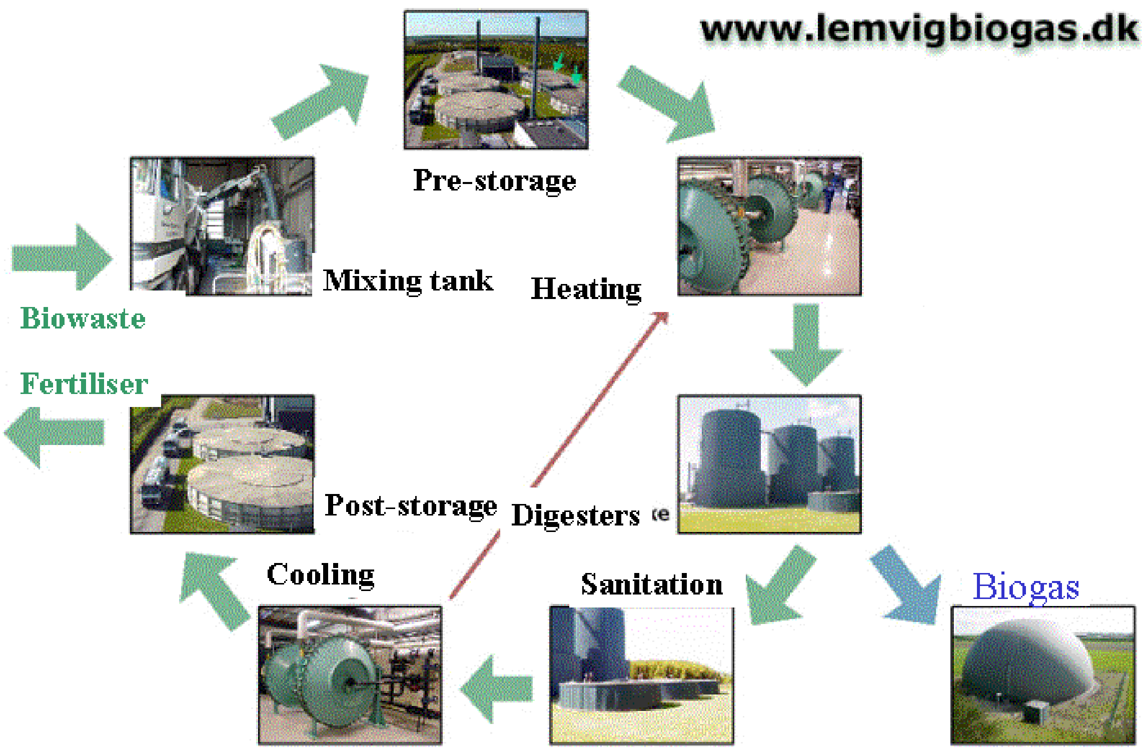

Figure 3: Lemvig biogas plant – process digestion, Source: www.lemvigbiogas.dk

Process description

The process itself takes place thus, that biomass continually is pumped into the reactor for 15 min. Simultaneously the same amount is pumped out of the next reactor. Subsequently there are 30 min. of pause between the pumping sequences into this same reactor, while in pumping takes place in the next two reactors (2x 15 min.) The digestion temperature in the reactor tanks is 52 ^{o}C.
There are two independent process lines before the reactors respectively called "the Industry line" and "the Manure line".

All biomass is received in the unloading hall, which has five gates:

Gate1: Manure delivered by the vacuum tankers of Lemvig Biogas plant
Gate 2: Manure delivered by the vacuum tankers of Lemvig Biogas plant
Gate 3: Solid manure delivered by external transporters
Gate 4: Stomach and intestinal content delivered by slaughterhouses by external transporters
Gate 5: Solid and liquid industrial wastes delivered by external transporters

Biomass is loaded on the vacuum tankers of Lemvig Biogas plant through the two funnels on top of the post-storage tank 1 and 2.

The manure line

- In the unloading hall the manure is supplied by vacuum tankers and pumped through the funnel to the mixing tank. The pipe stub on the vehicles of Lemvig Biogas plant closely shut in the funnel, so that the material is kept into a closed system. In the mixing tank biomass is stirred to a homogeneous mass.
- Subsequently the manure that is fetched from the farmers is pumped into the pre-storage tanks 1 and 2.
- From the pre-storage tanks 1 and 2 manure is lead through either macerator 1 or 2. The macerators are equipped with 12 mm perforated disc.
- After the partition in macerator the manure is pumped through the heat exchangers 4 and 3, after which two new pumps take over and pump the manure on through the heat exchangers 2 and 1. The temperature before heat exchanger 1 is approx. 14 ^{o}C and the temperature after heat exchanger 4 is 55 ^{o}C.
- The heated manure is now pumped directly into the top of the reactor.

The industrial line

- At gate 5 different forms of solid and liquid industrial wastes are loaded off into the industrial tank 2. In industrial tank 2 the biomass is stirred to a homogeneous mass.
- Subsequently the industrial waste is pumped through a macerator that minces the solid particles into max. 5mm in diameter, and further on to industrial tank 1.
- From industrial tank 1 the industrial waste is pumped on through a lay-by cell, consisting of 490-meter pipes. At max. load it takes an hour to pump the industrial waste through the lay-by cell. At the passage from the lay-by cell the temperature is over 70 ^{o}C.
- After the lay-by cell the industrial waste is pumped directly to the top of the reactor.

Digested biomass

From the reactors the digested biomass is continually pumped into the post-sanitation tanks. The process itself takes place thus that biomass is continually pumped into a post-sanitation tank for 8 hours and simultaneously the same amount is drawn out of the next post-sanitation tank, in which there will be pumped. Then there is a 16 hours pause in the pumping of this post-sanitation tank while pumping takes place in the two next post-sanitation tanks (2x8 hours)

- The temperature in the post- sanitation tanks is 52 ^{o}C.
- From the post-sanitation tanks the digested and sanitized biomass is pumped through heat exchangers 2, 3 and 4. This is to exchange heat with the cold raw manure.
- After heat exchanger 4 the digested and sanitized biomass is lead into stock tanks 1 or 2.

- The vacuum tankers of Lemvig Biogas plant collect the digested and sanitized biomass by sucking it up from the pipe stubs of the stock tanks. Then the digested and sanitized biomass is directly transported to the farmers' own storage tanks.

The biogas

- During the formation of the biogas a pressure of approx. 20 mbar occurs in the reactor and in the post- sanitation tanks appears. This pressure leads the biogas into the gas pumps.
- The gas pumps raise the pressure to 500 mbar and the temperature to 80 ^{o}C.
- From the gas pumps the biogas is pumped through a 5km long pipeline to Lemvig heat and power station, were the biogas is transformed into electric power and heat.
- The condensate, which is drawn from the pipeline, is pumped back to the post-storage tanks.

GERMANY

In Germany the main drivers for the biogas sector are the 'Feed In' laws which guarantee the prices offered for electricity generated from renewable energies. The first 'Feed In' law was called the "Stromeinspeisegesetz" which came into effect in 1992. The first version of the Renewable Energy Sources Act (EEG) was implemented in April 2000 while a second version came into force in August 2004. The EEG Act obliges electricity grid operators not only to pay a specified price for electricity, but also to give priority to the purchase of electricity from solar energy, hydropower, wind power, geothermal power and biomass.

The price offered for the electricity produced is based on the production costs. Investors are guaranteed fixed rates for their electricity sales for a 20-year period. This is an important factor when securing finance from the banks. There has been a considerable boom in the construction of new biogas installations in recent years with over 2500 farm-based plants now in operation. The German Renewable Energy Sources Act has set a positive example to other countries of how appropriate legislative support can encourage a new renewable energy sector to develop.

Today, renewable energies are responsible for around 2.9 % of the total energy provision in Germany, while the renewable energy sector as a whole provides around 130,000 jobs. The Federal Government aims to double the share of renewables in the national energy supply by the year 2010. Under this aim, the share in annual primary energy consumption will rise from 2.1% in 2000 to 4.2% in 2010 and the share in gross electricity consumption from 6.3% in 2000 to 12.5% in 2010. By the middle of the century, half the country's energy requirement will be generated from wind power, solar energy, biomass and hydropower. Currently the share of electricity from biogas is less then 3%.

The price support for electricity derived from bioenergy has been fixed at a level which should ensure that the real costs of production are covered. As there are significant differences in the production costs of different bioenergy technologies, support rates are varied to take this into account. For new plants the price support (Table 4) for electricity is lowered by 1.5 % each year starting in 2005. By this mechanism the government intends to promote the mix of renewable energies as well as encouraging improvements in the technology used so that production costs can be continually lowered. The year of commissioning determines the compensation given over the project's life (20 years).

With the Renewable Energy Act (EEG) of 2004 the base compensation for electricity from biogas has now been adjusted to a full cost basis. In addition a bonus system has been initiated which fixes additional funding for:

- Electricity produced from energy crops
- The use of heat coming from CHP units
- The use of new technologies i.e. fuel cells

These different compensations can be combined so that a total compensation of up to 21.5 eurocent per Kilowatt-hour (kWh) can be achieved. For example a biogas plant with an installed capacity of 150 kW, using energy crops as substrates, providing heat and using new technologies could achieve this rate.

Table 4: Compensation Fees for Electricity from Biogas in €/kWh

Installed Capacity of the Plant:	<150 kW_e	150 - 500 kW_e	500 - 5 MW_e	> 5 MW_e
Base	0.115	0.099	0.089	0.084
Energy Crop Bonus	0.06	0.06	0.04	
Heat Bonus	0.02	0.02	0.02	0.02
Technology Bonus	0.02	0.02	0.02	

The most important point for the German biogas sector is the new energy crop bonus. By being paid for the production and use of energy crops a biogas plant on a full cost basis is now an economic proposition for many farmers. In the context of this additional support, an increase in the number of biogas plants is expected. It is estimated that there may be up to 4,000 plants by the end of 2005. This would give a total installed electric capacity of 950 MW.

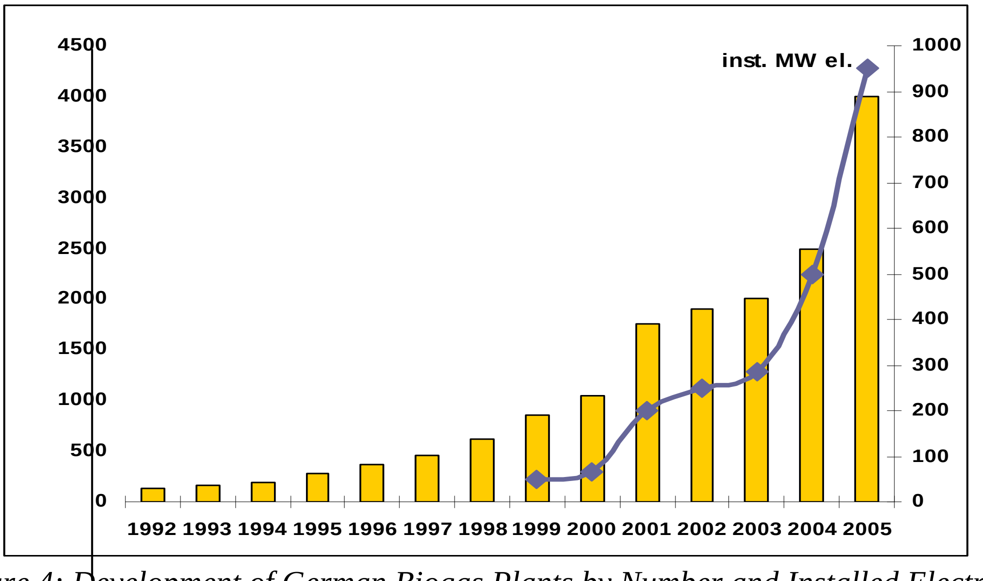

Figure 4: Development of German Biogas Plants by Number and Installed Electric Capacity from 1992 to 2005, Source: German Biogas Association 2004

Germany currently has the highest number of farm-based biogas plants in Europe. It also has the most experience and expertise with at least 200 small and medium sized enterprises active in the sector. The German Biogas Association estimates that at least 6,000 people are currently employed directly in the biogas sector. If the full technical energy potential from energy crops and agricultural residues was utilized, it is estimated that it would produce 430 Petajoules per year and around 33 Terawatt hours of electricity [Source: Hartmann, H. And Kaltschmitt M. (2002). *Biomasse als erneuerbarer Energieträger, Landwirtschaftsverlag,* Münster, Germany.]. Using these figures there is the potential for the employment of more than 100,000 people in the German biogas sector.

