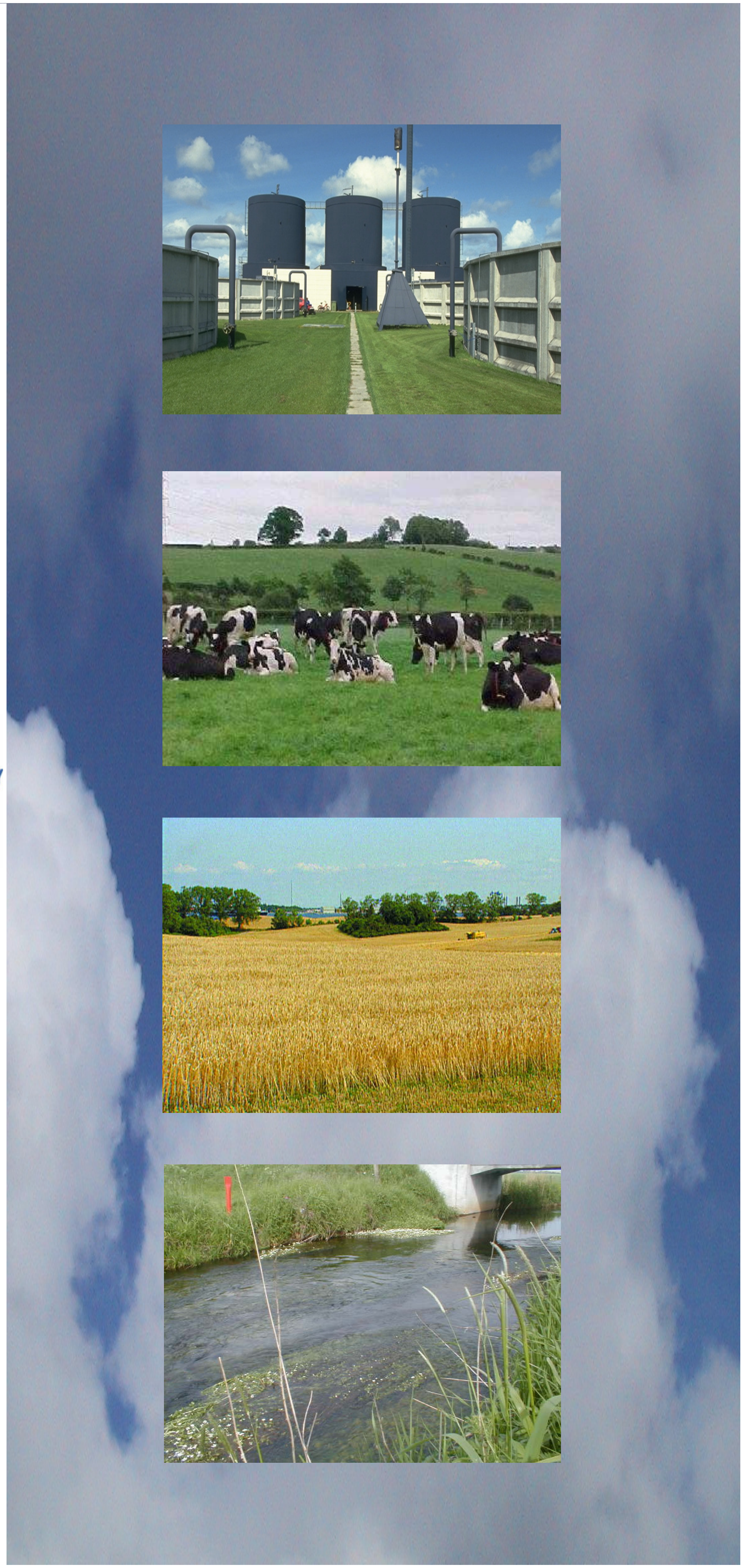
The Future of Biogas in Europe II



European Biogas Workshop
October 2-4, 2003
University of
Southern Denmark
Esbjerg/Denmark

COLOPHON

European Biogas Workshop

Organised by:
University of Southern Denmark, Bioenergy Department,
Co-ordinator of ALTENER project "BIOEXELL - The European Biogas Network of Excellence".
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The Future of Biogas in Europe II

European Biogas Workshop

October 2nd to 4th, 2003
UNIVERSITY OF SOUTHERN DENMARK
Esbjerg / Denmark

The accomplishment of the goals of the Kyoto protocol and the EU directives concerning nutrient management, human and animal health and food safety as well as the overall pollution prevention issues increasingly require a sustainable animal production sector, where pre- and post-treatment technologies combined with anaerobic digestion of animal manure and various types of bio-wastes play an important role.

The aim of the workshop is to look closer and discuss the above mentioned topics, to disseminate existing knowledge, know how and expertise, successful case stories and new ideas as well as to analyse further strategies for the development of biogas systems in Europe.

The workshop addresses to biogas experts, farmers, researchers and technology developers, biogas plants suppliers and users, legislative-, administrative- and local authorities, farmers' organisations and associations etc.

This European Biogas Workshop is part of the activity of the European Biogas Network of Excellence – BIOEXELL, co –financed by EU DG TREN, the Altener II Programme.

The organiser of the workshop is the University of Southern Denmark, the Bioenergy Department, which is also the main co-ordinator of the BIOEXELL network, in collaboration with all the members of the network.

Altener

RENEWABLE ENERGY FOR EUROPE
Campaign for Take-Off
RE Partnership

UNIVERSITY OF SOUTHERN DENMARK

Danish Biogas Links
www.sdu.dk/bio; www.biogasdk.dk; www.biogasbranchen.dk; www.biogasinfo.org; www.lr.dk

Thursday 2 October 2003

8:30 Registration

9:00 Welcome and practical issues
By Jens Bo Holm-Nielsen, SDU, Denmark

9:10 Energy technologies for the future -a full supply of renewable energy scenario from Ringkøbing County.
By Benny Christensen, Ringkøbing County, Denmark

Biogas and the Kyoto Protocole

9:30 Biogas versus other biofuels: a comparative Environ mental assessment.
By G.A. Reinhardt, IFEU, Heidelberg, Germany

10:00 The role and potential of biogas for the reduction of emission of greenhouse gases from animal production.
By Søren. O. Petersen, Danish Inst. of Agricultural Sciences, Foulum, Denmark

10:30 Coffee break - further registration

Animal Health and Food Safety

11:00 The new EU regulation on animal by-products not intended for human consumption – purpose and implementation in Denmark.
By Bruno Sander Nielsen, Danish Agricultural Council

11:30 Treatment of animal waste in co-digestion biogas plants in Sweden.
By Åke Nordberg, JTI, Sweden

12:00 Lunch break

13:30 Implementation stages of the EU-directive on animal by-products and food waste in Austria and Germany.
By Rudi Braun, IFA Tulln, Austria

AD as a Key Technology for Nutrient Management

14:00 Evaluation of the newest biogas plants in Germany with respect to renewable energy production, greenhouse gas reduction and nutrient management.
By Peter Weiland, FAL, Germany

14:30 The potential of an integrated AD system to offer solutions for both the agriculture and the industry sector.
By Torben A. Bonde, GFE, Denmark

15:00 Biogas from AD as a key technology for nutrient management in Great Britain and N. Ireland.
By Clare Lukehurst /DSTBC, N. Ireland

15:30 Coffee break

16:00 Discussion forum, groups of max 10 persons.

17:30 End of session.

18:00 Workshop dinner

Friday 3 October 2003

Pre- and Post-Treatment Technologies

9:00 Separation of slurry – a potential option for the animal production sector.
By Teodorita Al Seadi, SDU, Denmark

9:30 Separation of slurry - technical and economical system analysis.
By Kurt Hjort-Gregersen, FØI, Denmark

10:00 State-of-the-art and perspectives for development of agriculture biogas technologies in Poland.
By Magdalena Zowsik, RECEPOL, Poland

10:30 Coffee break

Biogas and Organic Farming

11:00 Pre-treatment technologies and optimisation of the AD process.
By Willy Verstraete, Ghent University Belgium

11:30 How to integrate biogas, organic farming and energy crops.
By Michael Köttner, BCC, Germany

12:00 Lunch break

Socio-Economic Aspects of Biogas Production

13:30 Socio-economic aspects of agricultural biogas production.
By Arthur Wellinger, Nova Energie, Switzerland

14:00 Important socio –economic elements of centralised co-digestion in Denmark.
By Lars Henrik Nielsen, Risø Research Institute/Denmark

14:30 Discussion forum.

16:00 Coffee break

Conclusions and Closing

16:30 The present and future of biogas in Europe.
By Jens Bo Holm-Nielsen, SDU, Denmark

17: 00 Closing session and the first announcement of the next European Biogas Workshop in 2004.
By Major of DSTBC John McGuigan and Clare Lukehurst, DSTBC, N. Ireland

17:15 End of the workshop

Saturday 4 October 2003

Site Visiting

One-day visit to selected anaerobic digestion plants in Denmark.

Programme:

08:00 Departure from Esbjerg, University of Southern Denmark, Niels Bohrs Vej 9.

10:00 **Visit at Green Farm Energy**, Over Løjstrup, Løjstrupvej 12, DK – 8870 Langaa. Phone: +45 7025 2755.

Green Farm Energy data:
Manure treatment capacity 25.000 t/y + deep litter 10.000 t/y + crops.

- *Energy production per year: 8.5 mill. KWh.*
- *Biogas production per year: 3.6-mill. m^3, converted in a CHP plant at the location.*
- *Nutrient separation plant capacity: N 300 t/y, P 150 t/y.*

Dir. Torben Bonde, Green Farm Energy, will conduct the visit.

12:00 Lunch at the Pavillon, Jernbanegade 33, Thorsø.

13:00 **Visit at Thorsø Environmental and Biogas Plant**
Kongensbrovej 10, DK 8881 Thorsø, Phone: +45 8696 6400.

Thorsø Biogas plant data:

- *Manure treatment capacity: 95.000 t/y + Organic waste, including intestinal content 18.000 t/y + Sewage sludge 5.000 t/y.*
- *Manure suppliers: 75 animal farms.*
- *Biogas production: 3.3 mio m^3, converted at Thorsø CHP plant + CHP-unit at the biogas plant.*
- *Plant Supplier; Burmeister & Wain Scandinavian Contractor Ltd.*

Ernst Klausen, plant manager and board member Viggo Bjørn, Thorsø Env. & Biogas Plant will conduct the visit.

14:30 Driving back to Esbjerg.

17:00 Arrival to Esbjerg.

CONTENTS

REGIONAL FORESIGHT ON THE USE OF HYDROGEN TECHNOLOGY IN A DANISH COUNTY

By Benny Christensen
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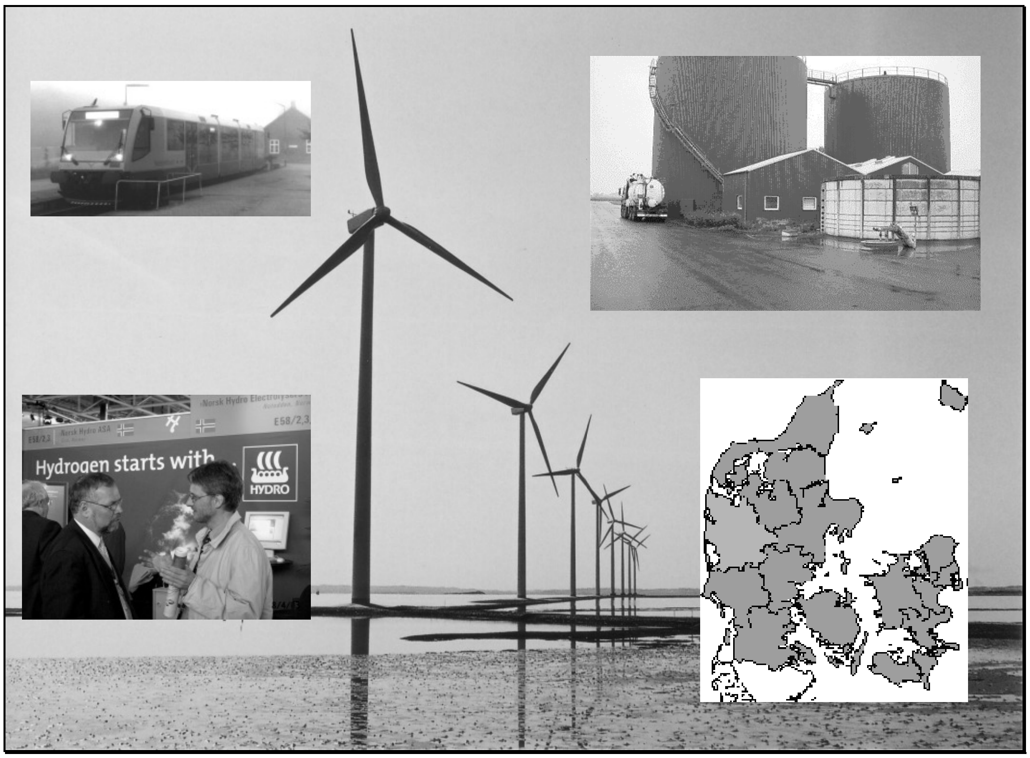

Ringkøbing County with 275,000 inhabitants is situated in Western Jutland and covers a total area of 4,900 sq.km. With a western coastline of 100 km exposed to the North Sea, the region has a plenty of wind energy resources. 857 wind turbines with a total capacity of 384 MW are situated in the county and **more than 35 %** of the electricity consumption in the area is produced by wind power.