Biogas in farming - typical farm-scale biogas plants in Germany

Objectives and advantages of biogas plants

- Generates electricity and heat
- Secures and raises earnings from farming activities
- Makes use of the potential energy and is an environmentally compatible way of disposing of organic waste
- Improves the pumpability ↑, flowability ↑, plant take-up ↑ and consistency ↑ of the liquid manure
- Biogas manure contains more ammonia nitrogen
- Reduces odor nuisance when spread in the field
- Reduces environmental contamination (by substituting fossil fuels, closed carbon dioxide loop)

Biogas plants

Farm biogas plants usually consist of a slurry pit in which the slurry is collected and homogenized, one or several digesters, one or several end slurry storage tanks, cleaning and treatment equipment for biogas, one or several combined heat and power units in which the biogas is converted in electricity and hear and the required equipment for feeding the electricity in the public grid and utilizing the heat produced.
Biogas

Biogas is a mixture consisting of

- methane (50 – 75 %)
- carbon dioxide (25 – 50 %)
- trace gases

Of the trace gases, hydrogen sulfide (H2S) is a very aggressive and corrosive gas. To prevent early failure of the motors, hydrogen sulfide must effectively be eliminated from the biogas (e.g., biological desulfurization by injection of atmospheric oxygen). The water vapor must also be removed from the biogas before the gas can be burned in the combined heat and power generator. Biogas is produced by anaerobic bacteria under absence of air. Organic material, which enters the processing system in a constant stream, is decomposed by microorganisms. Methane and carbon dioxide are produced by methanogenous bacteriad.

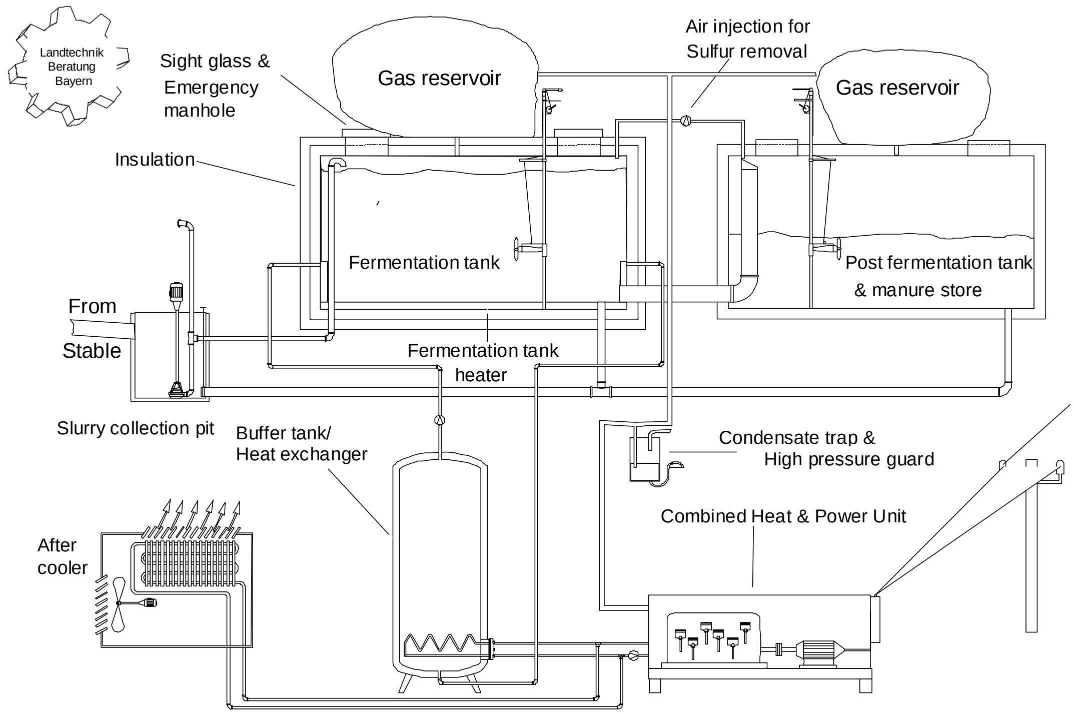

Figure 5: Scheme of typical German farm scale biogas site (Source: Landtechnik Weihenstephan, Freising, Germny)

How to “feed” a biogas system?

Biogas plants on farms usually use liquid or solid manure as feedstock. In many cases fermentation aids are added to improve the biogas yield from the plant. Such digestion aids may be waste from fruit peeling or vegetable processing, fat from flotation, renewable raw material or food processing waste. The addition of digestion aids is regulated by law (for Germany: biological waste directive BioAbfV, fertilizer directivet DüMV).

Gas yields from different feedstock in m³ of biogas from one ton of feedstock
(source: dlz, 5/00)

Cattle manure (8% dry matter)	22
Pig manure (6 % dry matter)	25
Laying-hen fresh feces (22 % dry matter)	76
Chopped barley straw (86 % dry matter)	300
Grass silage (40 % dry matter)	200
Corn for silage (35 % dry matter)	208
CCM (5 % raw fiber, 35 % dry matter)	414
Meadow grass (18 % dry matter)	95

Slurry collection pit

The manure collects and homogenizes in the pit to produce the feedstock for the biogas plant. The size and technical equipment of the pit (mixer, crusher, pumps) depends on the feedstock.

Fermentation tank

The digester can be of vertical or horizontal type. The digester size depends on the amount of substrate to be digested and the required residence time in the digester. The digester is heated and equipped with an agitator and the required equipment for withdrawing the biogas.

Post fermentation tank & manure store

Here the fermentation residue is stocked until spread in the field. The fermentation residue store can be a gas-tight post-fermentation tank from which the biogas produced after the principal fermentation process is collected.

General conditions for economic viability

The cost of a biogas plant can be calculated by dividing the total investment cost (depreciation, interest) into the lifecycle years of the plant and further considering the cost of connecting the system to the public power grid, current operating cost (maintenance and repairs, operating materials), plus wages (plant operator). This is opposed to the revenue from selling the electricity generated and earnings from the use of fermentation aids. Prospective builders of a biogas plant should also inform themselves of available government subsidies and grants.

Properties/data for guidance

- Calorific value (c.v.): 4 -7.5 kWh/m³ (depending on methane content)
- 6.0 kWh/m^3 on average
- Fuel oil equivalent: approx. 0.62 l fuel oil per one cubic meter of gas
- Ignition concentration of gas in air: 6-12%
- Ignition temperature: 700°C
- Gas output: approx. 1-1.5 m³/GV*d (cattle manure)
- Electricity yield factor: approx. 1.8-2 kWh_{el}/m³ biogas

Gas reservoir

The gas store is a buffer tank to store the gas until further processing. The gas store can be integrated in the digester or post-digestion tank or it can be set up as a separate unit. Where the gas is stored above the digester or post-digestion tank, these are covered with plastic film under which the gas collects. Otherwise a gas collection bag is installed apart from the digester.

Combined heat and power unit

The biogas, from which sulfur and water have been removed, is converted to heat and electricity in the combined power and heat generation plant. About one-third of the energy stored in the biogas is converted to electricity and about two-thirds are converted to heat. The electricity can be fed into the public power grid, the heat is used on the farm or locally.

<u>Table 5:</u> *Data of typical farm scale biogas site (Source: German Biogas Association)*

Small farm scale energy crop Co – digestion plant	
YEAR OF CONSTRUCTION	2004
IN OPERATION SINCE	September 2004
TOTAL DIGESTER VOLUME (m^3)	1650
DIGESTER SYSTEM	continuous flow tank reactor
MEAN RESIDENCE TIME (d)	60-70
DIGESTION TEMPERATURE	40^0C
SUBSTRATES	Corn silage (20 ha), manure (300 bulls, 50 mother-cows), grain (50t)
BIOGAS USE	Electricity generation, 1 CHP, 500 kW_{el} (Double Fuel Injection unit).
USE OF DIGESTATE	Fertilizer, farm land
INVESTMENT COSTS (€)	280,000
ENERGY PROD. ELECTRICITY	70,000 kWh / month (since November 2004)
ELECTRICITY RATES (€ cents / kWh)	11.50
INCOME (Energy, € / ´month)	8,000

GREECE

During the 80's, a few efforts for biogas energy exploitation applications were carried out in Greece, the feedstock for them being in principal animal excrements and wastes from food processing industries, such as oil olive mill wastes. Some of these efforts were demonstration projects that after the initial enthusiasm and insurance of scientific support were fallen into disuse. This was mainly due to lack of information, proper infrastructure, state interest and financial incentives.

Nowadays, the <u>legislative infrastructure</u>, *(*Law 2244/1994 *"Regulation of power generation issues from renewable energy sources and conventional fuels and other provisions,* Law 2773/1999 for the liberalization of the electricity market, Law 2941/2001 *"Simplification of procedures for establishing companies, licensing Renewable Energy Sources plants,* Law 3017/2002 *"Ratification of the Kyoto Protocol to the Framework-convention on climate change"*, Law 3175/*2003 "Exploitation of geothermal potential, district heating and other provisions")* **financial instruments** (The Operational Programme "Competitiveness" (OPC), National Development Law 2601/98) and **favourable socio-economic conditions** (public awareness for environment protection, forthcoming deregulation of energy markets etc) have changed the environment, so that new developments have emerged and a bright future is foreseen.

In Greece, the electricity consumption in 2002 amounted to 50.6 TWh, with an installed capacity of 11,739 MW of PPC-operated plants and 515 MW of auto producers and RES generators. The transmission lines in the interconnected system have a length of 10,330 km whereas the distribution lines extend to 200,989 km.

The number of customers served is 6.7 million. The main fuel source was domestically extracted low-calorific-value lignite (70.3 million tons), which accounts for 59.1% of the total. Oil, mainly used by the power plants of the islands not connected to the mainland system, had a share of 14.0%.

Natural gas imported from Russia and Algeria in the form of LNG covered 12.7%. In the same year the large-scale hydroelectric plants yielded 6.3%. Lastly, wind energy, small hydro, biomass (especially from biogas) and photovoltaic combined, appeared on the scene with 2.4% whereas the net of imports-exports made up the remaining 3%. The capacity in MW of the RES plants up to the end of 2003 is given in Figure 6.

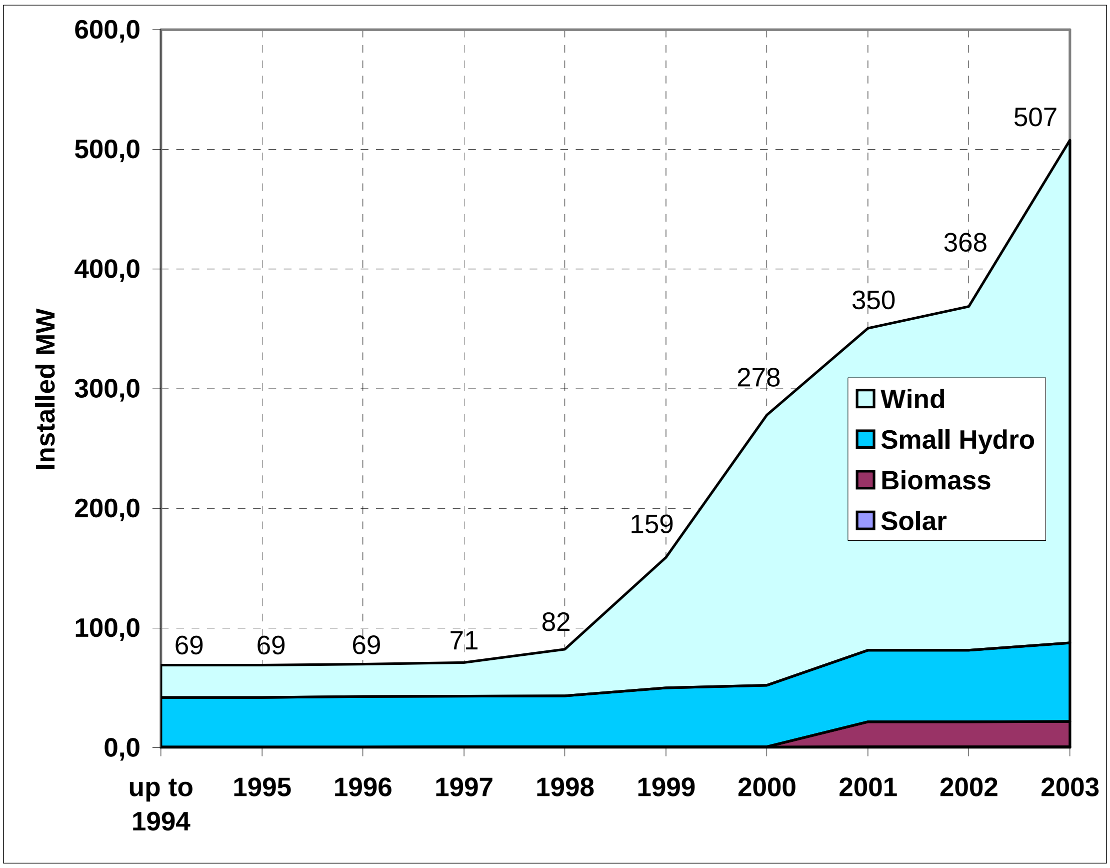

Figure 6: Progress of RES installed capacity

On the basis of CRES data, in 2001 the energy from RES amounted to 1.02TWh, 74.12% from wind farms, 18.14% from small hydroelectric plants and **7.75% from biogas**. No marked difference was noticed during 2002 since there was only a small increase in the installed capacity.

The current installed capacity for biogas energy in Greece is about 27 MW, which come from the exploitation of landfill generated in Sanitary Landfills (SL) and biogas generated in Municipal Wastewater Treatment Plants (MWTP), (Table 6),

Table 6: Greek AD plants

Plant	Feedstock	Amount (m^3/day)	Gas production (Nm^3/day)	Installed Capacity (MW)	Produced Electricity (MWh_e)	Produced Heat (MWh_{th})
1. Sewage of Metamorfosi	Sewage sludge*	20,500	4,150	0,65	3,900	4,800
2. MWTP of Heraklion	Sewage sludge	23,000	2,460	0,17	1,120	n/a
3. MWTP of Volos	Sewage sludge	27,000	2,800	0,23	2,100	n/a
4. MWTP of Psyttalia	Sewage sludge	1,000,000	72,000	11,4	64,000	86,000
5. SL of A.Liosia	Landfill gas	3500 **tn/d**	184,000	14	104,000	78,250
6. SL of Tagarades	Landfill gas	1500 **tn/d**	1,200	0,24	720	n/a
TOTAL				**26,69**		

Note: * Sewage sludge contain urban, sewage and industrial wastes
MWTP: Municipal Wastewater Treatment Plants

SL: Sanitary Landfills

So far a number of additional requests for permits have been submitted to the Regulatory Authority for Energy (RAE) and approved for about 32 MW of additional electricity generation until 2010 (Table 7)

Table 7: Additional requests for permits submitted to RAE until 2003.

A/a	*Name*	*Prefecture*	*Installed capacity (MW)*
A0298	A. ZAHAROPOULOS S.A	Lakonia	3.00
A0299	A. ZAHAROPOULOS S.A	Preveza	4.00
B213	ENVITEC - CHRISTODOULOU BROSS	Argolida	3.00
A0315	DEYA PATRAS	Ahaia	0.90
A0314	DEYA RODOU	Dodekanisa	0.50
A0081	BEAL LIOSSION	Attiki	9.50
A0253	HELECTOR S.A	Thessaloniki	8.16
A0252	HELECTOR S.A	Kerkyra	2.71
TOTAL			**31.77**

This figures are relatively low compared to the potential energy generation from landfill sites and biogas generating plants. Currently in Greece there are about 32,875 calf-breeding farms with 723,000 breeding animal heads, 36140 pig-breeding farms with 970,000 heads, 2700 olive oil mills, 25 secondary olive residues treatment facilities and a considerable number of food industries. However, only three plants (one pig farm cooperation and two food industries) have applied for a permit to RAE (see Table 7). The rest of the applications refer to SL and MWTP.

This is due to the following reasons:

- Large plants owners (i.e. 1457 livestock pig units of more than 100 year sows, and 580 livestock calf units with 75,000 animals) that is of subsequent size to sustain an economically viable investment) are not properly aware of the technologies for manure treatment and potential biogas applications.
- Small plants cannot effectively combine forces with other producers to form clusters of enterprises and create viable biogas plants.
- The few potential investors that are fully aware of all the benefits of biogas exploitation mentioned are discouraged to proceed to similar investment due to the high investment cost and the low public subsidy (grant). Although this subsidy is rather adequate on a % basis (approx. 40% of the eligible capital cost), the specific eligible cost is very low for such investments (approx. 1500 €/installed kWe), which, apparently does not account for the entire development and capital costs necessary for such an investment.
- Liberalisation of the energy market is proceeding very slowly in Greece.
- Although new laws and ministerial decrees have been adopted, which improve the institutional and the legal framework for such investments, these investments are resource-limited, i.e. the “polluter pays principle” is not applied practically, which would greatly improve operational costs by imposing gate fees to polluters and help remove uncertainties for the power plant owners.

What is needed to turn biogas energy cost completive to conventional energy sources?

As mentioned before, according to the investors and constructing companies, a biogas plant investment to be attractive should rely on both: a mixture of grants and capital cost subsidies (to help reduce the capital cost) the imposition of “gate fees” to waste generators through the activation of the Regulation Authorities and the “polluter pays principle” (to minimise operational costs)

Since these types of interventions combine multi-disciplinary measures, acting not only as energy and environmental investment but also as a tool for “best-practice” agriculture, combined policies from all public bodies (Ministries and Authorities) is sought.

Installation for the utilization of biogas landfill at the area of a. liossia for the production of electrical and thermal energy

Objectives

The objective of the financed project is the collection and exploitation of the landfill gas (LFG) produced by the deposited waste at the Ano Liossia landfill, which is the main landfill that serves the greater Athens area. Up to starting of construction the LFG produced was uncontrollably escaping in the atmosphere.

LFG is mainly a mixture of methane and carbon dioxide, as a consequence its dispersion in the atmosphere is creating a series of potential environmental problems (greenhouse effect, danger of explosions and fires, negative impacts on flora). The operation of the power station aims at the protection of the environment on the one hand through its collection and combustion, while on the other hand aims at the substitution of a significant quantity of fossil fuels for electricity and heat generation.

This project comprises the construction of a cogeneration power station utilizing the LFG of the Ano Liossia landfill as fuel. The installed generation capacity of the power station is 14,94MW, while the net output is 14,3MW. The station is capable of generating 128.700MWh of electricity annually. At present, all of the production is sold to the Greek Public Power Corporation (PPC – the State utility), which will be substituted by the Grid Administrator in the immediate future (according to the law 2773/99). The interconnection with PPC is effected through a double underground HV (20kV) line and the electricity sold is estimated to be sufficient to cover the demand of about 14.000 households.

The heat produced is 109.000MWh annually and is recovered form the hot exhaust gases of the internal combustion engine and from the water cooling circuit of the engine. The heat from those sources if not recovered is rejected to the environment.

The heat generated could be utilized in the near future at the Mechanical Waste Recycling Facility and at the Clinical Waste Incinerator, projects that are both still in the construction stage.

Technical Description

The main tasks of the project were:

a. Construction of a LFG collection network at the unrestored part of the Ano Liossia landfill (40 acres).

b. Connection of the existing LFG collection network of the already restored part of the landfill (30 acres) consisting of 109 LFG extraction wells.

c. Construction of a cogeneration power station producing heat and electricity of net power output $13MW_e$ and $13MW_{th}$.

d. Construction of an interconnection line to supply the electricity produced to the Grid.

More specifically, the initial design of the project comprised:

1. An LFG extraction and collection network, consisting of 200 wells, connected in groups of 10 – 12 to well stations through an underground secondary pipe network. The well stations are further connected through a primary underground pipe network to two main headers, both of which are connected to a central gas mixing system. The connection of the existing LFG network of 109 wells is also effected at the gas mixing point in order to feed all the units of the power station with gas of the same quality.
2. A power station consisting of 10 units of 1,3MW net capacity, as well as all the ancillary equipment to support their operation and to supply the electricity generated to the Grid.

   Each unit is completely autonomous and installed in a standard 12m container, inside and above which all the ancillary equipment is located. Each container is sound proof and contains the genset (DEUTZ 620 TBGV16K), the 400V/20kV transformer, the gas blower, ventilation fans, electronic administration system for the gas engine, the control system for the whole unit and the ancillary systems (fire and gas detectors, fresh and waste oil tanks, etc.). The remaining equipment is installed on the roof of each container and consists of radiators, pumps, stack, gas train and associated piping.
3. Heat recovery equipment that recovers waste heat from the hot exhaust gases and the cooling water circuit of each engine.

a. The temperature of the exhaust gases is approximately 430°C and the heat can be utilized to produce either hot water or low pressure steam. The exhaust gases will be cooled down to 120°C.

b. The engine cooling water provides hot water of 92°C which in turn can produce hot water of approximately 85°C. The hot water form each unit will be collected in a main supply line ending at the fence of the power station site. Another return line is located alongside of the supply line and distributes cold water to the heat exchanger secondary circuit.

The LFG is supplied to the power station through two main pipes that originate from the gas mixing system. Each main pipe is split into two and each of the four smaller pipes ends up in a condensate separation vessel. These vessels supply the main fuel pipe that distributes the fuel to the power generation units. The power generation units are controlled through a central SCADA system, which is interfaced with the individual unit control systems and is located in the central control room.

The following table shows the project items to be financed by the initial contract and the final deliverables according to an approved budget increase.

Table 8: Financing items.