Wind energy is also an important background for the industrial development in the region. Two of the words largest wind turbine producers are situated in Ringkøbing County. Together they cover nearly 30 % of the world market for wind turbines, and 5-6,000 persons are involved in the wind turbine industry and its sub-contractors.

Apart from the wind energy the area has other valuable resources of renewable energy. Biomass is already used for heat production and in cogeneration plants, and one of the world's largest biogas-plants is under construction in the region. There are also probable future possibilities of using wave energy along the 100 km North Sea coast. Right now a prototype wave energy plant is tested at the shore of Limfjorden, just at the northern county border.

A Vision for the Future

The vision is to establish and develop Ringkøbing County's status as a leading international player in the field of renewable energy technologies.

- To strengthen the region's research and development effort with focus on integration of renewable energy sources in the total energy system
- To retain, develop and attract companies end employees working with new energy technologies end energy systems
- To make the region attractive by providing space for demonstration projects in which renewable energy sources partly or completely replace fossil fuels.

The first step against some of these goals was a conference at HIH in May 2003, where a vision for a regional future was introduced. Here hydrogen technology and fuel cells played an important role.

A further step after this conference was the start of a **Regional Foresight** on the possibilities of using hydrogen technology and fuel cells in the continued development of the region.

Development and Innovation

The county administration is playing an important role in the industrial development of the area. Last year a centre of knowledge and education in relation to the wind turbine industry was established.

It is situated in BIRC (Birk Innovation and Research Centre) in Herning in close connection to Herning College of Business and Engineering (HIH).

A project also aims to establish an active and creative educational environment around **hydrogen technology and fuel cells** at HIH. This may find expression in:

- Educational modules and in-service training courses
- Acquisitions of equipment for practical experiments
- Implementation of study projects in cooperation with local companies and Ph.D. projects in cooperation with Risø National Laboratories and other institutions.

The Regional Foresight

Four working groups concerned with specific part of the topic were established in the spring 2003. These groups consisting of members from the regional development unit, industry, utility companies and institutions will generate an overview on the options – if possible in a form which can serve as the basis for the implementation of demonstration projects. Proposals for several such projects have already been outlined.

Risø National Laboratory's Department of System Analysis has been engaged in a consultancy role. An early working relationship was also made with the Danish Board of Technology, and a report on the foresight project will be given at a conference arranged by the Board in autumn 2003.

The subject of this conference will be **Energy Technology as a Growth Area** and the conference will take place in the Danish parliament building (Christiansborg) in Copenhagen on Monday 27 October 2003.

Some of the options being considered:

- Combined H_2/O_2 production with windpower at a local fish farm.
- Various kind of use for small fuel cell cogeneration units.
- Hydrogen as fuel in a regional train.
- Fuel cells in fishing vessels.
- Fuel cell driven light vehicles for disabled persons.

For further information contact:
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BIOGAS VERSUS OTHER BIOFUELS: A COMPARATIVE ENVIRONMENTAL ASSESSMENT

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Abstract
Is biogas an environmentally friendly energy form? To answer this question biogas generated by the means of corn, rapeseed meal and liquid manure was weighed against a number of liquid and solid biofuels. By comparison biogas has got a large potential for reducing green house gas emissions depending on the bioenergy carrier used. Biogas from corn for instance performs much better than liquid biofuels, reaching almost the results of best solid bioenergy carriers. However, like other biofuels as well, the use of biogas affects the environment regarding acidification, eutrophication, photo smog, and ozone depletion.

Introduction
One possible strategy to reduce green house gas emissions is the application of renewable bioenergy sources - in the form of biogas, liquid and solid biofuels - instead of non-renewable fossil fuels. The ecological performance of bioenergy carriers however varies considerably, and utilising bioenergy carriers affects the environment with regard to impact categories other than global warming. Therefore comparative studies are necessary to assess their feasibility. For a number of liquid and solid biofuels studies have already been published [1, 2, 3]. In contrast, until now information about the ecological performance of biogas is scarce. In the current study biogas has been evaluated against a large number of biofuels regarding the ecological advantages and disadvantages.

Objective and procedure
The objective of this study was to contrast biogas with liqud and solid biofuels regarding their ecological advantages including their potential for reducing green house gas emissions. The biofuels considered in this study are based on various energy sources. The different options are listed in Table 1.

Table 1: Biofuels analysed in this study grouped by the source of materials used.

Fuel type	Energy carrier		
	Biofuels based on energy crops:		
Biogas	Silage corn, rape seed meal	versus	Electricity, light oil
Liquid biofuel	Rape seed oil, RME*, SME**	versus	Diesel fuel
	Bioethanol, ETBE***, (potato, wheat, sugar beet)	versus	Gasoline
Solid biofuel	Short rotation coppice(poplar), whole plant (wheat), miscanthus, cocksfoot, silage corn	versus	Light oil/coal
	Biofuels based on residues/waste materials:		
Biogas	Rape seed meal, liqiud manure	versus	Electricity, light oil
Solid biofuel	Wheat straw, rape seed meal, forestry waste, yard waste	versus	Light oil/coal

*Rapeseed oil methyl ester
**Sunflower oil methyl ester
***Ethyl tertiary butyl ether

One basic life cycle was assumed for each biofuel representing the most likely utilisation for that specific fuel. For all of the energy carriers the entire life cycle was considered. Agricultural reference systems, co-products and additives were taken into account. Crop residues as well as waste materials were assumed to be available at no costs. For further details on the scope of the study and the underlying assumptions see [1], [2] and [3]. The impact categories and the corresponding indicators as well as the underlying LCI parameters considered in this study are listed there as well. Examples of two different life cycles are presented schematically in figure 1.

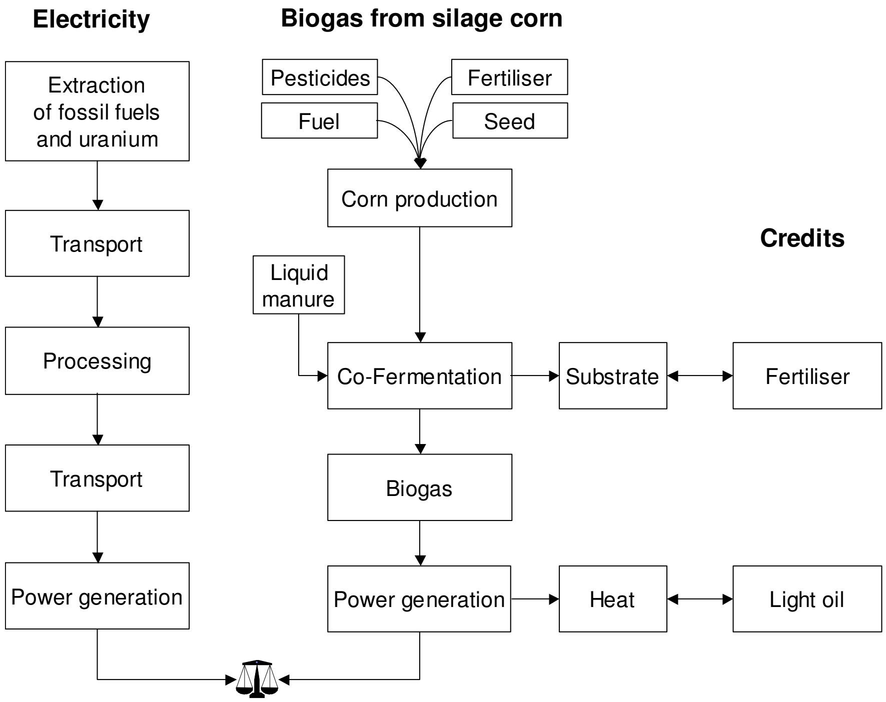

Figure 1: Schematic life cycle comparison of "Electricity" and "Biogas from silage corn".

3. Results

3.1 Generating biogas from energy crops

Biofuels based on crops grown specifically for energy vary in their potential to reduce the emission of greenhouse gases including CO_2, N_2O, and CH_4 especially. This potential can be expressed as the amount of CO_2 equivalents per hectare and year that can be saved due to the substitution of non-renewable energy sources. This value comprises the performance of the bioenergy crop as well as of the biofuel production and consumption. Ranking the biofuels according to their performance is presented in figure 2.

The main results regarding biogas may be summarised as follows:

- The selected biogas options for biogas based on energy crops both lie within the range of liquid and solid biofuels.
- The CO_2 reduction potential of the biogas options is variable, depending on the energy crop used. However, for that reason biogas exhibits a large potential to reduce green house gas emissions.
- Generally, biofuels utilising the entire plant (e. g. corn) perform better than those making use of specific components (e. g. rapeseed meal) only.

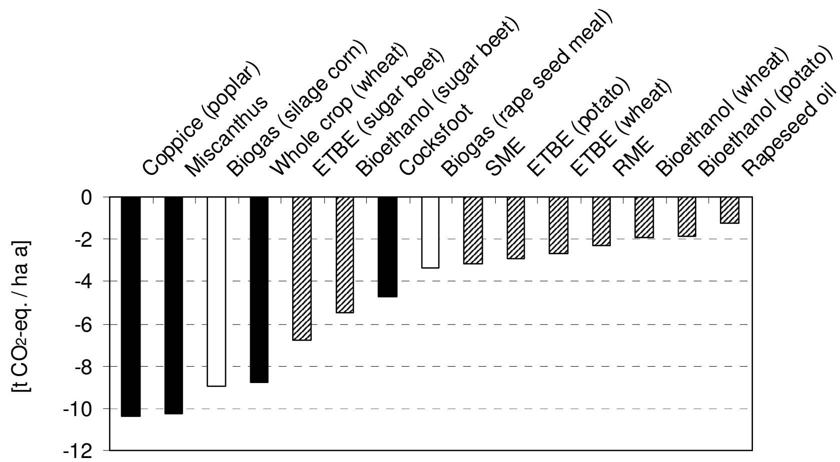

Figure 2: CO_2 reduction potential of solid biofuels (black columns), biogas (white columns) and liquid biofuels (hatched columns) based on energy crops related to unit area.

3.2 Generating biogas from residues and waste materials

Residues or waste materials usually accumulate as outputs of various processes. Therefore, unlike biofuels based on crops grown for energy, biofuels based on residues or waste materials are typically difficult to relate to units of area. Instead, for this kind of biofuels the amount of CO_2 equivalents per gigajoule of primary energy saved was calculated, in order to provide a basis of comparison. In principle this value represents measure of the efficiency of the combustion process. Ranking the biofuels according to their performance with regard to CO_2 efficiency is presented in figure 3 (left). For the purpose of comparison CO_2 efficiencies of a number of biofuels based on crops grown specifically for energy have been included (Fig. 3, right).

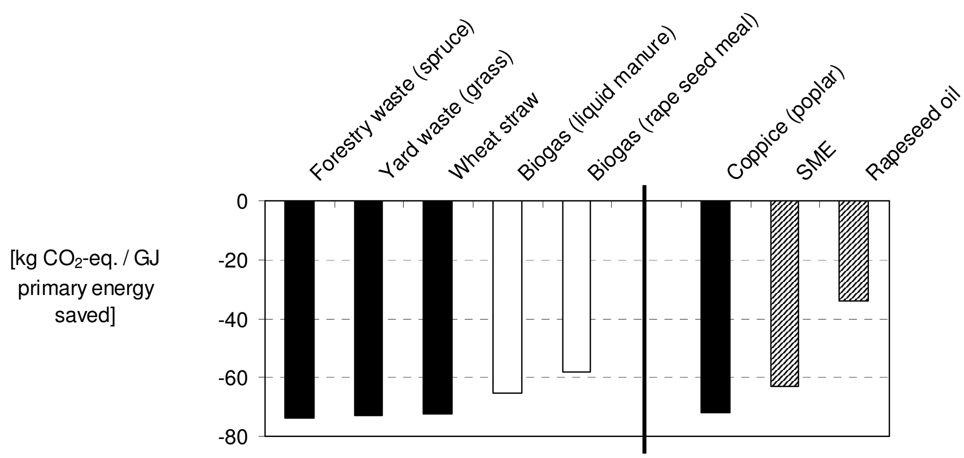

Figure 3. CO_2 efficiency of biogas (white columns), solid biofuels (black columns) and liquid biofuels (hatched columns) related to the amount of primary energy saved.

The main results regarding biogas may be summarised as follows:

- CO_2 efficiency of biogas based on liquid manure and rapeseed meal was 10% and 20% less than the average value of the solid biofuels.
- The performance of biogas was similar to the performance of the top liquid biofuels.
- With respect to CO_2 efficiency solid biofuels generally perform better than both liquid biofuels and biogas.

3.3 Biogas generation in comparison with other modes of use

Most bioenergy carriers can be used in different ways, which have a different impact on the environment. In order to evaluate the possible consequences, two different options for corn (biogas generation, direct combustion) and three different options for rapeseed meal (animal feed, biogas generation, direct combustion) have been analysed (Table 3).

Table 2: Impact of different modes of use of bioenergy carriers on the environment.

		Silage corn		**Rapeseed meal**		
Impact category	**Unit**	**Biogas**	**Combus-tion**	**Animal Feed**	**Biogas**	**Combus-tion**
Energy demand	GJ/ha	-168,86	-287,03	-6,46	-25,27	-31,73
Global warming	t CO_2-eq./ha	-8,96	-17,55	-0,93	-2,03	-2,27
Acidification	kg SO_2-eq./ha	74,35	235,41	-3,01	20,30	20,44
Eutrophi-cation	kg PO_4-eq./ha	14,23	22,34	-0,37	3,98	1,64
Photo smog	kg Ethene/ha	0,29	0,44	-0,26	-0,03	0,02
Ozone depletion	kg N_2O/ha	7,78	13,08	-1,59	-1,17	0,29

The main results regarding biogas may be summarised as follows:

- Burning silage corn directly instead of generating biogas almost doubles energy yield and CO_2 reduction potential. However, the negative impacts in the categories eutrophication, photo smog and ozone depletion will be twice as high. In addition, acidification will be almost three times higher.
- Using rapeseed meal as animal feed results in no negative environmental effect. Burning rapeseed meal directly instead of generating biogas increases energy yield as well as CO_2 reduction potential and reduces eutrophication. However, ozone depletion will be increased while other impact categories are affected just marginally.

3.4 Biogas in relation to fossil fuel

Substituting fossil fuels with biogas results in positive as well as negative environmental effects. In order to quantify those effects, equivalent values per capita were calculated and used as a reference unit (Fig. 4). The amount of fossil energy that can be substituted by the corresponding biofuel forms the basis for the comparison.

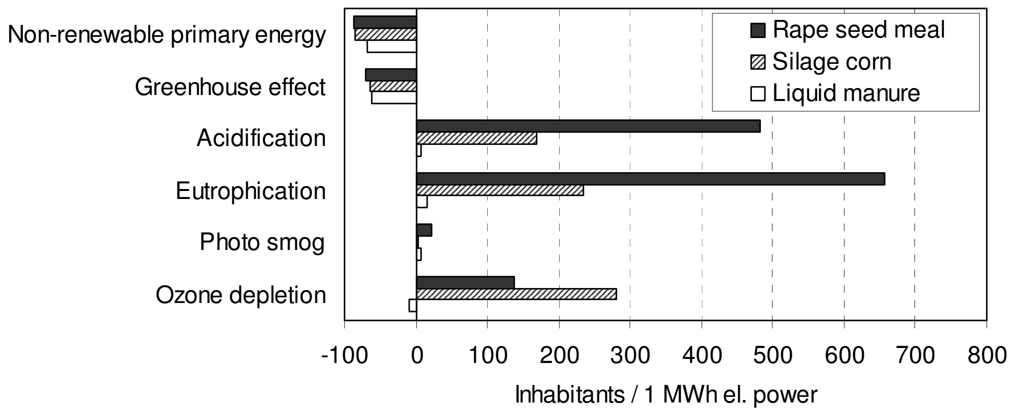

Figure 4: Impact parameters of the life cycles "biogas from rape seed meal", "biogas from corn" and "biogas from liquid manure" in relation to fossil fuels.

Example how to read the diagram: The quantity of green house gases, by which the emission can be reduced if biogas from rapeseed meal is used to substitute 1 TJ of non-renewable primary energy, equals the average green house gas emission of about 5 German citizens.

The main result regarding biogas may be summarised as follows:

- By comparison, biogas made from liquid manure revealed to have the highest CO_2 efficiency on a primary energy basis. This option in addition resulted in very low impacts regarding all other categories.

4. Conclusions and outlook

- Like other forms of bioenergy, biogas has got the potential to save non-renewable energy carriers and thus to reduce green house gas emissions.
- Biogas on the other hand, again similar to other bioenergies, affects the environment with respect to other impact categories like acidification, eutrophication, photo smog, and ozone depletion.
- In most cases, from the environmental point of view, the direct combustion of the biomass may be preferred to biogas production. However, a number of non-ecological reasons like for instance logistics, manageability, or costs may argue for the use of biogas.
- Biogas can compete easily with the most excellent solid biofuels and at the same time provides a number of other possible applications.

Due to the large number of possibilities to generate and to utilise biogas the environmental implications have to be quantified for each case separately. Life cycle assessment as a balancing tool may help to maximize the positive and to minimize the negative environmental effects via sensitivity analysis as well as weak-point analysis for the entire biogas life cycle from provision to utilisation.

References

[1] IFEU (ed.): Bioenergy for Europe: Which Ones Fit Best? A Comparative Analysis for the Community. IFEU (coordinator) with BLT (A), CLM (NL), CRES (GR), CTI (I) , FAT/FAL (CH), INRA (F), TUD (DK). Supported by the European Commission, DG XII; 09/1998-08/2000. For details see www.ifeu.de/nr_fair.htm

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[3] Borken, J., Patyk, A., Reinhardt, G.A. (1999). Basisdaten für ökologische Bilanzierungen: Einsatz von Nutzfahrzeugen für Transporte, Landwirtschaft und Bergbau [Fundamental data for LCAs: use of utility vehicles in transport, agriculture and mining], Vieweg Verlag, Braunschweig/Wiesbaden

THE ROLE AND POTENTIAL OF BIOGAS PRODUCTION FOR REDUCING GREENHOUSE GAS EMISSIONS FROM ANIMAL MANURE

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Introduction

During more than a century there has been a gradual increase in global mean temperature which has been associated with anthropogenic activities [i]. Models describing this so-called greenhouse effect invariably predict a further increase in global temperatures and rising sea levels during the next century. Further, the patterns of net precipitation may change dramatically in large parts of Europe. In face of these changes, a large number of countries in 1997 signed the Kyoto protocol with specific greenhouse gas (GHG) mitigation targets.

The European Union has commited itself to an average reduction of GHG emissions of 8% by 2008-2012 relative to 1990. Agriculture is currently projected to obtain a 17% reduction in GHG emissions, partly due to decreasing use of fertilizers and increasing productivity [ii]. The agricultural sector is responsible for >40% of anthropogenic methane emissions and >50% of nitrous oxide emissions [iii]. The main sources of methane are enteric fermentation and manure management, while nitrous oxide is mainly derived from the turnover of nitrogen in fertilizers, manure and crop residues, and indirectly from the turnover of nitrogen lost to the environment via ammonia volatilization or nitrate leaching. Both methane and nitrous oxide are potent greenhouse gases with global warming potentials (for a 100-year time horizon) that are, respectively, 21 and 310 times greater than that of CO_2. Significant reductions in GHG emissions are therefore possible if methane and nitrous oxide emissions can be reduced via improved management practices.

Mitigation options

For Denmark, different mitigation options within agriculture were recently evaluated based on available literature and modelling [iv,v]. These included changed feeding practices, reductions in ammonia volatilization, growth of energy crops and anaerobic digestion of liquid manure (slurry). The current projections for biogas treatment of slurry in Denmark would not result in a major effect on the national GHG budget. However, anaerobic digestion of slurry appears to be a cost-effective mitigation option, since this treatment can have multiple effects on the GHG balance of animal production. These effects include energy production that can substitute fossil fuels. Also, methane production during digestion may reduce the potential for methane production during subsequent storage. Finally, digestion affects the physical and chemical properties of the slurry with possible impact on plant N availability and nitrous oxide emissions.

Quantification of GHG emissions

Currently, national GHG inventories are prepared using a set of guidelines developed by the Intergovernmental Panel on Climate Change (IPCC). Basically, the methane inventory for animal production is based on numbers of animals, energy intake and excretion per head, and emission factors, while the nitrous oxide inventory is based on numbers of animals, nitrogen excretion per head, and emission factors [vi]. The emission factors for manure management are specified for a number of different storage conditions. Geographic and climatic variations are accounted for by subdividing the world into a limited number of regions based on annual mean temperature, i.e., <15°C (Cool), 15-25°C (Temperate) and >25°C (Warm). Almost all of Europe, from Northern Portugal to Finland, belongs to the Cool climate region.

Energy substitution due to anaerobic digestion is not specified in the GHG inventory for agriculture, as defined by the IPCC methodology. Also, no effects of storage temperature on methane emissions, or of anaerobic digestion on nitrous oxide emissions, can be estimated. Temperature relationships are defined by climate zone, and nitrous oxide emissions are exclusively linked to the nitrogen content of manure which does not change as a result of digestion. Therefore, it is currently not possible to account for effects of biogas production on methane and nitrous oxide emissions, even though such effects have been indicated by experimental results.

Experimental results

Methanogenesis is highly dependent on temperature, and strategies to lower the storage temperature before and after anaerobic digestion can significantly reduce methane emissions to the atmosphere. In animal houses, this can be achieved by frequent transfer to a cooler outside storage, or by cooling of slurry channels. The temperature of outdoor slurry storages generally follow the air temperature of the surroundings, and therefore methane production may continue at a considerable rate if digested slurry is transferred to an open storage tank at the process temperature. In a storage experiment with untreated cattle slurry and digested slurry from Ribe Biogas in Southern Denmark, the emission of methane from untreated slurry was only 69% of the emission from digested slurry due to the higher initial temperature [vii]. Hence, it is important to have a confined storage with methane collection at least until the slurry is cooled to ambient temperature.

Several studies have shown a reduction in methane emissions in the presence of a surface crust during summer storage, and it was hypothesized that methane was consumed within the surface crust. This was recently confirmed in our lab where it was documented that methane oxidizing bacteria are present and active in both natural surface crusts and in an artificial surface crust of straw. Furthermore, it has been shown that a solid cover may further reduce methane emissions from slurry storages with both untreated and digested cattle slurry. Clearly, storage conditions must be an integrated part of strategies for mitigating methane emissions from slurry.

Upon field application of slurry, methane emissions are insignificant and can normally be acoounted for by release of dissolved methane. In contrast, there will be an extensive nitrogen turnover in the soil that can lead to nitrous oxide emissions. When digested slurry is applied to soil, there appears to be a reduced potential for nitrous oxide emission compared to untreated slurry [viii]; in a two-year field study the reduction was 20-40% [ix]. The IPCC methodology uses of a fixed emission factor for animal manure and will therefore not capture such an effect.

Modelling GHG emissions from untreated and digested slurry

In an attempt to estimate the full effect of anaerobic digestion on GHG emissions from manure handled as slurry, a simple model was developed which – besides the energy substitution - accounts for effects of slurry temperature on methane emissions during storage, and for effects of volatile solids degradation on nitrous oxide emissions after field application [x]. Three different scenarios were considered, i.e., a reference system with no anaerobic digestion, a system using present-day biogas technology, and an optimized system with an improved technology and handling of the slurry (see Table 1). Cattle and pig slurry composition was defined according to Danish norms, and volatile solids were considered to consist of a 90% degradable fraction (fats, protein, simple carbohydrates) and a 1% degradable fraction (complex carbohydrates). The conditions for field application of slurry have been summarized elsewhere [x]. It was further assumed that there was no interaction between slurry and organic waste degradation.

Table 1. Assumptions used for calculating methane emissions during storage of cattle and pig slurry for three scenarios, a reference, a typical system with biogas production, and an optimized system with biogas production.

	Reference	Biogas I	Biogas II
Organic waste composition	<20% volatile solids, not kitchen waste or sewage sludge		
Methane losses from reactor via leakages		3%	1.5%
Collection of methane from storages		Until digested slurry reaches ambient air temperature	
Storage time in house	30 d		1 d
Temperature in house	20°C (summer), 15°C (winter)		
Slurry storage temperature	Corresponding to monthly mean temperature		
Slurry storage emptied	April		

At this point there is a lack of experimental data for verifying the temperature dependency of methane emissions from slurry. Therefore, the model was calibrated against the IPCC methodology so that emissions from untreated cattle and pig slurry were identical. Methane emissions from the reference and the two biogas systems are shown in Fig. 1. Considerable reductions in methane emission was suggested for the two biogas technologies. Energy substitution per kg VS was similar for the two technologies. In the field, a 30-40% reduction was predicted for slurry, in line with the experimental results on which the model was based.