Project item	Initial scope of financing	Final deliverables
Power generation units	10	11
LFG extraction wells	200	243
Condensate separation vessels	2	4
Interconnection line		Twin underground line
LFG flare system	3	3

Conclusions and Significance

The importance of the project is significant especially in relation to the quality of the environment in the immediate area. The area is stressed with a lot of industrial and construction activity, hence the operation of the project is a step towards lowering the overall environmental burden.

The cogeneration station, which is among the largest ones of its kind, contributes significantly to lowering the greenhouse gas emissions for Greece and participates to the EU aim to achieve the Kyoto target. Furthermore, it is an important step towards the establishment of proper administration practices to the landfill problem in Greece.

This project proves that, beyond the wind potential that is abundant in Greece, there is still a significant but yet untapped potential in the biomass sector in general. This project, being the first large scale project in this sector, shows the road for the wider utilization of this energy source.

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Fig. 7

Fig. 8

Fig. 9


Fig. 10

Figure 7: Biogas plant in A. Liossia
Figure 8: Connection of the biogas distribution line with the cogeneration power station
Figure 9: Connection of the biogas storage sub-station with the primary distribution network
Figure 10: Cogeneration unit

Biogas utilization through cogeneration at psyttalia wastewater treatment plant

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The Psyttalia Wastewater Treatment Plant (Psyttalia WWTP) is the main wastewater treatment facility in the greater Athens area, serving a population of over 3 million people. The average wastewater inflow to the Psyttalia WWTP is 760,000 m^3 daily.

The Psyttalia WWTP has been built in two stages: Stage A and Stage B. Stage A works have been in operation since 1994, and stage B works have recently been under trial operation. The Greek Ministry for the Environment, Regional Planning and Public Works was responsible for the construction of both stages.

In January 1996, EYDAP, the Athens Water Supply and Sewerage Company became responsible for the operation of the Stage A works at the Psyttalia WWTP. The Stage A works include wastewater pretreatment at Akrokeramos installations, through debris removal, screening, grit removal and odor control. The pretreated wastewater is directed through 2 submerged siphons to the Psyttalia Island, where wastewater is treated in primary sedimentation tanks, while the primary sludge treatment includes pre-thickening, anaerobic digestion, post-thickening and dewatering.

The Stage B works include the biological stage of the wastewater treatment by means of the activated sludge system, consisting of bioreactors and final settling tanks, as well as the biological sludge treatment, including belt-thickening, anaerobic digestion, post-thickening and dewatering.

The primary sludge digestion process, taking place in 4 digesters, produces a daily average of approximately 50 000 m^3 of biogas. Biogas consists mainly of 61 – 65 % Methane (CH_4) and 34 – 38 % Carbon Dioxide (CO_2). It also contains hydrogen sulfide (H_2S) at concentrations of 1000 – 1200 ppm. Biogas is utilized as the fuel of the 7,14 MW_e Heat and Power Cogeneration Unit (CHP Unit), which EYDAP has constructed on Psyttalia, and has been operating since October 2001.

The CHP Unit consists of three internal-combustion engines, capable of producing 7,14 MW_e and 10,35 MW of thermal energy. The following flow-diagram of the CHP Unit presents the processes taking place in the Unit.

The biogas that is produced in the digesters is directed to the gas-holders, and after being cleaned in the scrubber, so that the hydrogen sulfide concentration reduces to less than 1000 ppm, it is being compressed in three compressors and subsequently dewatered. The compressed biogas is being burned in the three gas-engines, and its chemical energy is being converted through the three generators into electrical energy, which is directed into the Psyttalia WWTP power grid, covering the wastewater treatment facilities power needs, as well as into thermal energy, through cooling of lubricants as well as water in the gas-engines heat-jackets, which covers the thermal needs of the digesters, by means of heat exchangers.

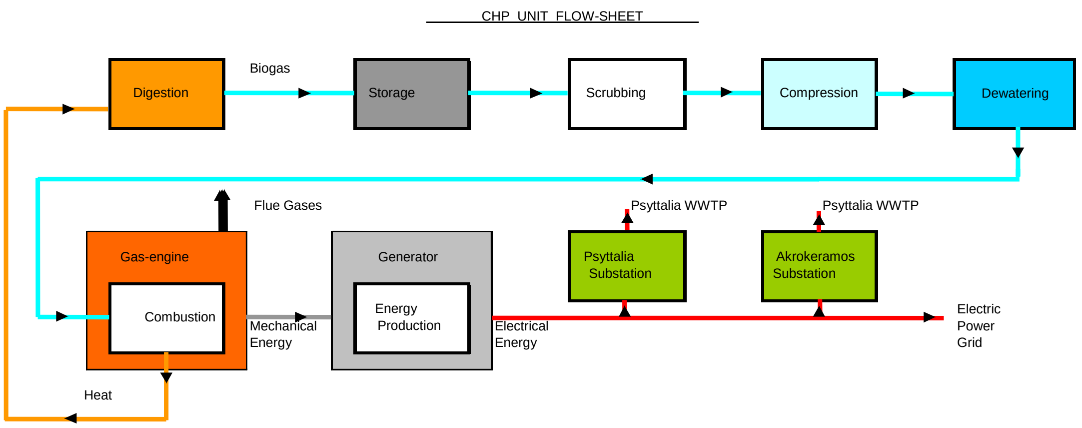

Figure 11: CHP unit flow-sheet.

The three installed gas-engines are Dresser Waukesha, AT27GL series, each equipped with 12 cylinders arranged in V-shape, with maximum mechanical power of 2521 MW, operating at 1000 rpm and burning biogas that is compressed at 3,2 bar. The generators are Leroy-Somer, with self-adjusted brushes and a capacity of 2900 kVA, operating at 1000 rpm and producing electric power at 3300 V and 50 Hz. This voltage is being transformed to 20 kV before becoming available to the Psyttalia WWTP facilities and to the greek power grid.

The additional biogas production through the operation of the Stage B works will be utilized by expanding the existing CHP Unit. At the present stage, the production of the CHP Unit covers the needs in electrical and thermal energy (heating of anaerobic digesters) of the Stage A installations, with a corresponding reduction in operational cost, while it provides some financial benefit, through sale of the surplus of electric energy to the greek power grid.

The total monthly production of electric energy reaches an average of 2700 MWh. The energy that is produced covers the monthly self-consumption of 225 MWh by the CHP Unit and the power requirements for the operation of the Stage A facilities that reach a monthly average of 1414 MWh, while the electric power average monthly surplus of 1031 MWh is being sold to the Greek power network.

The operation of the CHP Unit additionally provides some additional important environmental benefits. Biogas is a renewable energy source replacing conventional fuels. The controlled combustion of biogas at internal-combustion engines results in significantly reduced release of air pollutants into the atmosphere, as compared with biogas burning in gas flares, which used to take place before the construction of the CHP Unit. The operation of the CHP Unit contributes to the self-sufficiency of the Psyttalia WWTP from the standpoint of energy, allowing it to operate independently of power supply by the greek power network, thus ensuring the continuous operation and efficient performance of the Psyttalia WWTP.

Water supply and sewerage corporation of Athens

Fig. 12

Fig. 13

Figure 12 and 13: Co–generation of electrical and thermal energy from the burn of the additional emitted biogas, of the phase b works; from the urban wastes of the sewage waste elaboration centre at Psyttalia, power 4,25 MWe (in addition to the already in operation since 2001, co-generation electricity thermal station with the burn of biogas, of phase a works, power 7,14 mwe)

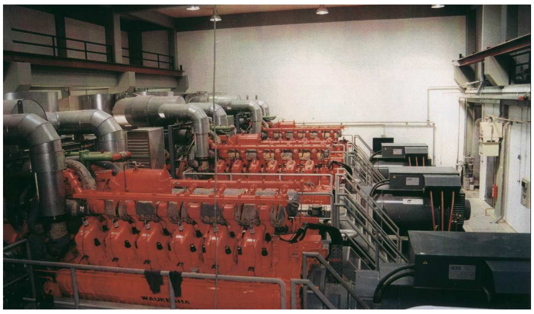
Figure 14: Biogas motor WAUKESHA 12V-AT27GL

ITALY

General remarks

Since the ‘80ies, the interest for biogas of public and private bodies has been proceeding ups and downs. Nevertheless the global trend is positive even if of modest value, as shown by the following figures drawn out from the National Annual Report 2004 on Energy and Environment issued by ENEA.

The awareness is now widespread that the main anaerobic digestion function is to reduce and stabilize the organic fraction present in many types of wastes, producing at the same time an useful gaseous fuel. Biogas is therefore considered as a co-product of the treatment of wastes.

Table 9: Balance of primary energy from biogas (Mtoe/year)

Potential	**Accessible quantity for energy use**	**Used quantity**				
		1995	2000	2001	2002	2003
8	**4**	**0.03**	**0.162**	**0.196**	**0.27**	**0.296***

*This figure represents 6% of the total primary energy of all types of biomass used for energy purpose, and only 0.1% of the global energy need of the Country.

Table 10: Electric energy from biogas (GWh)

1995	1998	1999	2000	2001	2002	2003
103	**494**	**583**	**566**	**684**	**943**	**1033****

** This figure represents 23% of the electric energy produced by all types of biomass, 2% of electricity from all RES, and 0.3% of the gross domestic electric energy consumption.

Trading biogas is almost impossible because of the high costs of purification, piping and storage. Very often it is burned without any recovery of energy, but when energy is recovered, electricity is produced in most plants together with heat for space heating or for other thermal needs of the farm. Modified Diesel engines are used to generate electric energy with a capacity ranging from 30 kW to 1 MW. This small plant size makes applications very flexible and plants easy to maintain.

A more detailed description of the national situation is reported in the following.

Anaerobic digestion plants for livestock

In 1999, 72 anaerobic digestion plants treating zootechnic slurry were in operation in Italy, 5 of them in centralized installations and the other in individual farms. Almost all of the plants are concentrated in the northern regions (39 in Lombardy, 7 in Emilia-Romagna, 12 in Trentino-Alto Adige).
Most of the plants operate on swine slurry. Only 12 farm plants, all of them in the Bolzano Province, and two centralized plants treat bovine slurry. There are still only a few plants that treat mixtures of different types of waste. Centralized plants also treat sewage sludge and agro-industrial waste, in particular, wastewater from the oil industry and the organic fraction, which comes from the separate collections of MSW**.**

In most of the farm plants in Alto Adige, even organic household waste is treated with bovine slurry. Most plants are very simple in structure and of low-cost: generally a plastic covering is placed over a tank or lagoon used for slurry storage.

These plants operate at ambient temperature or at more or less controlled temperatures. In regards to the use of biogas, cogeneration is prevalent. Co-generators have been installed in all types of centralized plants and in 40 farm plants. In 21 plants, generally connected to cheese factories, the biogas is burned directly into the boilers, as in the plants for the production of Grana Padano or Parmigiano-Reggiano cheese. From 1999 to 2003 approximately 30 plants have been activated.

The anaerobic treatment of other wastes

In Italy, as in the rest of Europe, anaerobic digesters are widespread used for the stabilization of sewage sludge. A survey, performed in the year 2000, identified approximately 120 anaerobic digesters operating in as many urban waste purification plants, with a capacity to treat sewage of up to 21.5 million inhabitants. A number of biogas plants were set up in the agricultural industry as well, particularly in distilleries, sugar factories, and factories for the production of fruit juice and sugar products. Little experience has been gained concerning the anaerobic digestion of the organic fraction of municipal solid waste, whether or not originating from the separate collection of the household wastes.