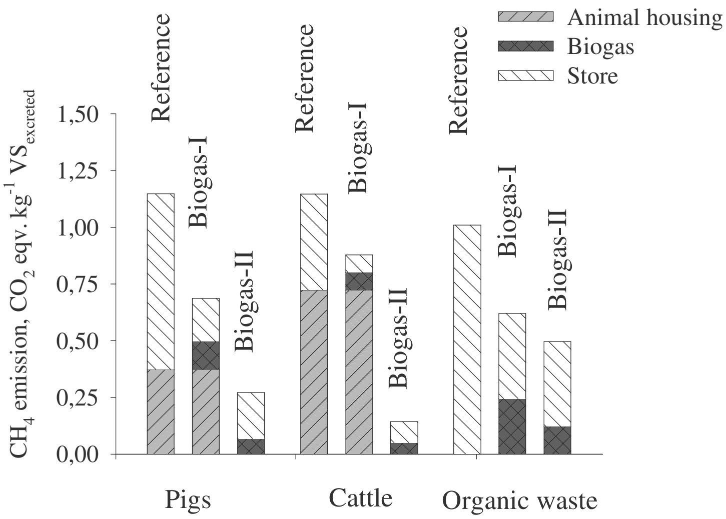

Fig. 1. Modelled methane emissions from housing, from reactor leakages and from the storage facility.

The GHG budget for each scenario was up-scaled for three different situations, i.e., i) a situation corresponding to the level of slurry and organic waste co-digestion in 2000; ii) a situation corresponding to the official goal set for 2012; and iii) a situation where all slurry and organic waste produced is co-digested. Using the present-day technology and manure management, the GHG mitigation due to biogas production corresponds to 0.15% of total antropogenic emissions, and the potential effect would be a reduction of 1.6% (all slurry and organic waste digested). With optimized technology and manure management the potential effect would approach 3% of total GHG emissions in Denmark.

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THE NEW EU-REGULATION ON ANIMAL BY-PRODUCTS NOT INTENDED FOR HUMAN CONSUMPTION – PURPOSE AND IMPLEMENTATION IN DENMARK

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Summary

In the autumn of 2002 the EU regulation 1774 was finally adopted and published, thus laying down health rules concerning animal by-products not intended for human consumption. The background for the regulation was to prevent the spreading of agents causing transmissible spongiform encephalopaties to food and feed causing diseases in humans and animals. The regulation categorises animal by-products and defines obligatory processing methods and acceptable final use of the by-products. Category 1 material must always be disposed by burning, whereas category 2 and 3 materials may be utilised in biogas plants after pressure sterilisation and pasteurisation, respectively.

The regulation hereby lays down the basis for building more biogas plants or increasing the available biomass. However, the regulation also imposes obligations and extra costs for the plants. The biogas plants have in co-operation with the Danish agriculture, food industry and the veterinary services and research institutions worked hard to make the implementation of the regulation as easy for the biogas plants as possible. The regulation has been in force since May 1st 2003, but the Danish authorities are still working on the implementation. Furthermore there are still numerous loose endings in the regulation.

Introduction

In the early nineties it was acknowledged that transmissible spongiform encephalopaties (TSE) may be spread by food and feed. Several times during the years still more thorough legislation was adopted in the European Community to guarantee the consumers about the safety of food. One of the important decisions is to abandon the use of animal by-products as feed. For many years it had been a widely acceptable and economically sound way of recycling of by-products from slaughterhouses and fallen stock. The Regulation 1774 of 3 October 2002 lays down very detailed health rules concerning the collection, processing and final disposal or use of animal by-products.

Categorisation

The basis in the regulation is to categorise animal by-products in regard to the risk of spreading not only TSE but also other agents that may cause diseases in humans or animals. Category 1 material must always be disposed as waste by incineration or co-incineration or in special cases buried after pressure sterilisation. Category 2 material may be used in biogas plants after pressure sterilisation at 133 ºC at 3 bars for 20 minutes. Category 3 material may be used in biogas plants after pasteurisation at 70 ºC for 60 minutes. Category 3 material may perhaps in the future be allowed for feed production, but still it is abandoned.

Category 1 material	Category 2 material	Category 3 material
All parts of animals that may contain prions which can transmit BSE	Fallen stock, by-products not fit for human consumption and all animal materials collected when treating wastewater from slaughterhouses. Manure and digestive tract content.	Parts of slaughtered animals and fish which are fit for human consumption, or are not fit for human consumption but have no risk for animals and humans; food and catering waste
Must always be destructed by incineration	May be digested in biogas plants after pressure sterilisation at 133 ºC for 20 minutes at 3 bar. However, manure and digestive tract content may be digested without pre-treatment.	May be digested in biogas plants after pasteurisation at 70 ºC for 60 minutes with maximum particle size of 12 mm.

Figure 1. Examples on conditions for use of animal by-products in biogas plants

Approval of plants and own check programmes

Use of category 2 and 3 material is only allowed in biogas plants that are approved by the authorities and have an own check programme that is approved by the authorities.

To be approved the biogas plants must
• have clear defined clean and unclean zones • establish and implement own check programme for monitoring and checking critical control points • ensure that digestion residues comply with specific microbiological standards • be equipped with a pasteurisation unit if digesting not pasteurised category 3 material • have adequate facilities for cleaning and disinfecting vehicles on leaving the biogas plant • have preventive measures against birds, rodents, insects or other vermin • have documented cleaning procedures for all parts of the premises • keep installations and equipment in good state of repair and measuring equipment regularly calibrated • have its own laboratory or make use of an external laboratory.

Figure 2: Obligations on biogas plants handling animal by-products

The Danish Biogas Association has worked together with the owners of the joint biogas plants, the Danish Veterinary and Food Administration and the Danish Veterinary Institute to expound and implement the regulation.

In October 2002 a template for the own check programme was released through the homepage of the Biogas Association www.biogasbranchen.dk to facilitate the biogas plants with the task of defining and implementing own check programmes. The template cannot be used as the individual biogas plants own check programme, but as inspiration for assessing the plant critically to identify the critical control points which are the key points in a HACCP programme (Hazard Analyses *of* Critical Control Points). It is the points where infectious agents may be spread. For all CCPs, acceptable levels must be defined and procedures described and implemented to handle unacceptable incidents.

It is crucial that the personnel on the biogas plant is participating actively in describing and implementing of the own check programme as it has no effect if the personnel doesn't understand the importance, purpose and instructions.

Critical control points
Raw materials
Transportation of raw manure and digested biomass
Transportation of waste from catering, industry and households
Pasteurisation
Storage facilities for digested biomass on the plant
Facilities for serving out the digested biomass
Repair of facilities and calibration of measuring equipment
Pest control programmes
Cleaning and disinfecting
Education of personnel

Figure 3. Critical control points – list for inspiration

Many biogas plants have described their own check programmes and some have sent it to the authorities. However, none of the plants or the own check programmes have been approved yet. According to a Commission decision from April 2003 biogas plants that only handle raw materials that were allowed before May 1st 2003 may continue until the end of 2004 by way of derogation from the regulation.

Undecided issues and problems

Today one year after the adoption of the regulation and almost 6 months after it entered into force there still are uncertainties about the implementation and the exact rules. And there are numerous problems in implementing the regulation. It is, however very important that the biogas plants work hard to live up to the obligations.

It is, however very difficult as long as several problems remain unresolved. This regards how to and where to take samples for microbiological quality: on the biogas plant where the plant can react on the results or also in the storage tanks for digested biomass at the farms? It also regards the keeping of records of the type and origin of the biomass. As long as a biogas plant is a continuous process it will be very, very difficult for the farmers exactly to keep records of "*categories and species of animal by-products from which they derive"*.

The most severe problem is, however, how to handle the band on applying other animal by-products than manure to pastureland. If it is not allowed to continue the long time safe-proven application of digested biomass from biogas plants on pastureland grazed by animals after a quarantine period then it will be the end of cattle farmers being members of biogas plants in most parts of Europe. Several member states is, however, working hard to get a solution.

Conclusion

The animal by-product regulation sets up very strict obligations to the biogas plants when handling animal by-products. On the other hand the society is confident in letting the biogas plants handle animal by-products. This puts a big responsibility on the shoulders of the biogas industry. By taking the obligations seriously the biogas plants must prove they deserve the societies confidence. In Denmark experimental use of pressure sterilised category 2 material has begun. These tests will show in which amounts animal by-products can be used in biogas plants as supplement to manure and waste from industry and households etc.

TREATMENT OF ANIMAL WASTE IN CO-DIGESTION BIOGAS PLANTS IN SWEDEN

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Introduction

The outbreak of Bovine Spongiform Encephalopathy (BSE) in Europe has drastically changed the situation for traditional use of animal by-products as animal feed. Thus, it is of great importance to find alternative solutions for handling these waste fractions. Utilisation of rumen, stomach and intestinal content, blood waste fractions and sludge from slaughterhouse wastewater treatment in biogas plants is rather common. However, the use of animal by-products in biogas plants has started only recently.

Due to high content of protein and lipids animal by-products are an energy-rich feedstock, which makes it interesting as a substrate for anaerobic digestion. However, the high content of protein may cause inhibition of the digestion process due to high ammonia concentrations. Therefore, co-digestion with other feedstock is an option to achieve satisfying stability and efficiency in the digestion process. In this paper we will present some Swedish examples and experiences from anaerobic treatment of animal by-products in co-digestion processes.

Implementation of biogas technology in Sweden

During the last decade different governmental programmes have given subsidies to municipalities for building biogas plants. The use of biogas as a vehicle fuel has been promoted in particular, since biogas has been classified as the most environmental friendly fuel (except for hydrogen and electricity). Biogas is free from tax (excluding VAT) during the next eight to ten years.

In Sweden, 13 full-scale plants treating solid wastes have been constructed and are currently in operation. Seven biogas plants are today (August 2003) utilising animal by products as a feedstock in co-digestion processes. (Table 1).

Table 1.Swedish plants treating animal by-products in co-digestion plants

Plant	Main feedstock	Gas utilisation
Helsingborg	Manure, slaughterhouse waste	Heat, electricity, vehicle fuel
Kalmar	Manure, slaughterhouse waste	Vehicle fuel
Kristianstad	Manure, slaughterhouse waste, MSW	Heat, vehicle fuel
Laholm	Manure, slaughterhouse waste	Upgraded gas to grid
Linköping	Manure, slaughterhouse waste	Vehicle fuel
Uppsala	Manure, slaughterhouse waste restaur.	Vehicle fuel
Vänersborg	MSW, slaughterhouse waste	Heat, vehicle fuel

AD of slaughterhouse waste in Sweden

Meat meal from carcasses has not been allowed in animal fodder since 1988 in Sweden (SFS 1988:537). In addition, the use of low-risk animal by-products in ruminant fodder was prohibited in 1991 (LSFS 1990:51). Due to this, the interest in using animal by-products as a substrate for biogas production increased. In order to obtain results and experiences that could be used for developing full-scale co-digestion processes with animal by-products from slaughter houses a range of different trials were performed at JTI.

Potential biogas substrates from slaughtered animal

The average quantity and composition of by-products from slaughter of cattle and pigs, calculated after Edström *et al.* (2003), is shown in table 2 and 3, respectively. In general, the low-risk waste fraction excluding blood represent 60-80 % of the total solids, nitrogen and phosphorous.

Table 2. Calculated average quantity and composition of waste and by-products from slaughter of cattle

Cattle slaughter (kg/cattle)	Weight	TS	Nitrogen	Phosphorus
Rumen, stomach and intestinal content	92	10	0,2	0,07
Animal low risk excl. Blood	116	39	3,3	0,52
SRM	38	15	1,1	0,18
Blood	19	3	0,5	0,01
Animal high risk	5	1	0,2	0,02
TOTAL	270	68	5,3	0,80

Table 3. Calculated average quantity and composition of waste and by-products from slaughter of pig

Pig slaughter (kg/pig)	Weight	TS	Nitrogen	Phosphorus
Stomach and intestinal content	7	0,7	0,02	0,015
Animal low risk excl. blood	17	5,2	0,47	0,079
Blood	3	0,6	0,08	0,001
Animal high risk	1	0,3	0,03	0,005
TOTAL	28	6,9	0,60	0,100

Laboratory and pilot scale studies

Batch digestion of pasteurised animal by-products has resulted in a methane yield of 0.76 L/g VS or 225 m^3 per ton of animal by-products (Edström *et al*. 2003). The total biogas potential from waste generated during slaughter is ca 1300 MJ/cattle and ca 140 MJ/pig (Edström *et al*. 2003). Animal by-products represent 62% and 82% of the biogas potential for slaughtered cattle and pigs, respectively.

Continuous digestion of representative mixtures of substrates available in the planning of a full-scale biogas plant was performed in laboratory and pilot scale. A description of the average waste mixtures used in one laboratory and one pilot study is shown in table 4. The animal by-products used came from a rendering plant where the by-products were crushed, minced and heat-treated (133°C, 3 bar, 20 min). Blood were included with the animal by-products. The stomach content and sludge includes rumen, stomach and intestinal content from slaughtered animal and sludge from slaughterhouse wastewater treatment. The results obtained are presented in table 5.

Table 4. Average waste mixture used in the experiments

Process	Animal by-products	Stomach content & sludge	Food waste	Dilution	Liquid manure	TS	Nitrogen
	% of mixture	% of mixture	% of mixture	% of mixture	% of mixture	% of mixture	% of TS
Lab	13	21	14	51	-	11	5,9
Pilot	15	28	-	15	42	12	6,0

Table 5. Data from laboratory and pilot digestion experiments

Process	HRT	OLR	pH	NH_4-N	NH_4-N/ TKN	m^3 biogas/ kg VS	m^3 methane/ ton waste
	d	g VS/L,d		g/L	%		
Lab	40	2,5	8,0	5,0	75	0,86	62
Pilot	35	3,2	8,0	4,5	65	0,70	55

The results obtained showed that feedstock mixtures with 13-15% of animal by-products, corresponding to 11-12% of the TS in the mixture, can be co-digested during stable conditions at OLR:s exceeding 2,5 g VS/L,d and HRT:s less then 40 d, reaching gas yields of 0,70-0,86 L/g VS.

Linköping biogas plant

There are seven biogas plants in Sweden that are approved for anaerobic digestion of low-risk material of animal origin. One of the first full-scale plant taken into operation based on animal by-products as a main feedstock was the plant in Linköping, which started in the end of 1996.

In table 6, the waste treated at the plant 1997-2001 is presented. After the 1st of November 2000 it has not been allowed to use sterilised high-risk waste for anaerobic digestion if the digestate is spread on farmland. The amount of low-risk animal by-products has increased and the manure decreased over the years. The mixture is hygienised at the plant (70 °C, 1 h) and afterwards the material is continuously fed to two mesophilic digesters, 3700 m^3 each, with a retention time of approximately 30 d. The digestate is stored at the plant only for a few days before it is transported to satellite storage tanks close to the farmers.

The plant has now seven years experience with treating animal by-products. The obvious positive experience is the high gas yield from this kind of feedstock. During the time when the sterilised high-risk waste was digested, it was considered as a feedstock not causing technical problems at the plant, mainly because it was delivered as homogeneous slurry. The low-risk material is today minced at the slaughterhouse before it is delivered to the plant.

The plant produces today more than 15 000 Nm^3 biogas/d. The gas is upgraded to vehicle fuel quality and used for running all the city busses. Approximately 50000 ton/year of digestate is produced. The farmers are individually contracted for receiving digestate.

Table 6.The amount of waste divided into different categories treated in Linköping biogas plant including the biogas produced since 1997.

		1997	**1998**	**1999**	**2000**	**2001**	**2002**
Slaughter-house waste							
High-risk waste	t/year	2830	7094	10785	8243	0	0
Low-risk waste **-Animal by-products** **-Blood** **-Sludge** **Rumen, stomach and intestinal content** **Manure from stables** **Process water**	t/year	4129	9588	10881	19840	31827	37432
Liquid manure	t/year	7404	23953	9033	8647	2318	4677
Other	t/year	0	7430	6784	10547	9583	8394
TOTAL	t/year	14363	48065	37483	47277	43728	50503
Biogas production	m^3/year		2.6mil.	3.7mil.	3.3mil.	4.4mil.	5.3mil.
Biogas production	GWh/year		18	25	22	30	36
m^3 methane/m^3 waste			37	67	47	68	71

Hygienisation control

The acceptance of the digestate as an organic fertiliser is a crucial issue for the plants treating animal-by products. Therefore, a voluntary certification system for compost and digestate from organic waste has recently been elaborated, involving different actors (producers of compost and digestate, agricultural and food producing organisations, authorities and researchers) in order to ensure a broad acceptance and a commercially attractive system. Linköping was the first biogas plan receiving the certificate in March 2003.

A hygienisation control routine has been developed within the framework of the certification system. This is in large compatible with the demands from the Swedish Agricultural Board, which is the authority approving the plants treating animal by-products. The hygienisation control consists basically of two parts;

1. Microbial test of the product according to the regulation (EC) No 1774/2002. The sample should be taken during "normal" operation conditions and there are clear instructions of how the sample should be taken

2. Technical inspection of the plant to get a description and judgement of the performance from a sanitation point of view.

Technical inspection

The technical inspection results in a description and judgement. The decision support is obtained through a questionnaire containing 25 control questions. These questions can be divided into mainly three categories:

- Technical design and function includes issues such as appropriate flow sheet available; closed transport of material; "clean" and "dirty" zones; possibility to lead content in the hygienisation tank back to pre-storage in case of malfunctioning sanitation; risk of cross flow of "clean" and "dirty" slurries; size reduction.
- Operation and maintenance includes questions regarding; operation instructions available; educated personnel; monitoring, control and documentation during operation (temp, holding time; stirring; valves); routines for handling disturbances in sanitation; action plans if not-sanitised material ends up in digester; avoidance of vector animals; established contact with local sanitation expert; plans for maintenance and renewing equipment; cleaning routines for incoming area; calibration of instruments.
- Transport includes avoidance of contamination of hygienised material by incoming material; cleaning/disinfection of vehicles inside and outside; instructions regarding cleaning; handling of cleaning water from vehicles and surfaces.

Criteria for approval

In addition to the official control, a system for self control has to be implemented in order for approval of the plant. The approval will be based on the criteria that the microbial test is fulfilled according to the demands. If larger deviations, such as technical solutions that will lead to insufficient sanitation, are detected, the plant will not be approved. However, if only minor deviations, such as missing control or maintenance routines are missing, then the plant can be approved under the condition that the deviations are corrected within 3 months.

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IMPLEMENTATION STAGES OF DIRECTIVE EC 1774/2002 ON ANIMAL BY-PRODUCTS

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1. Introduction

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.

Anaerobic digestion can provide a method accessing the energy and nutrient content contained in organic material. Therefore, the utilisation of anaerobic digestion for organic waste management permits a significant movement up the waste hierarchy over current management methods.

For decades anaerobic digestion has been used for industrial wastewater treatment, stabilisation and volume reduction of sewage sludge, animal manure and organic wastes digestion. These years of experience have shown that, if correct processing methods are followed, the spreading of digested material on land of whatever type has not caused any health problems.

Anaerobic Digestion also provides a method of increasing the measurability and plant availability of the nutrients contained in organic material. With correct storage and application methods of the digested material, best agricultural practice for the application methods and restrictions on the season of application, the risk of volatilisation and runoff of nutrients can be greatly reduced compared to storage and application of untreated organic waste and manure.

Therefore anaerobic digestion makes nutrient management much more accurate and reduces the risks of excess application of artificial nutrients on top of organic based nutrients. This will greatly help to achieve the targets of the EC Water Framework Directive 2000/60/EC. It is important to utilise management methods that enable all nutrients to be recycled beneficially if the Water Framework Directive is to be achieved. Anaerobic digestion helps to achieve this goal.

More recently AD has received increasing attention as a mainstream energy conversion process, based on renewable agricultural biomass (energy crops), as well as on co-digestion of various industrial by-products, including animal by-products and wastes.

2. Overview on Euopean Legislation Affecting Waste Collection, -Treatment and Recovery

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 theses regulations profoundly influence the technological developments and practical applications of AD. Among the most important EC-regulations are:

- Council Directive 75/442/EEC of 15 July 1975 on waste,
- The Sewage Sludge Directive 1986/278/EEC,
- The Water Framework Directive 2000/60/EC,
- Council Directive 1999/31/EC on the Landfill of Waste,
- Soil Protection Strategy COM(2002) 179 final,
- Directive on the Promotion of Electricity Produced from Renewable Energy Sources in the Internal Energy Market 2001/77 EC,
- Working Document Biological Treatment of Biowaste, 2nddraft (2001) and
- Animal Byproducts Regulation (EC) No1774/2002.

2.1. 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 therefrom and any other process for the re-use of waste.

2.2. 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.

2.3. 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 page 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.

2.4. 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.

2.5. 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 a 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.

2.6. 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's" indicative target of 12 % by the year 2010 provides a useful guidance.

Biogas is one of the possible renewable alternatives and and it's broader penetration as an energy source should therefore well benefit from these efforts.

3. 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 biotreatment,
- directives for waste collection, handling and treatment,
- approval of treatment plants and allowable processing emissions,
- quality classes for biotreatment residues and compost,
- control and analysis of endproducts and
- application standards for the endproducts.

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 then 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.

Table 1: Allowable limiting values for heavy metals, trace organic compounds and impurities according to the forthcoming EC regulation on biological treatment of biowaste

Parameters (mg/kg total solids)	**Compost / solid end-products**		**Stabilised waste**
	Category 1	**Category 2**	
Cadmium	0.7	1.5	5
Chromium	100	150	600
Copper	100	150	600
Mercury	0.5	1	5
Nickel	50	75	150
Lead	100	150	500
Zinc	200	400	1500
PCB	-	-	0.4
PAH	-	-	3
Impurities >2mm	<0.5%	<0.5%	<3%
Gravel/stones >5mm	<5%	<5%	-

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

4. 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. The Commission has already amended and will amend the original Regulation with Regulations from the commission (Regulations (EC) No 808/2003 to 813/2003: OJ L 117, 13.05.2003) and proposed transitional measures in several Member States through Decisions of the Commission (2003/320/EC to 2003/329/EC: OJ L 117, 13.05.2003 and 2003/334/EC: OJ L 118, 14.05.2003).

4.1. Goals

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.

It has been estimated that humans directly consume only 68% of a chicken, 62% of a pig, 54% of a bovine animal and 52% of a sheep or goat. Every year, more than 14.3 million tons (1998) of animal by-products derived from meat from healthy animals not intended for human consumption are processed in the EU. This material is then transformed into a variety of products used in human food, animal feeding, cosmetic, pharmaceutical and other technical use. In 1998 16.1 million tons of animal by-products (therefrom 14.1 million tons derived from healthy animals) were processed into 3 million tons of meat and bone meal and 1.5 million tons of fat (COM(2000)574).

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.

4.2. 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 corespondend treatment and utilisation possiblites.

In the following, a short overview of the amended 95 pages (including 11 attachments) regulation (EC) No 1774/2002 (OJ L 273; 10. 10. 2002) will be given.

<u>Category 1 materials</u>

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, scrapie etc.)

The SRM (specified risk materials) representing the material of (healthy) animals having the highest potential of containing the TSE infectant 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 pretreatment system removing all animal material with a particle size of more than 6 mm.

<u>Category 2 materials</u>

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 pretreatment 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 colostrum from animals not suspected to spread any diseases.

<u>Category 3 materials</u>

Category 3 contains all animal materials derived from healthy animals slaughtered for human consumption which are not intended for human consumption because of beeing 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 material.

4.3. 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 possiblities according to the 3 categories previously described.

Detailed requirements for all steps of the collection, transport, handling of animal by-products are defined. Furthermore requirements of processing and control measures for treatment plants processing animal by-products are defined.

In the following, a short overview on the principal treatment requirements for the corresponding categories will be given.

Category 1 materials

Category 1 materials have to be collected without undue 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 material 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 catergory 1 catering wastes from international means of transport) may be processed in an approved biogas or composting plant according to national legislation.

4.4 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 2). Whether biotreatment will be applied or not will be determined by the demands of pretreatment, process equipment requirements and allowable use of the endproduct digestate (compost). Consequently the treatment costs resulting will decide the appropriate allowable process selection.

In principle biotreatment 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 sterilised, 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 biotreatment, 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 2: 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	Sterilisation (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)

4.5. Practical approach with allowable category 2 and 3 materials

Manure, stomach and intestine contents, milk and colostrum are classified in category 2. This 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 to be applied 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 fertilisers (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. Endproducts 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 material 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 therefrom until October 2006 under very strict treatment and control measures.

Anaerobic digestion of catering wastes may therefore possibly increase considerably.

4.6. 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

[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 therefrom 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

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:

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:

I.) Specific requirements for the approval of biogas and composting plants

(as defined in Regulation (EC) No 1774/2002 Annex VI, Chapter II, Part A)

A.) Premises

1.) Biogas plants must be equipped with:

a.) a pasteurisation / hygienisation unit, which cannot be bypassed with:

i.) installation for monitoring temperature against time

ii.) recording devices to record the results of these measurements continuously and

iii.) an adequate safety system to prevent insufficient heating and

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.) Composting plants must be equipped with:

a.) a closed composting reactor which cannot be bypassed with:

i.) installation for monitoring temperature against time

ii.) recording devices to record the results of these measurements continuously and

iii.) an adequate safety system to prevent insufficient heating and

b.) adequate facilities for cleaning and disinfecting vehicles and containers transporting untreated animal by-products.

3.) Each biogas and composting plant must have ist 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.*

II.) Handling and transformation of animal by-products

B.) Hygiene requirements

(as defined in ABP regulation Annex VI, Chapter II, Part B and C)

4.) 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.*

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

6.) 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.