As far as the treatment of the gross wastes is concerned, important plants are located in:

- Verona (Venetia Region), treating 350 t/day of organic fraction;
- Villacidro (province of Cagliari, in Sardinia), treating 120 t/day of organic fraction;
- Bassano del Grappa (province of Vicenza in Venetia), having a capacity of treating about 80 t/day of organic fraction and 80 t/day of separately collected organic fraction;
- Pinerolo (province of Turin, in Piedmont), treating 120 t/day of the wet fraction of MSW and 20 t/day of organic fraction coming from the separate collection of MSW;
- Rome where a plant is starting up, treating 40.000 t/year of municipal waste;

As far as to the treatment of the pre-selected organic fraction, it is worthwhile to mention:

- The Agrilux plant that works primarily on zootechnical slurry, agro-industrial sludge and separately collected organic fraction;
- The plant in Treviso (Venetia Region) that co-digests sewage sludge (80 t/day) and separately collected organic fraction (10 t/day);
- Another plant under construction in Camposampiero (Padua), which offers a clear example of an integrated system. In fact, the centralized plants closely links - from managerial and technical point of view – several phases, such as biological purification, anaerobic co-digestion, cogeneration and aerobic composting.

The recovery of biogas from landfills

A push towards the-production of electrical energy from biogas generated from landfills came the governmental decree named Cip 6 of 1992. On the basis of this decree power plants of approximately 100 MW have been authorized. Data from the GRTN (National Transmission Grid Operator), for the year 2000, identifies 89 plants of this kind operating in Italian dumps, for a total of approximately 128 MW of installed power and an electrical energy production of approximately 566 GWh/ year.

The overall hypothetical capacity of all the Italian dumps is close to 1000 MW. Actually, only a fraction of this, estimated at approximately 30%, can be utilized for energetic purposes. Since a large part of this capacity is concentrated in medium-sized and large dumps, an objective of 200-300 MW for 2008-2012 seems viable.

Regulations

There still does not exist a complete and extensive body of technical regulations for biomass, despite the efforts of the past few years made by institutions appointed to create them, both in Italy and in Europe, including:

- UNI (Italian National Agency of Unification) that for this sector works with CTI (Italian Thermotechnical Committee) and CUNA
- CEN (Committee of European Normalization), for Europe;
- ISO (International Organization for Normalization), which functions on the global level.

The reasons of this incomplete and less than satisfactory issuing of technical regulations are numerous, some of the most significant being:

1. the complexity of the biomass system, arising from the great number of different raw materials, conversion techniques and final uses;
2. the ongoing confusion between organic material that can be re-used in the production cycle or in energy cycle, and organic wastes that must be disposed of;
3. the overlap of national and European regulations, which makes unclear the procedures.

The only noteworthy document concerning the biogas sector is UNI 10458 regulation, which concerns plants for the production of biogas. The constructional requisites for plant as well as and the rules for production, purchasing and testing biogas, are specified. There is no regulation on the use of biogas in thermal engines and heat generators.

Anaerobic digestion plant for waste treatment in Bassano del Grappa, Italy

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The waste treatment plant in Bassano del Grappa was built and is now managed by Daneco, a joint-stock Company of Waste Italia Group, on behalf of Brenta Services, a Consortium among several municipalities located in the Bassano's area.
The installation has been conceived as an integrated system for recycling materials and recovering energy from Municipal Solid Wastes (MSW) collected within associated municipalities. The original concept of the project hinges on an anaerobic digestion phase treating the wet fractions of MSW together with the urban sewage sludge. The separate collection of MSW, as it is practiced in some municipalities, let the dry fractions (paper, paper-board, glass, plastics, metals, etc.) to be sent directly to the recycling process; the bulk wastes, as they are collected in other municipalities and the fractions composed of materials with a high Organic fraction and Green Residues (OGR) are sent to the plant together with the sewage sludge, coming from the purification process of urban waste waters.

Figure 15: Bassano del Grappa (Vicenza) Anaerobic Digestion Treatment Plant

Characteristic of the plant

The plant is designed for treating approximately 32,000 t/year of bulk MSW, more than 30,000 t/year of OGR coming from separate collection and 3,000 t/year of sewage sludge. The waste is riddled and selected, obtaining RDF, organic fractions and reusable materials. An integrated outstanding centre is so in operation recovering energy, re-usable materials and fertilizers from wastes. The organic fraction, together with sludge, is treated in anaerobic digesters of 2,500 m^3, while the organic fractions and green residues, coming from separate collection, are treated in two other digesters of the same sizes. The biogas produced in the digesters feeds two generator groups each of 1,200 kW, with production of more than 10,000 MWh/year of electricity.
The original features of the installation are: the possibility of recovery the energy content of the wet fraction of wastes, and the integration between the anaerobic, for biogas generation and the aerobic, for compost production sections.

In fact, the outputs of the plant are:

- electric energy, generated by burning biogas obtained through the anaerobic digestion of organic fractions;

- production of high heat value RDF, obtained as a by-product of the pre-selection of incoming wastes;
- a high quality compost from OGR;
- compost from refining the organic fraction of MSW, pre-digested;
- unrefined compost useful for landfill cover;
- re-usable materials.

Figure 16: Bassano del Grappa A.D. plant: Municipal Solid Waste storage bunker.

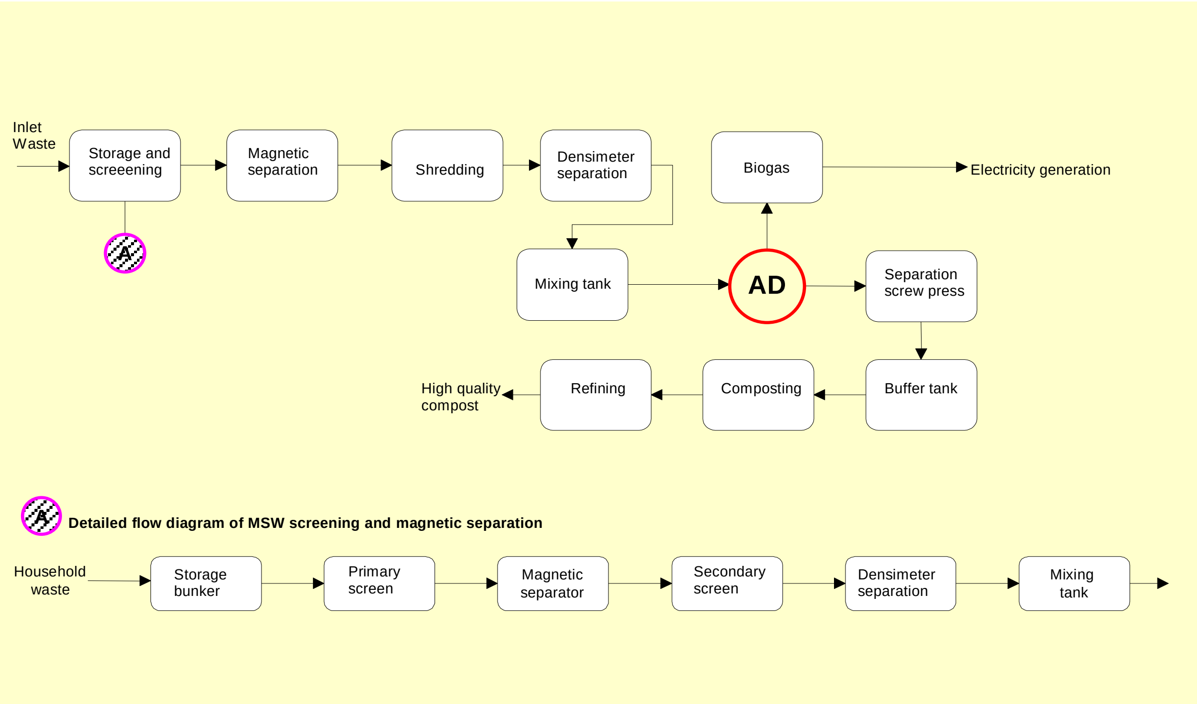
Short description of the plant

The incoming wastes are let in a closed hall and piled up in three concrete pits: one for the MSW, one for OGR and another one for biological sewages. In the same hall another pit stores up the refuse-derived fuels (RDF) produced by the plant. The pits have a capacity to store an amount of waste corresponding to a three-days collection and are located in a closed hall where pressure is kept low in order to avoid emission of bad smells. By means of an overhead-travelling crane equipped with a hydraulic bucket, the bags are opened, the wastes homogenised, and cumbersome refuses removed. MSW and OGR are conveyed to a primary revolving screen, where the oversize material (“shorts”), mainly dry fractions of MSW, is separated from the organic screenings.

Figure 17: Bassano del Grappa A.D. plant: Municipal Solid Waste pre-sorting section.

After stripping ferrous particles, the shorts are crushed in order to reach an homogeneous particles sizes. The oversize materials are mixed with the screening ones coming from the primary screen. A deep mixing is accomplished between the screening materials, wet and rich in digestible organics and the crushed and less damp oversize materials. This mass moves on a secondary screening for a final separation of the screening fraction from the oversize fraction; the latter forms the RDF, which may be used as a fuel also in third party plants. The secondary screening fraction is sent to the anaerobic fermentation process after removal of unusable particles.

Flow diagram of the plant



Source: Brenta Servizi S.p.A.

Figure 18: Bassano del Grappa A.D. treatment plant: biomass flow diagram and main separation steps.

Process description: anaerobic digestion and energy recovery

The plant is composed of:

- three anaerobic digesters: one for the organic fraction of MSW and two for the organic fraction from OGR;
- a biogas distribution system;
- a biogas utilization systems;
- an expression system for the digested sludge (digestate).
-

The anaerobic digestion occurs according the following sequences:

- preparation and conveyance of the mixture to the digester;
- a high density digestion in a medium having 15-20% of dry weigh;
- the stirring of the digester by means of a biogas lance;
- aerobic treatment of digested material.
-

The digesters receive:

- the fresh organic fraction coming from the mechanical pre-selection;
- digesters re -circulating fluid;
- the bulk water deriving from the squeezing of the digested material;
- biological sludge (as far as the MSW treatment is concerned);
- the steam used for pre-heating the mixture at the digesters input.

Figure 19: Bassano del Grappa A.D. plant: View of three Anaerobic Digesters.

The organic mass is homogenised in a mixer and heated at 40 °C by means of steam, before being conveyed into the digesters. Part of the biogas produced is used for stirring the fluid mass inside the digesters; this enhances the bacterial activity and favour the maximum production of biogas.

The process takes place in three concrete cylindrical digesters –equipped with control and safety apparatus - each of 2500 m^3 in volume. The tanks have flat covers and bottoms, and the vertical walls span over the whole tank height and on 2/3 of the diameter. After 25-30 days the digested material is extracted by gravity from the digester. It has the consistency of a sludge, which must be pressed to obtain solid and liquid fractions. The latter is re-circulated in the mixer. The former is a thick sludge, which feeds the composting unit.

The biogas from the three digesters is conveyed into a unit where, besides regulating re-circulation in the digesters, the gas is dewatered and cleansed from H_2S content. The purified gas is fed to the generator sets, and to the boiler for space heating. Dewatering take places in two heat exchangers and in an industrial refrigerator. The dry desulphurisation occurs in an adsorbent unit where iron oxides react with hydrogen sulphide getting ferrous sulphides. The latter separate from the gaseous phase settling on the catalyst surface. The biogas, having a low heat value of about 5,500 kcal/Nm^3, is compressed over 100 mm for feeding the generator sets.