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

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

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

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

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

C.) Processing standards

12.) 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: 70^0C and*
- *c.) minimum time in the unit without interruption: 60 minutes*

13.) Category 3 material used as raw material in a composting plant must be submitted to the following minimum requirements:

- *a.) maximum particle size before entering the composting reactor: 12 mm*
- *b.) minimum temperature in all material in the reactor: 70^0C and*
- *c.) minimum time in the reactor at 70^0C (all material): 60 minutes*

However, pending the adoption of rules in accordance with Article 6(2)(g), the competent authority may, when catering waste is the only animal by-product used as raw material in a biogas or composting plant, authorise the use of specific requirements other than those laid down in this Chapter provided that they guarantee an equivalent effect regarding the reduction of pathogens. Those specific requirements may also apply to catering waste when it is mixed with manure, digestive tract content separated from the digestive tract, milk and colostrum provided that the resulting material is considered as if it were from catering waste.

Where manure, digestive tract content separated from the digestive tract, milk and colostrum are the only material of animal origin being treated in a biogas or composting plant, the competent authority may authorise the use of specific requirements other than those specified in this Chapter provided that it:

(a) does not consider that those material present a risk of spreading any serious transmissible disease;

(b) considers that the residues or compost are untreated material.

III.) Check by the competent authority
(in accordance with ABP regulation, article 26, Official control and lists of approved plants)

Article 26 defines the frequency of inspections and supervisions of approved plants by the competent authority. Furthermore a list of approved plants with unique identification numbers assigned to each plant has to be established by the national administration.

IV.) Establishment and implementation of monitoring and checking methods of the critical control points

The ABP regulation underlines the principle of self responsibility of the plant owners and requires the establishment of a self control system according to the principle of Hazard Analysis and Critical Control Point (HACCP – concept). The potential hygienic risks must be minimised by applying strict criteria for animal by-product acceptance / refuse, pasteurisation, hygienic operation e.g. definition of clean and unclean divisions. An example of critical control point concepts for biogas plants has been established by Baggesen (2002).

V.) Microbial standards for the digestion residue and compost

D.) Digestion residues and compost
(as defined in the ABP regulation, Annex VI, Chapter II, Part D

15.) Samples of digestion residues or compost taken during or on withdrawal from storage at the biogas or composting plant must comply with the following standards:

Salmonella:
No Salmonella may be present in 5 samples of each 25 g

<u>Enterobacteriaceae:</u>

In 5 samples each 1 g: Samples with < 10 cfu/g of Enteriobacteriaceae
2 Samples with a value between 10 cfu/g[3] and 300 cfu/g of Enteriobacteriaceae

5. Conclusions

Recently issued and forthcoming EC waste- and veterinary regulations will greatly influence the development and application of „biotreatment“ processes (anaerobic digestion, composting), as well as the reuse of treated (endproducts, compost, digestate) or untreated organic by-products on arable and pasture land.

Existing and upcoming veterinary and waste regulations need to be further harmonised and their practicability has to be proved.

Since the upcoming EU landfill ban for organic wastes will further push source separate collection of wastes, huge amounts of organic wastes to be alternatively treated or recovered will result in most EU countries.

If the safety and security requirements laid down in the respective regulations are followed strictly, biotreatment and especially anaerobic digestion can therefore become a mainstream treatment and recovery process, both for bio-wastes and selected animal by-products.

In many areas of application, anaerobic digestion is not concerned at all by the strict requirements of the new ABP regulation (EC) No 1774/2002.

Manure, stomach, gut and digestive tract contents, milk and colostrum (animal by-products, category 2 materials) may be used for biogas or compost production. As long as manure (or the deriving digestate with energy crops, other co-substrates or biowaste) is not traded or placed on the market, no further restrictions or requirements are laid down in the ABP-regulation. If waste is used as co-substrate, waste management regulations have to observed.

Category 3 catering wastes (excluding such from international means of transport) can be processed as single substrate or in mixtures (e.g. manure) in biogas or composting plants, approved in accordance with national legislation.

The treatment of animal by-products (category 3 material with pasteurization and category 2 material with sterilization) requires an approval of the biogas plant in accordance with article 15 of the Regulation (EC) No 1774/2002. Those highly demanding requirements laid down will lead to an increase of the technical state of the art of bio-treatment plants. Therefore the practicability of biological waste treatment in an agricultural context will become much more difficult.

[3] cfu means: colony forming units

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EVALUATION OF THE NEWEST BIOGAS PLANTS IN GERMANY WITH RESPECT TO RENEWABLE ENERGY PRODUCTION, GREENHOUSE GAS REDUCTION AND NUTRIENT MANAGEMENT

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Introduction

The number of agricultural biogas plants is growing continuously in Germany as a consequence of the *Renewable Energy Sources Act (Erneuerbare Energien-Gesetz EEG)* which guarantees a fixed compensation for the produced electricity for a period of 20 years. The purpose of this act is to facilitate a sustainable development of energy supply in the interest of managing global warming and to achieve a substantial increase of biogas production in order to double the share of renewable energy in total energy consumption by the year 2010. The enhanced compensation paid for the produced electricity and several national promoting programs create conditions which make it possible to run biogas plants under economic reliable conditions. In the middle of the year 2003 around 2000 biogas plants exist with a total installed electric capacity of about 250 MW_{el}. In order to evaluate the actual status of the newest biogas plants a measuring programme has been started 2002 for determining the technology and efficiency of a representative number of plants with different concepts, technologies and substrates. Preliminary results of this study are presented in this paper.

Substrates

Around 94 % of the agricultural biogas plants in Germany are operated with co-substrates in order to achieve a more efficient biogas production. More than 30 different organic by-products and wastes from food- and agro-industry are used for co-fermention, but energy crops and crop residues from harvesting are the most often applied substrate types (Fig. 1).

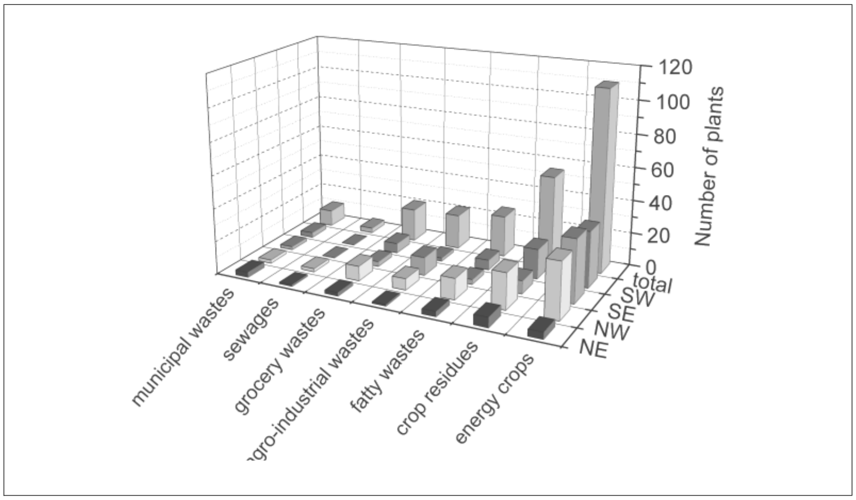

Figure 1: Types and frequency of co-substrate used in modern biogas plants.

Normally, between one and three different co-substrates are used. Only in the north-east (NE) region co-substrates are relatively seldom applied because the large farm-scale in this area allows an economic fermentation of manure without co-substrate addition.

Most of the conventional agricultural crops can be applied for co-fermentation, because the methane yield per ton of organic dry matter (ODM) is similar for the different crops and in the range between 350 and 450 m^3/t ODM (Fig. 2).

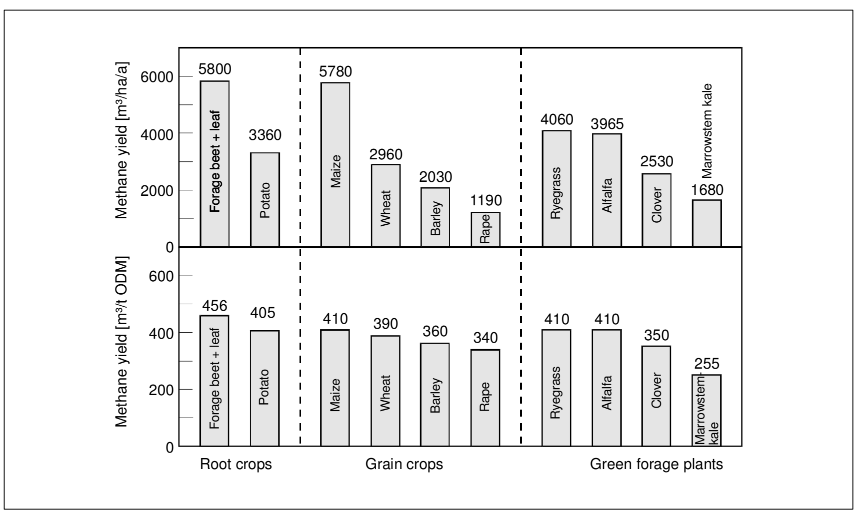

Figure 2: Methane yield of different crops.

Maize and grass are the most often applied energy crops, because maize results in a very high methane yield per hectare and grass is characterized by low input costs.

Only few biogas plants are operated with mono-fermentation of crops. Process control of these plants is more difficult due to the low buffer capacity and the biogas productivity is sometimes inhibited due to the accumulation of salts and ammonia nitrogen from process water recycling. In most of the plants the basic substrate is cow manure or pig manure which is used with a share between 50 and 80 %.

Fermentation technologies

Today, continuously operated wet fermentation systems dominate, whereas dry-fermentation systems are applied only in few demonstration or pilot plants. Most often used are upright fermenter systems with typical reactor volumes between 800 and 1.500 m^3. In centralized plants also large digesters with a size between 2.000 and 5.000 m^3 are standard. Horizontal plug flow systems are mainly applied for low treatment capacities or for substrates with a high solids content. The typical reactor volume is between 150 and 600 m^3. Horizontal reactor systems are often used in the south-east region (SE), which is characterized by small family farms or for the first stage of two-stage systems, because good mixing conditions can be achieved even at a high total solids content (Fig. 3).

The top of upright fermenter with a volume up to 1.000 m^3 are often fitted with a double-membrane in order to store the gas in the top of the fermenter. The inner membrane is the gas-holding buffer which is flexible in height, whereas the outer one is the weather cover which is always ball shaped. A blower maintains a slightly elevated air pressure in the space between both membranes to support the structure. Approximately 30 % of the plants use a membrane roof also for the storage tank, in order to collect the gas from post-digestion, because 5-20 % of the formed gas is generated in the storage tank. This concept is important for reducing the emission of greenhouse gases.

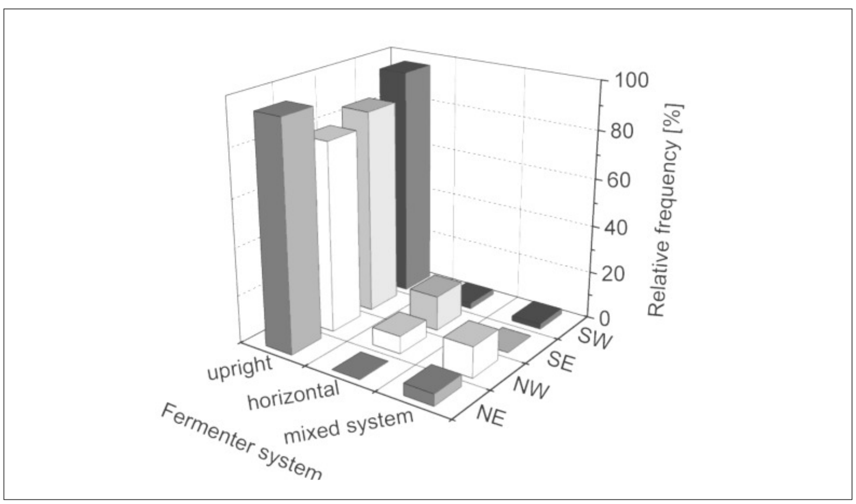

Figure 3: Application of different fermenter types

For co-fermentation of energy crops in wet-fermenters direct charging systems find increased application, because energy demand and odour emissions are much lower compared to external mixing tanks (Fig. 4).

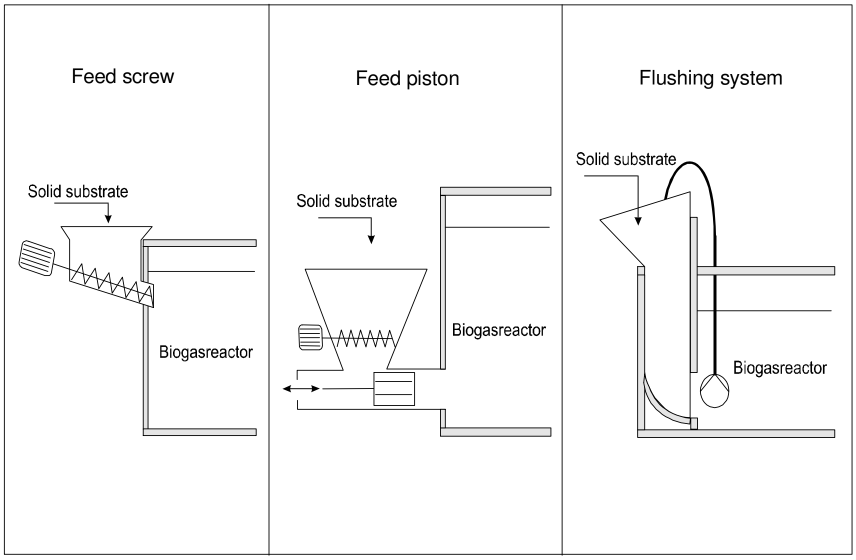

Figure 4: Direct charging systems for solid substrates.