Composting section

The digestate coming out of digesters is fed to the composting section, in order to complete the mineralization of the organic materials and to achieve the maturation and following refining, depending of marketable compost characteristics: compost deriving from MSW and sewage sludge is utilized for land filling or environmental restoration; compost deriving from OGR is utilized as organic fertilizer.

The composting process is characterized by reduced oxygen consumption and by a slow temperature rise. After, the digested materials are removed to the maturation department and arranged in the storage piles; the digestate is let into the end of a pile and then discharged on a reversible conveyor, setting crosswise at the storage piles. For the treatment of the digested materials, produced by MSW and sewage sludge, the piles are arranged for the entire length of the threshing-floor (or we realized a single pile, which take all the piles area); the digestate is dewatered and stabilized by blowing air into the composting piles.

Figure 20: Bassano del Grappa A.D. plant:

The homogenizing and the maintenance of the porosity of the compost, during the process, are obtained by means of periodical turning over of the piles.
The piles turning over machine removes automatically the digestate from a threshing-floor to the contiguous area and finally at the conveyor belt.
For composting of the digestate deriving of OGR, the piles are stored in seven maturation areas, employed for the production of high quality compost; this compost is finally conveyed to the refining unit.

By means of a revolving screen, the stream is then divided in the following three portions:

- primary under screen: grains with diameter below 10 mm;
- secondary under screen: grains with diameter ranged from 10 and 40 mm;
- reject, essentially made of plastic materials.

The secondary under screen is carried out at the grains-breaker mill and then joined together a primary under screen and refined by a densimeter equipment; the light portion coming out of the densimeter equipment, after the final maturation, is used like high quality compost.

Air and wastewater treatment

The process air treatment unit withdraws by suction the air from the waste and sludge storage house that is maintained in depression as to outside.
The air blown from the composting house is collected to the removal and absorption system, equipped with two bio filters, as final purification stage.

Figure 21: Bassano del Grappa A.D. plant:

The process wastewater is pre-treated in oxidation and sedimentation basins, before to be sent to the physico-chemical and biological municipal treatment plant.

Main biomass data

The main biomass data, that summarize the energy recovery bilance, are reported in the following points; the data concern to daily average, computed on plant operation of 312 day a year.

Materials in inlet

- MSW remaining after source sorting:	70.5 tons
- Under screen coming from others plants:	32.0 tons
- MSW putrescibile fraction from source sorting:	96.0 tons
- Sewage sludge:	9.5 tons

Production and e characteristics of biogas

Produced amount:	about 23,000 Nm^3
- Average calorific value:	5,500 kcal/Nm^3
- Methane content:	55 – 70 %
- Methane yield:	
• from under screen	115 Nm^3/tons
• putrescibile fraction	160 Nm^3/tons

Power generation

- Produced amount:	about19,000 kWh
- Two set of generators:	a 570 kW and 750 kW engines

SPAIN

Biomethanisation in Spain is increasing steadily. In a survey carried out within the BIOEXCELL program, the following digestion plants were identified *(Not including sewage sludge digesters):*

a) Industrial

ACOR 1. Valladolid. UASB. 1200 m^3. Sugar industry
ACOR 2. Olmedo (Valladolid). UASB. 1200 m^3 Sugar industry.
Paniberica. Valladolid. Contacto. 5000 m^3. Yeas plant.
EBRO. Peñafiel (Valladolid). Contacto. 3000 m^3. Sugar industry.
EBRO. Miranda de Ebro (Burgos) UASB. 1600 m^3. Sugar industry.
Anaga. Tenerife. UASB. 400 m^3. Brewery
Heineken. Madrid. Lecho fluidizado. 5 x 300 m^3 Brewery
Heineken. Jaén. UASB. 2 x 750 m^3. Brewery
Heineken. Sevilla. IC. 500 m^3. Brewery
Heineken. Valencia: UASB 2 x 750 m^3. Brewery
Heineken. Arano (Guipúzcoa) IC 500 m^3. (En construcción)
Smurfit. Mengibar (Jaén). UASB. 1500 m^3. Paper industry.
Europac. Cinca (Huesca) UASB. 1200 m^3. Paper industry
Cooperativa del Jerte. Caceres. UASB 600 m^3. Distilery.
Puleva. Sevilla. UASB 600 m^3. Dairy industry.
Catalana de Polimers. Barcelona. UASB 500 m^3. Chemical plant.
Celestar. Santo Domingo de la Calzada (Rioja). UASB 1000 m^3. Sugar.

b) Plants of biomethanisation of the organic fraction of municipal solid waste:

In Spain, due to different factors, including the activities carried out under the Altener program support, with complete visits to running plants in Europe, anaerobic technology for treating OFMSW has reached some maturity.

This fact has transformed Spain into the first country with installed capacity to treat the OFMSW by biomethanisation, with more than 1,000,000 tons/year (around 700.000 t/y in running plants or in plants in the start-up phase and around 380.000 t/y in plants that will come into operation in 2005). This figure represents around 35% of the installed capacity in Europe (2,800,000 in accordance with de Baere, 2004 and 2004a)

There are 6 plants using wet technologies, in operation or starting-up: Among these, there are 2 using LINDE-KCA technology, the first in Barcelona with a capacity of 140,000 t/y and the second in Pinto (Madrid) with a capacity of 80.000 t/y. The other 3 use ROS-ROCA technology: These are the plants located in Àvila, Palma and Zonzamas with capacities of 32,000, 35,000 and 36,000 t/y, respectively. Finally, there is one plant in León, using Haase technology (70,000 t/y).

On the other hand there are 4 plants using dry technology: 3 using VALORGA technology in Coruña, Cadis and Montcada (Barcelona) with 70,000, 80,000 and 115,000 t/y respectively (this latter one is ready for operating but is waiting the solution of some political problems to start). The other dry technology plant is the one in Valladolid, with a capacity of 15,000 t/y is using LINDE-BRV technology.

In addition concerning wet technology, there are 3 ROS-ROCA plants that are presently in construction in Barcelona, Tudela and Jaen (90,000, 28,000 and 20,000 t/y respectively) and 2 of LINDE-KCA in Burgos and Alto del Negro (40,000 and 75,000 t/y respectively). With reference to the dry technology, there are 2 plants in erection in Tarrasa and Vitoria (25 mil and 20 mil t/y, respectively) using DRANCO technology and 1 plant of 75,000 t/y of

KOMPOGAS in Logroño. Summarizing, and taking into account both plants in operation, start-up or in erection there are the following:

Wet technology:
12 plants: 6 of Ros-Roca, 4 of LINDE, 1 of BTA and 1 of Haase.
Dry technology:
7 plants: 3 of Valorga, 2 of Dranco, 1 of LINDE-BRV and 1 of Kompogas.

Table 11: OFMSW treating plants, working, in start-up period or in erection phase, in Spain

Technology/ LOCATION	ROS-ROCA (wet)	VALORGA (dry)	DRANCO (dry)	LINDE (wet:KCA /dry: BRV)	OTHERS (wet or dry)
Ecopac-1 Barcelona				KCA (wet) 140.000 t/y Urbaser/Comsa Emte	
Coruña		70.000 t/y TecMed			
Valladolid				BRV (dry) 15.000 t/y FCC	
Avila	36.500 t/y Urbaser				
Ecopac-2 Barcelona		80.000 t/y Urbaser/Fcc/ Tirssa			
Pinto (Madrid)				KCA (wet) 80.000 t/y Urbaser	
Palma Mallorca	32.000 t/y Urbaser				
León					HAASE (wet) 70.000 t/y Fcc/TecMed
Zonzamas (Lanzarote)	36.000 t/y Sufi				
Miramundo Cadiz		115.000 t/y Sufi			
Ecoparc-3 Barcelona	90.000 t/y Tersa				
Tudela	28.000 t/y FCC				
Jaen	20.000 t/y EGMASA				
Logroño					KOMPOGAS (dry) 75.000 t/y Cubiertas
Pamplona					BTA / MAT (wet) 64.000 t/y Ferrovial
Terrassa			DRANCO 25.000 t/y		

			CESPA		
Burgos				KCA (wet) 40.000 t/y FCC	
Alto del Negro (Las Palmas)				KCA (wet) 75.000 Isolux	
Vitoria			DRANCO 20.000 t/y CESPA		

Finally to point out; the analysis of all the AD plants reveals that on the possible uses for biogas, but in Spain due to the policy and present legislation, the cogeneration of electricity and heat is the most profitable and thus, the option taken by nearly all the plants installed.

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UNITED KINGDOM

Background

In 2004 at least 60 biogas plants are known to be working in the UK for the digestion /co-digestion of slurry and food waste/industrial residues. In addition there are nearly a thousand AD systems operating in the water treatment industry some of which have a co-digestion facility. There is also an increasing number of plants being installed by the food processing companies to handle their own residues and effluent as for example sugar, fish, baked beans and products defined within the ABPO legislation.

There have been three development phases each with different drivers:

- 1978- 1990 about 45 plants were constructed on farms mainly with financial assistance from the Farm Waste Management Grant Scheme The main driver was the need to offset the impact of volatile oil costs on farm businesses but other factors including the improved value of the digestate as a fertiliser and odour control were also seen as derived benefits. As far as it is known 29 of these plants are still operating satisfactorily where the problems that occurred in the early years have been overcome. The difficulties were attributed to failures of pumps and augers, separator belts, digester sedimentation, engine failures and as a consequence high operating and maintenance cost

- The 1990s were characterized by a shift from the farm-scale plants to the large commercial / centralized systems based on the co-digestion of manures and other organic residues. This change was stimulated by the Electricity Act (1989), whereby electricity supply companies were required by the Secretary of State to purchase a prescribed percentage of power from renewable sources. This requirement was known as the Non Fossil Fuel Obligation (NFFO) A developer could bid for a 15 year indexed linked contract. This stimulated a burst of activity among AD developers and resulted in the award of seven contracts but to date only one contract has been activated – the Holsworthy Biogas plant commissioned in 2002. This plant is designed to process 246,000 tonnes/yr of animal manures and industrial waste. The failure to realize the remaining tender offers can be attributed largely to the mismatch between the estimated capital costs in relation to the offered electricity price albeit at 7.1 Euro cents/kWh.

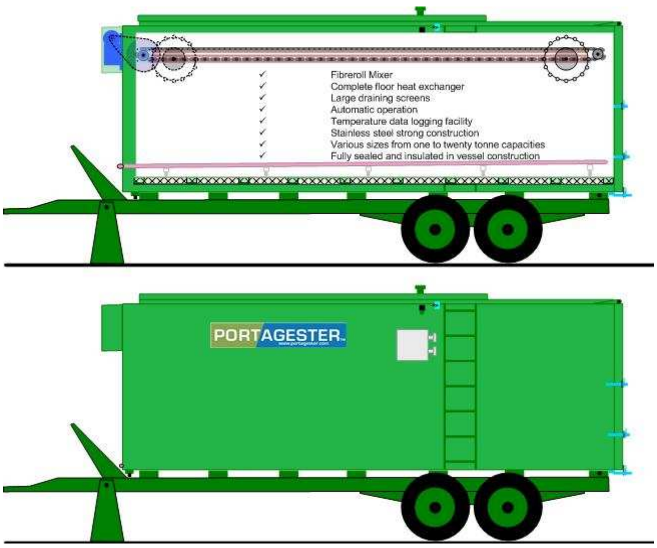
- From 2002 to date the combined effects of the Landfill Directive and EU Regulation 1774/2003 concerning the management of animal by – products have provided a new climate for the adoption AD. This is reinforced by pollution control legislation through the Nitrates Directive for the protection of soil and water and the consequences of the Kyoto Protocol for the protection air from greenhouse gas and ammonia emissions. The latter is being implemented by renewable energy targets (defined as electricity in the UK) and the Renewable Obligation imposed on the power supply companies. In Scotland the remit for AD has been extended to an R&D programme to test the potential for its adoption as a measure for reducing the pollution risk of animal slurry and the protection of bathing water. In Northern Ireland the adoption of any AD scheme must be able to demonstrate that it can also contribute to more effective phosphate management and thereby reduce the risks of eutrophication of lakes and rivers. The new legislative structure has reversed the role of renewable energy (with its input management) from the key driver as it was under the NFFO regime to become the economic anchor that supports the role of AD as a mechanism for pollution avoidance and a system for sustainable resource management.

Progress under the new legislation

During the last four years the fruits of the R&D of a number of British companies have come to fruition with the commissioning of at least 10 new plants since 2002 of which 6 have been built this year. Three systems are illustrated below each of which fulfils a different purpose albeit with energy production fulfilling an integral role.

- **Organic Power Ltd (Horsington, Somerset)** has adopted a two-pronged approach whereby its technology combines aerobic and anaerobic digestion in a series of minimum energy shaped lagoons of water, which are heated by solar power to replace the conventional cylindrical tanks. The result is maximum energy production and the complete conversion of the organic materials into renewable natural gas, fertilizers and other valuable materials whilst allowing the recovery of heavy metals. The first 50m^3 digester was commissioned in 2002. Parallel development of purpose designed engines for two Mercedes cars to run on renewable natural gas was launched to the public at the EU BIOEXELL Conference/Workshop held at the Killyhevlin Hotel in Enniskillen, Northern Ireland between the 21st – 23rd October 2004. Further models are now on the production line at the Mercedes factory in Germany. Also negotiations for the first 13,000-tons/yr digester for a local authority are well advanced.

- **Bioplex Ltd in association with Sustainable Waste Systems Ltd.** have launched the Portagester. This is a farmer designed simple, modular, easy to operate system for the processing of dry organic residues. The tractor drawn Portagester can be used to collect waste/residues from the producer and return the load to the processing site without the need for double handling.



Three demonstration/R&D plants have been operating for the last 10 years and the first 5,000 tonne/yr. commercial Portagester was commissioned on a farm in Co. Durham in 2003. Two more plants for just under 1000 tonnes/yr and another modular plant to reach 8,000 tons/yr are on the order books for delivery in 2005.

Greenfinch Ltd has developed the first biogas plant designed to operate specifically on kitchen waste and plans are now well advanced for the installation of the first commercial 5,000 tons/yr system. The company is also participating in two government funded R&D programmes. In 2004 it designed, built and commissioned six on farm digesters for the management of cattle slurry with a range of throughputs from 900-4,500 tonnes/yr. The seventh plant is currently under construction for installation in 2005. The digesters form part of the Scottish Executive Water Environment Division's enquiry into the potential for AD to reduce the risk of diffuse pollution to bathing water from slurry run off and to establish how the capital costs of such plants can be reduced through the simplification of the plant designs.

In addition to the progress made by British companies a number of Danish and German firms experienced in the design and construction of biogas plants have established UK subsidiaries. These too have reported a significant increase in interest from prospective purchasers especially among waste management companies, local authorities including some of the London Boroughs for processing the biodegradable fraction of MSW. Leicester City Council/Biffa Waste Ltd. for example, incorporates anaerobic digestion for processing the organic rich fraction of household waste.

The waste as it is delivered to the plant is passed through a Ball Mill to fragment it and to remove inert materials such as plastics, glass and metal. Thereafter, the remaining organic rich material is hydrolysed to commence the aerobic and anaerobic processes over a 21-day cycle and treated in compliance with the ABPO. For every 1 tonne introduced 300kg remain as a carbon base for addition to sewage sludge and spreading to land. The plant has a 1.5 MW_e capacity enough to power 1500 homes. A second plant is under construction in Wales, while other waste management companies, elsewhere in Great Britain, have already brought further capacity into operation.

These initiatives are additional to those companies that have been supplying digesters to the water industry and the water companies that already have developed considerable in house expertise an increasing number of which have co-digestion facilities.

Barriers to adoption

In this section attention is addressed to the newer (for the UK) concept of biogas plants and does not apply to the long practiced use of AD technology in wastewater treatment.
The problems fall relate to four main areas:

- Regulation and classification of the bio-fertiliser
- Capital costs and plant economics

- Technical reliability of plant design and odour control
- Levels of political and interdepartmental awareness in government especially in Great Britain

Currently the ***bio- fertiliser*,** whether manure from more than one farm or the product of co-digestion, is classified as *a waste product* under the waste licensing regulations. In consequence each farm that uses the new product albeit with a quality hygiene and nutrient declaration must also apply for a license if the bio-fertiliser is to be stored on the farm and applied by the farmer himself and the license renewed annually. Apart from the bureaucracy and the excessive costs it degrades the quality of the new product and creates a highly damaging barrier that relegates AD to a waste disposal system. This has serious consequences:

- Farmers working under Quality Assurance Schemes to supply supermarkets will not wish to appear to lower their standards by spreading a classified exempt waste governed by Waste Licensing Regulations on their land in spite of the certified nutrient and health quality status of the new bio-fertiliser.
- Supermarkets and public aversion to purchasing food from farms that spread an exempt classified ‘waste’ on land albeit in practice a quality assured new bio-fertiliser delivered and applied under far stricter standards than any ‘natural’ slurry produced from a farms own livestock or used on organic farms.
- Public confidence in AD as an environmentally friendly sustainable system.

However, progress to clarify the situation is being made by the Department of Environment and Rural Affairs and the Environment Agency. The former has implemented a derogation under the Regulation 1774/2003 to allow the use of the bio- fertiliser on grassland and for grazing to resume after a three week interval. The latter is introducing a new definition of a waste product such that it is to be defined by the producer. In those cases where the residue after one stage of a process automatically becomes part of the next production stage (including its use in a digester) then the motive of that producer will be used to define the input and it will not be defined as a waste product but as the material for its next process. This is a complex matter that has not yet been put to the test but in principal makes a positive step showing willingness to reducing the barrier**.** *This issue needs urgent attention with sound evidence produced to support the Environment Agency initiatives.*

High capital costs and poor returns on investment have been a characteristic of developments to date and associated with the perception that AD cannot/will not be able to stand on its own economic feet. At policy and decision-making levels the imprinted recollection of the high costs, poor performance and technical failures that dogged many of earlier developments continues to create a significant obstacle and tends to create a negative perception of AD generally. As awareness of the new generation of British designs and the models of well-proven (over the last 20 years) AD systems operating across Scandinavia, Germany and Austria in particular disseminates to wider audience these barriers should gradually be reduced. Currently the UK companies are focusing on simplifying designs and management and demonstrating reliability both for on-farm and centralized plants. There is, therefore, an interrelationship between these two issues.

Odour control has emerged as a concern at one of the new biogas plants. As co-digestion of organic by-products from the meat and other food processing industries with animal manure comes to the public attention it has already shown itself to be a major factor that unless addressed vigorously could escalate very rapidly into a major obstacle on a level with that which is now associated with incineration. Such circumstances arise when there is a failure of consultation and extreme fear of the unknown.

At the policy level the raft of recent new legislation in relation to the landfill sites, animal by-products, nutrient management planning for the protection of soil and water and need to address greenhouse gas (and ammonia) emissions has provided a secure basis for the development of AD technology in diverse situations. While the legislative infrastructure has been established, the individual policy components are the responsibility of a number of government departments. *This sectoral administration* of, for example, waste management, water planning, energy, transport, soil protection, rural development, veterinary health and food safety, etc. is shared between two major UK Government Departments and a number of others within these main foci of policy and administration. Each has its respective responsibilities and in the present context its *mitigates against* the awareness that AD technology has a relevance to activities within all these fields and *the potential to contribute across their a policy objectives.*

IRELAND

Although there is considerable potential [1] for the utilization of animal and green wastes for the production of biogas in Ireland, the development of AD at the single farm or centralized level is significantly behind many of the leading EU states. However there is growing interest in the technology from both industry and Government agencies. In a recent report by the Irish Environmental Protection Agency [2] three environmental policy objectives in which anaerobic digestion could play a significant role were identified.

Table 12: Irish On-Farm Biogas Plants 2004 [3]

Location	Year Built	Digester Size	Feedstock	Energy Utilization
Adamstown, Co. Wexford	1995	300m^3	Cow slurry, Kitchen waste, Grease trap waste	Hot water for cheese production plant. 100kWe CHP plant installed
Ballymacarbry, Co. Waterford	1996	2 digesters of 72 m^3	Cow and pig slurry, farm yard manure, chicken litter, organic sludge	Digester and domestic gas boiler
Callan, Co. Killkenny	1999	150 m^3 and 450 m^3	Cow slurry and organic wastes	Two 85kW_{th} boilers and one 200kW_{th} providing heat to a community district heating system
Roughty Valley Co. Kerry	2003	1,350 m^3	Pig slurry	Heat for pig houses. 100kWe CHP plant installed

The policy objectives relate to the Nitrates Directive/water pollution, renewable energy and the Kyoto Protocol/global warming. Another potential driver for the sector is increased slurry storage requirements of between 16 to 20 weeks. This will require substantial investment in slurry storage capacity on many farms. The requirement for additional slurry storage potentially gives the opportunity to look at the development of anaerobic digestion at the same time.

In Ireland four on-farm biogas plants have been developed in recent years. These plants have developed independently and for different reasons. They have not benefited from a national AD development support programme or national strategy.

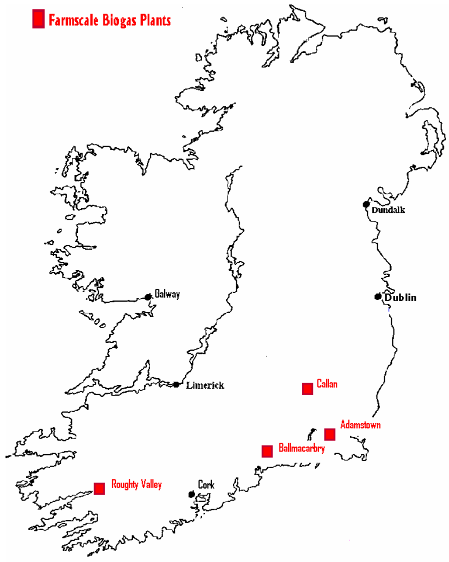


Figure 22: Farm-scale plants in Republic of Ireland

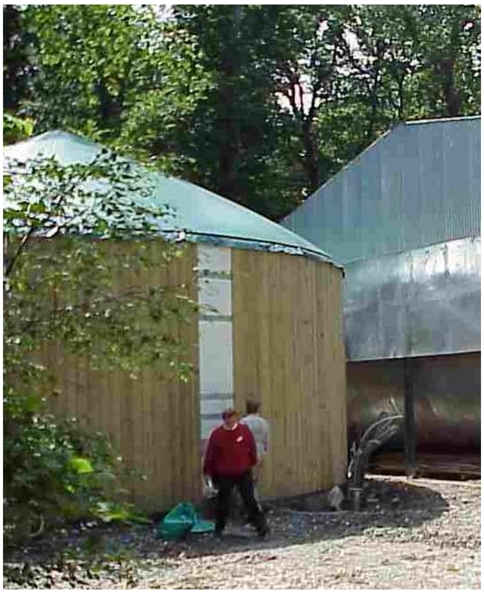


Figure 23: AD Plant at Callan, Co. Kilkenny

<u>Table 13:</u> AER VI Competition, List of Winners – Biomass Anaerobic Digestion (AD) [6]

County	Company	Size (MWe)
Kilkenny	Art Generation Ltd	1.452
Waterford	Bioresolve	0.04
Kildare	Bioresolve	0.04
Dublin	Bioresolve	0.085
Kerry	Bioresolve	0.06
Kilkenny	Bioresolve	0.13
Limerick	Bioresolve	0.085
Westmeath	Bioresolve	0.045
Donegal	Bioresolve	0.085
	Total	2.022

While progress has been slow to date there is considerable interest in biogas in Ireland. This perhaps is best illustrated by the results of the most recent round of the Irish Alternative Energy Requirement (AERVI) competition (which offers guaranteed electricity prices for projects over a 15-year period). Nine plants were awarded contracts, with the potential installed capacity of 2.022 MWe. It is expected that six of the smaller projects will be commissioned in 2005 [4] this would bring the total number of on-farm plants in Ireland up to ten. The larger plant in Kilkenny is still in the planning process [5].