Screw feeder systems are arranged at the top of the reactor short below the liquid level and can be used for short fibrous and bulky substrates. Piston feeding systems are liquid tight and can be arranged at the bottom of the fermenter which result in a better substrate mixing in the reactor and makes the charging of the system easier. The solids are transported by two contra-rotating screws into the cylinder space and a hydraulic piston transport the substrate into the fermenter. Flushing systems are operated with a mobile nozzle in order to flush the substrate via the flushing pocket into the fermenter. This technology can be applied for solid, pasty and sticky materials but odour emissions can escape from the open pocket.

Dry-fermentation systems are of increasing interest for mono-fermentation of energy crops but also for the treatment of yard manure from cows, pigs and poultries. Several batch-processes without mechanical mixing were developed, but only few concepts are operated in farm-scale. Two different process types were tested recently: container processes with percolation and bag processes without percolation (Fig. 5).

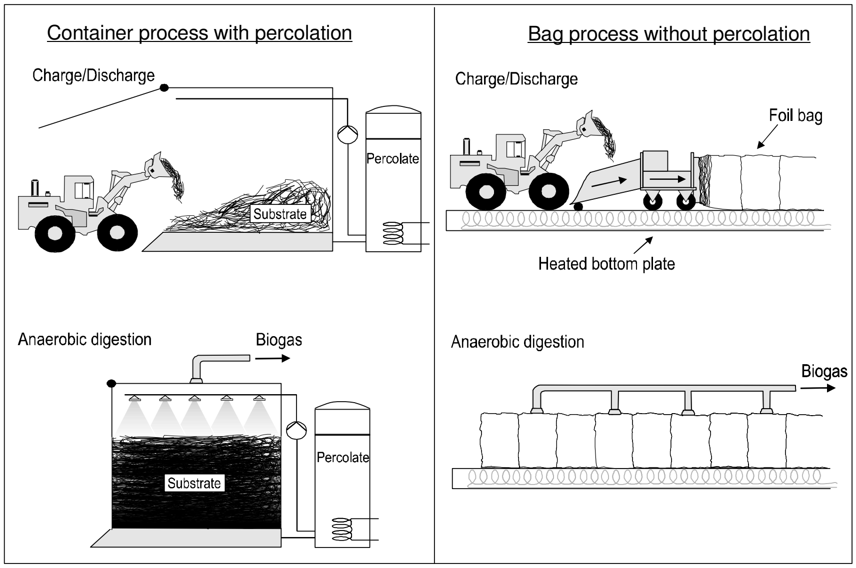

Figure 5: Typical processes for dry-fermentation.

For the percolation process a gas tight fermenter box with a typical volume of about 150 m^3 is used which is coupled with a tank for storage and heating the percolation water. The bag process uses a gas tight foil bag for fermentation which is normally used for ensiling of forage crops. The bag is located on a heated bottom and is isolated during the operation time. The bag is filled with a mixture of fresh substrate and anaerobic treated matter for inoculation. The ratio of fresh and digested material has to be defined carefully in order to avoid an uncontrolled acidification.

Biogas upgrading and utilisation

About 98 % of all biogas plants use combined heat and power plants to produce electricity and hot water. Up to an installed electrical power of 200 kW_{el} mainly dual fuel engines are applied which need 8-15 % diesel fuel for gas ignition. The electric efficiency is between 33 and 37% even for small engines which is very important for the economy of smaller farm-scale plants. Dual fuel engines have the advantage that they can be utilised for biogas with a poor methane content which is typically for the treatment of energy crops. For plants with an electrical power above 200 kW pure gas engines with spark ignition are standard. The electric efficiency is between 34 and 35 %. The useful life period is longer but the investment costs are a bit larger than for dual fuel engines.

An interesting alternative to gas engines are micro gas turbines which are used up to now only in few plants. The technology is based on auxiliary turbines of air crafts. The generator, the compressor and the turbine are mounted on the same shaft resulting in a high reliability due to few moving elements (Figure 6). Another advantage of this technology is that no lubricants or cooling water are necessary and very low pollutant emissions are formed. The exhaust gas temperature is on a high level of 250–280 ^{o}C which enables manifold forms of heat utilisation. The electric efficiency is only between

25 and 28 % and therefore much lower compared to gas or dual fuel engines. Therefore, micro gas turbines which are available with an electric power between 30 and 100 kW_{el} will be utilised only on biogas plants which can use the produced heat during the whole year.

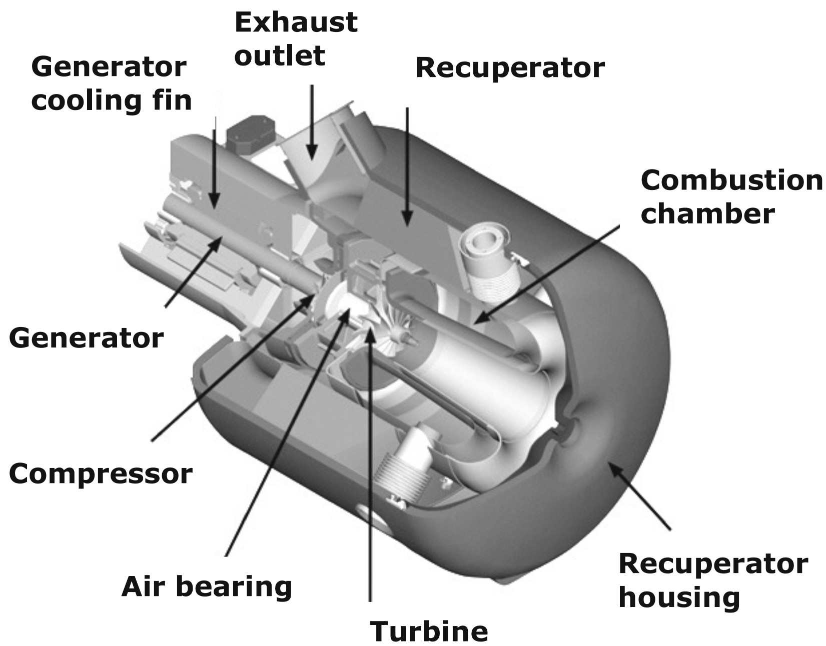

Figure 6: Micro gas turbine (Capstone).

In few years fuel cells will become an interesting alternative to conventional CHP, because a higher electric efficiency (40-60 %) is possible and the heat can be formed at different temperature levels dependent on the applied fuel cell type. A first pilot-scale application has been started in 2003 at the 600 m^3-biogas plant of the Federal Agricultural Research Centre (FAL) in Braunschweig in cooperation with the company farmatic biotech energy ag in Nortorf. An intensive upgrading of the gas is necessary before it can be used in fuel cells because the toxic compounds for catalysts, e.g. hydrogen sulphide and ammonia, have to be removed completely, the carbon dioxide content has to be reduced in order to increase the electric efficiency and methane has to be converted into hydrogen. The typical process route is shown in Figure 7.

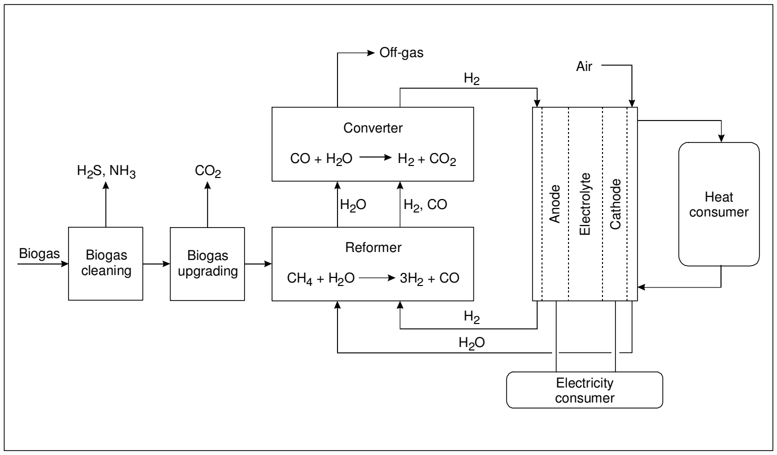

Figure 7: Process route for fuel cell application.

For biogas upgrading a combination of biological and physico-chemical technologies are applied. A new type of reformer is used for the first time which combines the reforming of methane into hydrogen with the removal of carbon dioxide by pressure cycle technology.

THE POTENTIAL FOR AN INTEGRATED AD SYSTEM TO OFFER SOLUTIONS FOR BOTH AGRICULTURE AND INDUSTRY.

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Abstract
Anaerobic digestion (AD) of a variety of organic wastes from agriculture, municipalities and industry is a well-established technology. However, the technology remains to gain impetus in order to reach a widespread stage where agriculture and societies may benefit in full from its potential.

Among the general disadvantages of conventional AD, which limits its expansion, count a poor economic performance, a limited production of sustainable energy and the fact that the disposal of the digested waste remains to be difficult and most often costly. Digested pig slurry for instance is still slurry despite being digested and the negative public perception of the slurry remains by and large unchanged. The agricultural benefits are also limited because the slurry shall be stored and applied in the fields at specified times with appropriate and expensive equipment. Some of the limitations of conventional AD are due to poor process performance in terms of limited digestion of the organic load This may be due to inappropriate process parameters or presence of elevated levels of inhibitory substances such as ammonia, long chain fatty acids, hydrogen sulphide etc. Conventional AD is also limited with a view to the various biomasses that may serve as substrate for biofuel production. Additional technologies offering solutions to these difficulties are therefore much needed.

Recently, the company Green Farm Energy A/S launched a plant concept for integrated nutrient refinement and AD, including a number of features such as thermo-chemical pre-treatment of the biomass input, several controls over the ammonia-concentrations, and complete refinement of the nutrients to fertilizers of commercial quality. The concept attempts to deal with some of the more important constraints and to offer a system more appealing to the plant owners, in particular farmers but also partly industries and municipalities. Slurry and a wide array of all possible organic wastes ranging from animal by-products to energy crops over deep litter and sewage sludge may be digested in the plant. Several commercial projects with plants having capacities of the order of 50.000 tonnes slurry and 15.000 tonnes solid biomasses are undertaken in Denmark. The installed effect is typically 2MW electricity and the output of pure fertilizers is in the range of 350 tons N, 100 Tonnes P and 250 tonnes K.

The versatility of these plants with respect to biomass input is one important feature, which ensures a high biofuel output. Equally important is the fact that the waste is done away with. It is converted to fertilizers and biofuel and the remaining water phase may irrigate onto a small area of land. The benefit to farmers of rendering waste to value, i.e. biofuel and fertilizers, is obvious. However, the potential to remedy emissions of the agricultural sector is significant in a broader perspective. Volatile losses of ammonia, nitrate and phosphorous losses and greenhouse gas emissions are all reduced substantially.

If the annual production of animal manures in Denmark along with other available biomasses from municipalities and industry were utilized for biofuel production and fertilizers the sum total of the reduction of direct and indirect emissions of greenhouse gasses would equal 10-15 mills tonnes annually. The Danish reduction target for greenhouse gas emissions is 21% relative to the 1990 level corresponding to 20 mills. Tonnes annually. Hence, a substantial contribution to reaching this target may be achieved by integrated AD. As argued in the presentation the cost is far lower as compared to many other possible measures.

BIOGAS FROM AD AS A KEY TECHNOLOGY FOR NUTRIENT MANAGEMENT IN GREAT BRITAIN AND NORTHERN IRELAND

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Bio-fertiliser as liquid or fibre (digestate) is a new commodity produced from the fermentation of organic materials in the absence of air. It is produced in a biogas plant as the centerpiece of an integrated and sustainable of food production from land to consumption and back to land as an overall system for land and environmental management. The raw materials are livestock manure, by-products from food processing and from food consumption. Before an attempt can be made to assess the role of the AD process and the type of technology available, the first task is to demonstrate the quantities of raw material that can be utilised. Suffice it to say that the technology is highly flexible with the capacity to handle liquids and solids in various combinations. In all cases it will be assumed that pasteurization or its equivalent forms an integral part of the system.

Livestock manures

The amount and quality of the raw material can vary quite significantly with diets, farming practices and especially the care with which the manure/ slurry has been stored. It can be delivered for processing either as slurry/ manure from cattle, pigs and poultry or deposited on straw bedding and known as farmyard manure (FYM). The estimates below have been based on standard figures used for nutrient planning and management [1] and attention is focussed on England and Wales as an illustration.