An increasing number of sewage treatment plants are using AD as part of their production process and there are approximately ten operating at present. There are also a small number of industrial plants using AD. Silverhill Foods in County Monaghan (one of the largest duck farming enterprises in Europe) are currently developing a project, which will use AD as part of a process to treat approximately 70,000 tons of duck slurry [7].

While there are many tangible benefits for the development of biogas in Ireland current barriers to development are considerable and include:

- Lack of viable access to the electricity market for small projects
- Low price offered for electricity produced from biogas through a competitive tendering process (the AER competition is currently under review)
- Limited number of working on-farm systems in Ireland and no examples of centralized plants
- Restrictive legislation on waste management
- No support from the Irish Government for the development of AD

REFERENCES:

[1] Sustainable Energy Ireland, (2002). *Briefing Note on Biomass*. Dublin, Ireland
[2] Environmental Protection Agency, Strategic Policy Unit, (2005), *Anaerobic Digestion: Benefits for Waste Management, Agriculture, Energy, and the Environment.* Dublin, Ireland
[3] Guest, C. (1999). *Overview of On-farm Anaerobic Digestion Plants in Ireland.* Paper presented at the AD-net Conference, *Anaerobic Digestion Opportunities and Solutions* in Galway, Ireland, 1999. Data updated September 2004.
[4] Heslop, V. (2004) Personal communication. BioResolve, Co.Waterford.
[5] Walsh, R. (2004) Personal communication. Art Generation Ltd.
[6] Department of Communications, Marine and Natural Resources, (2003) *Results of the Sixth Alternative Energy Requirement (AERVI) Competition,* available from http://www.marine.gov.ie/display.asp/pg=802.
[7] Silver Hill Foods (2004). *The Silver Hill Foods Environmental Project*. Available from http://www.silverhillfoodslife-env.com/index.asp. [Accessed 16 September 2004].

FRANCE

During this period, AD and biogas use have started to appear in official document as a promising technology for environmental benefits and renewable energy production . The first biogas farm plant has been connected to the greed near Nancy. Tests are on hand. More than 4 biogas plants are under construction, one of them is a dry fermentation plant. Two co–digestion biogas projects are near to start the building phase in French Brittany. More and more farmers are asking information about biogas and more than 30 biogas studies have been conducted. At the end of 2004 the opposition to incineration and greening of agriculture open new perspective for biogas.

MSW:

Existing Plants: - Amiens (Valorga)
- Varen Jarcy (Valorga)

New plant under construction:
- Martinique (kompogas Vinci)
- Lille 120 000t biodechets (Linde KCA)

Invitation to tender:
- Montepellier; 200 000t
- Saint Lô; 60 000t

- Paris ; 2 x 100 000t

And some place with positive approach :

- Marseille,
- Anger,
- Arcachon,

Farm waste and co-digestion:

Old plants : less than 10 (20 years old)
New plants

- Claudepierre (Dairy farm)
- Di Gracia (Dairy farm)
- Pierre Lebbe (Dry fermentation manure)

Under construction :

- Reulier (Dairy farm)
- Mineur (Dairy farm)

The two collective plants projects in French Brittany , Lannilis and the Cuma Mené have been stopped by negative public perception.

EARL Lebbe- Biological Farming. Dry digestion of goat manure

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France
Tel: 05 62 96 47 27
Fax: 05 62 96 94 64
pierre.lebbe@free.fr

Manure is not the easiest organic substrate for AD, but there is a great market for manure based biogas plants. The economical conditions for electricity production with biogas at farm scale are not good in France. The price of electricity is too low. Farmers with income from basic production have high difficulty to justify investments in biogas plants. Farmers with high quality products, selling their products directly to “connoisseurs”, need very clean and environmentally friendly conditions of production.

Pierre Lebbe’s farm is well representative for this kind of farms. Though it is not a representative pig farm from Brittany or a milk farm from Normandy, his example could increase the awareness about the benefits and the potential of biogas/AD systems. All the farm practices biological farming. The farm income comes from the high quality of the products and not from a large quantity. Only 140 goats are at the basis of this business. The produced biological goat milk is transformed in cheeses of high quality. The cheeses are sold in best quality shops in Toulouse and exported as far as to the U.S.A. On the farm, biological beer is also produced.

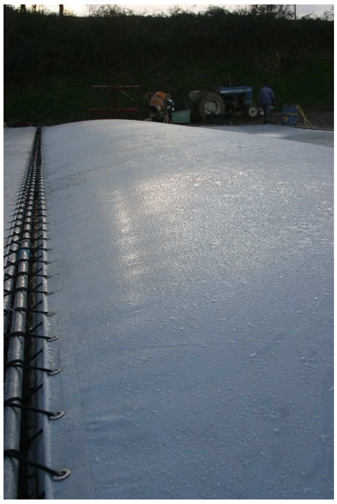
Organic waste used in the AD process.

Table 14: Biomass residues for AD, produced at the farm.

		Waste & manure	Composition		
Organic source	Quantity	Tones	%DM	%OM	Access frequency
Goats	140	300	48%	37%	All year
Kids	80	90	32%	16%	Nov-dec
Whey		60			
Cheese w. water					Daily
Brewery w.w					3 times/month
Total		450 t or 580 m^3			

The manure is extracted 4 time/year. Fresh manure density: 0,75t/$m^{3.}$
The liquids from de chesses and brewery activities are used to immerse the manure in the digester. Other products could be used as the rest of filtration from a neighbour oil production.

The 3 bunkers and the green liquid storage



Plastic cover inflated by biogas

Digestion system.

The targets of this biogas plant are simple, low cost and minimum work. The concept is to use a derived of a well-known farmers technology: bunker silos.

Differences are:
- Insulation of floor and externals walls,
- Channel for liquids circulation
- Sloping entrance
- Heated floor
- Immersion of manure
- Plastic cover with skirt for hydraulic seal
- Manure floating device

The plant have 3 joint bunkers of 100 m^3 each, tanks for liquid transfer to empty the bunker at the end of fermentation and immerse the new manure at the start of a new fermentation. Tanks are recycled fuels storage insulated. The only engine for the process is a small transfer pump (the way in the manure acted as a water filter and prevent collapse in the water circulation system).

Juice transfer and heating pipes

Pierre Lebbe (farmer)

The plant is running since one year and the farmer consider now having a good control of the plant after a long tuning period. Gas production is regulated if needed by whey injection in the circulation system. The production is less than 150 m^3/day. Improvements are expected. This production is used on the farm for the transformations processes (cheese & beer), and for domestic purpose.

Gas uses

- The brewery uses a part of the gas for: 80m^3/ brewing (malt drying, heating of brewing tanks, boiling to stop fermentation). Cheese processing uses the other part of the gas.

Economy and future challenge

The plant cost is of 50 000 € in furniture the work have been done by the farm. Most of the silage silos are building by farmers in southwest France.

The energy substitution from propane to biogas (propane is used for transformation process and home heating) permit by 100m^3/d is equivalent o 17 t of propane.
With the actual propane price: 18000€/year. 2,8 years of return time of the biogas plant investment!

More data have to be collected but it opens a field for this type of farm. One of the satisfactions of Pierre Lebbe is to run a 24 ha farm and employ 4 persons. By this he maintains people in rural area, stop rural depopulation and contribute to increasing the quality of life in his village. It’s a small but important brick in building a sustainable world.

Useful European addresses and www-links

Austria

Institute for Environmental Biotechnology
Department for Agrobiotechnology IFA Tulln
A-3430 Tulln, Konrad Lorenz Strasse 20
Prof. R. Braun

Inst. für Land-, Umwelt- und Energietechnik
A-1190 Vienna, Peter Jordan-Strasse 82
J. Boxberger, T. Amon

Technical Univ. Vienna
Institut für Wassergüte u.Abfallwirtschaft
Abteilung für Wassergütewirtschaft
A-1040 Wien, Karlsplatz 13 / 2261
H. Kroiss

Inst. für Verfahrenstechnik
Brennstofftechnik und Umwelttechnik
A 1060 Wien, Getreidemarkt 9
A.Friedl, H. Hofbauer

Technical Univ. Graz
Institut für Umweltbiotechnologie
A-8010 Graz, Petersg. 12
K. Robra

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Bioenergy Department
Niels Bohrs Vej 9
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www.sdu.dk/bio

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Axelborg, Axeltorv 3,
1609 København V
Tel: +45 33 39 40 00
www.biogasbranchen.dk

Foreningen for Danske Biogasanlæg
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Kurt Hjort Gregersen
Tel: +45 65 50 41 67
E-mail: khg@bio.sdu.dk
www.biogasdk.dk

See also:
www.biogasinfo.org
www.lr.dk
http://www.dkbiogas.com/

France
http://www.lebiogaz.info
http://biogaz.free.fr/suite.htm
http://www.biogaz.atee.fr/
http://www.eden-enr.org

Plant suppliers
http://www.valorgainternational.fr/

Germany
General information
http://www.biogas.org

Combined Heat and Power Generation CHP:
http://www.minibhkw.de/
http://www.bhkw-info.de/
http://www.bhkw-infozentrum.de/index_next.html
http://www.biogas-baustelle.de/
http://www.bhkw-biogas.de/

UK
Renewable Power Association
http//:www.r-p-a.org.uk
Composting Association
http//:www.compost.org.uk
Contact: info@compost.org.uk
http://www.britishbiogen.co.uk/

Ireland
http://www.irbea.org
http://www.irish-energy.ie/content/content.asp?section_id=442&language_id=1
http://www.irbea.org/rags/
http://www.camphill.ie/camphill_in_ireland.htm
http://www.irishpowersystems.ie/

Greece

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E-mail: zacharopoulos@edrasis.gr

Italy

http://www.biogas.it/

Spain
Asociación productores energías renovables- APPA
(Association of producers or renewable energy in Spain)
http://www.appa.es/dch/renovables_espana.htm

Sweden
http://www.biogas.se/

Switzerland
http://www.biogas.ch/
http://www.biomassenergie.ch
http://www.novaenergie.ch/

Other links

Brazil
http://www.biogas.com.br/

USA
http://www.biogasworks.com/
http://www.michiganbioenergy.org/