Table 1 Estimated output of animal manure in England and Wales in million tonnes / year

Source	Slurry/manure	FYM
Cattle	24.70	27.60
Poultry	03.85	-
Pigs	03.30	6.73
Total	**31.85**	**34.33**

The highest densities of cattle manure are concentrated in the south western and the western counties of England and generally in Wales. The concentrations of pig and poultry manure though ubiquitous are concentrated in Central and Eastern England [2,3]. The estimate of total nutrient in this material, should it be realized to full advantage, is quite substantial.

Table 2: Estimated nutrient content of animal manures in England and Wales (kt).

Source	**N**	**NH_4-N**	**P_2O_5**	**K_2O**
Cattle slurry	67.70	33.80	29.60	79.10
Pig & Poultry	80.00	23.80	64.80	49.00
FYM: Cattle	165.60	41.40	96.60	220.80
Pig	47.10	12.10	47.10	33.70
Total	**360.40**	**111.10**	**238.10**	**382.60**

The manure is used as a top dressing for 80% of the forage maize and leafy forage, 74% of the root crops for stock feed and 70% of all grass used for the dairy herds in England and Wales [4]. Barely 40% of other grazing receives an application. Unfortunately the data available does not take into account its nutrient content of vis - a - vis mineral fertilizers that are applied to the same land. The question will need to be addressed as to the place of these nutrients in fertilizer management planning. Some indication can be derived from the variable take up rates for nitrogen when it is applied by different methods and at different times of year from dairy slurry with a 6% TS content.

Table 3: Impact of timing and application method for the uptake of available nitrogen(kg/t)[5].

Method of application	**August/October**	**November/January**	**February/April**	**May/July**
Splash plate spreader	0.3	0.6	0.9	0.6
Injection	0.3	0.9	1.5	1.5

When grass growth is usually vigorous the crop can take up and use the whole of the available nitrogen when it is injected. This compares with between 20% and 60% when applied at the same time of year with a conventional spreader. This issue needs to be addressed below in the context of a typical system of management for a biogas plant.

By-products from food processing and manufacture

The quantities of by-products that are currently spread to land are more difficult to establish. However, some insight can be gained from the investigation undertaken by ADAS and the Water Research Council for the Environment Agency in 1999 [6] This research investigated the quantities of nutrients and heavy metals in the 'wastes', the total quantities in fresh weight and their suitability for spreading to land – a disposal route used for decades.

Table 4: Indicative nutrient content of by- products spread to land (kt fresh weight)

Source	m.tonnes	N	NH_4-N	P_2O_5	K_2O
Blood [1]	00.145	01.70	00.14	00.12	00.10
Stomach and gut content[1]	13.24	41.08	04.00	19.88	08.00
Dairy, food and drink	02.49	02.85	00.25	01.92	00.50
Paper sludge	01.75	00.53	-	00.18	00.18
Bio–sludge	02.90	04.93	00.58	02.61	00.58
Total	**20.535**	**51.09**	**04.97**	**24.71**	**09.36**

Source: Meldrum, K (2003) Meat and livestock Commission

The bio-solids arise from the biological treatment works in the larger food and drink manufacturing industries. The total nitrogen and phosphate holds an especial interest as a contrast to the very low NH_4-N in so far as nutrient planning on the farm is concerned.

By –products of consumption

The final stage for completing the cycle of sustainable food production lies in the use of the residues from the consumption of that food. These, otherwise classed as 'catering waste' have been in the full public gaze since the outbreak of the Foot and mouth Disease epidemic. They are nevertheless, a huge resource. Estimates suggest that each of the 20 million households in England and Wales produces 3.5kg of catering waste per week in which case this would amount to some 3.6 million tonnes per year [7]. This could contain some 26 kt of total nitrogen and almost 10 kt of potash and phosphate all of which could make its way back to land after composting or transformation in a biogas plant into bio-fertiliser. In all there is a huge quantity of material from which to produce bio-fertiliser especially when that from public catering is also taken into account.

Table 5 Indicative nutrient in by-products spread to land in England and Wales (kt)

Source	N	NH_4-N	P_2O_5	K_2O
Livestock manure	360.40	111.10	238.10	382.60
Food industry by-products	51.09	04.97	24.71	9.36
Catering 'waste'	25.90	00.52	9.70	9.70
Total	**437.39**	**116.59**	**272.51**	**401.66**

These are undoubtedly underestimates. Nevertheless, it is worth trying to calculate their monetary value so as to set them in the context of fertilizer management and planning. It has not proved possible to separate expenditure on mineral fertilizers applied to forage crops. These are subsumed within general tillage (4) However, 2099 kt of mineral fertilisers were applied to grassland in 2001 of which 25% was ammonium nitrate and 66% very high nitrogen compounds. At spot prices as in June 2003 the total value of these applications amounted to £294 million (382 million €). The value of the nutrients derived from the animal manure, food processing by-products and 'catering waste' would amount to £128 million (166 million €). The key factor hinges upon the storage, spreading method and timing of applications for this value to be realized. The question must arise therefore, as to the place of the biogas plant in the management of nutrients from sources that are already spread to land.

The role of the biogas plant

The biogas plant is a complex assemblage of components including pasteuriser(s), digester(s), pre-storage and mixing tanks for the receipt of the raw material, a reception building, cleansing equipment, gas store and after storage tanks for the bio-fertiliser on site, a dedicated transport system for manure/bio-fertiliser handling, storage facilities on farm for this new product and above all a management system for such a commercial enterprise to maintain productivity and quality. Torridge District Council (for the Holsworthy biogas plant) has set the precedent for their definition as agricultural processing enterprises within the planning system. Management to meet output targets and bio-fertiliser quality is at the heart of a total package in the creation of a wholly sustainable cycle of production. This envelopes the whole operation so as to ensure the quality of the animal manure, food industry by- products and catering residues from their point of origin to the final training in the management and use of the end product – the bio-fertiliser. Similarly, attention to detail and moreover a requirement for delivery contracts in managing the balance of raw materials the fermentation process can also achieve optimum production of saleable energy.

The process itself transforms the raw materials into a homogenous product with a nutrient declaration and a certified standard of hygiene. The effect of the process can be illustrated by the predicted nutrient status of the bio-fertiliser from a plant under development in Northern Ireland. The raw materials include 51% dairy slurry, 17% from pigs and poultry, a 31% by-product mix from dairy processing and meat plants and the balance from catering waste to produce 100 kt of bio-fertiliser per year.

Table 6: Predicted impact of AD processing of bio-fertiliser nutrient content (kg/t).

Source	**N**	**NH_4-N**	**P_2O_5**	**K_2O**
Raw cow manure	3.00	1.50	1.20	3.50
Raw food industry by-products	5.19	1.50	3.06	2.89
Bio-fertiliser	5.58	3.93	3.29	3.11

Even though such a raw by-product mix would be a prohibited under the EU animal by-products legislation its inclusion above illustrates the changes in nutrient status that can arise from alteration of the raw material .The total nitrogen and phosphate content is increased by 73 % and 155 % respectively , potash is diluted but there is no change in the amount of ammonium nitrate for take up and use by the crop following application. In contrast the AD process transforms the raw material into a homogenous non – glutinous liquid, concentrates the nutrients by an approximate 6% reduction in the overall mass, breaks down proteins and raises the pH. This increases the ammonium nitrate content still further so that, in all, it more than doubles the amount of the original raw slurry.

Table 7: Predicted impact of fertiliser application for a 70-cow dairy farm (t).

Application of available nutrient	**N**	**P_2O_5**	**K_2O**
Current: mineral	15.02	03.38	03.74
slurry	02.33	00.93	04.83
Crop nutrient need	*16.45*	*01.25*	*02.61*
With nutrient planning applies:			
slurry	02.33	00.93	04.83
mineral	14.12	00.32	**None**
With planning and bio-fertiliser: biofertiliser	06.12	02.56	04.35
Balance from mineral fertiliser	**10.33**	**None**	**None**

This table, albeit a prediction on limited data, illustrates two key issues. First, it has assumed that the farm can derive full benefit from the slurry. With less than two months storage this cannot be achieved. Additional storage is also required to benefit from the available nitrogen even with a nutrient management plan [8]. Farm incomes are too low for this to be implemented. The lack of storage is overcome by joining a biogas plant as a slurry supplier as the extra tank in the model forms part of the package. Secondly, the problem of excess potash and phosphate appears to be exacerbated in the bio-fertiliser in an area where soils are already oversupplied. However, this is not new phosphate or new potash. It is already applied to the land. This analysis has just highlighted a previously unacknowledged situation arising from the spreading of food processing residues to land already receiving dressings of slurry. Nevertheless, for present purposes it highlights the need for separation of the fibre but concomitantly the need to develop markets for that fibre.

An attempt can now be made to place a monetary value on the impact of changing to bio-fertiliser for an individual farm, in this case in a very remote area far from the centre of distribution and therefore unable to purchase at the spot prices.

Table 8: Comparative monetary benefit of using bio-fertiliser (£/€/pa).

	Remote area price	**Spot price**
Current expenditure on mineral fertiliser	£ 9151 (€11896)	£2166 (€ 2856)
With nutrient planning	£ 6425 (€8353)	£2019 (€ 2625)
Nutrient planning with bio-fertiliser	£ 4714 (€6128)	£1446 (€ 1880)

The wide difference between the local and spot price in a remote area emphasizes the disadvantage of peripherality. Perhaps of greater importance, however, it highlights the vulnerability of farms in such areas to price fluctuations. Moreover, it reinforces the value of the bio-fertiliser made from local raw materials that could be delivered to the biogas plant under a long -term contract at negotiated prices. The next step, if it is acceptable, is to try to extrapolate from the case study to the wider context of mineral fertiliser use on grassland in England and Wales. At a cautious estimate the total expenditure could amount to £ 271million (352 million €) of which 27% is for ammonium nitrate and 65% straight nitrogen and high nitrogen compounds. If one farmer can reduce his application of nitrogen fertiliser by 27% it might be contended that a similar percentage might be achieved elsewhere thereby reducing annual expenditure by a similar amount.

Conclusion

It is contended that bio-fertiliser is more than a mineral fertiliser replacement. It is a value added commodity delivered as part of a total package of land and business management in a sustainable environmental system. The biogas plant is an agricultural processing system for the production of a quality assured bio-fertiliser both with respect to nutrient content and the bio-security of freedom from slurry- born pathogens responsible for the recycling of endemic diseases among livestock where <100/g of bacteria of Faecal Streptococci are measured before delivery.

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[8] Derived from Farmer Questionnaire (by courtesy of Fivemiletown Creamery)

SEPARATION OF SLURRY – A POTENTIAL OPTION FOR THE ANIMAL PRODUCTION SECTOR

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Abstract
Sustainable practices for handling, treatment and recycling of animal manure and slurries are important premises for the Danish society in order to accept a large animal production sector.

In this context, there is a growing interest in slurry separation technologies, which for many years were seen as the way of solving the problems caused by the excess of nutrients in intensive animal production areas and to comply with an increasingly restrictive agro-environmental legislation. A variety of technical solutions and combined concepts were developed, of which a number are full scale implemented and tested. A recent amendment to the agricultural legislation offers new incentives and makes separation of slurry a potential option for many farmers. The paper gives a brief survey of slurry separation technologies and concepts in Denmark and outlines the new legislative incentives.

Introduction
Storage, transport, handling and application of slurry are related with significant costs for farmers compared with the fertiliser value, because of its large volume and low dry matter content. These costs increased significantly in Denmark after the adoption of the Water Environment Plan I in 1987. After this date slurry storage capacity for 9 months was mandatory, restricting the season for slurry application and the input of nitrogen from animal manure per hectare. In parallel, a requirement of minimum share of own land for livestock farms was enforced, causing a significant increasing of land prices and limiting the possibilities of many intensive farms for further expansion. Many farmers from intensive areas have problems today complying with the legal requirements in a situation where getting agreements for export of slurry is often very difficult.

Although the existing legislation only regulates the input of nitrogen, there is a lot of awareness about the excess of phosphorus that affects the high manure density areas, as the nitrogen to phosphorus ratio in slurry is always to low, compared to crops demands. If the input of phosphorus should be controlled, then manure treatment in regions with excess of nutrients should always include some kind of phosphorus separation. A regulation of the input of phosphorus is expected to be included in the next Water Environment Plan, to be adopted by the end of year 2003.

The strict legislative framework requires transport and redistribution of nutrients away from intensive areas. There is a potential of reducing transport and spreading costs by separating the slurry into a nutrient-rich solid fraction and a liquid fraction, where only the solid fraction is exported. Several companies from Denmark and abroad carried out important research and development work and various technologies and combined concepts of separating the nutrients contained in slurry were developed, some of them including also anaerobic digestion. Of these some are full scale implemented and documented, many are yet to be tested and demonstrated.

What is slurry separation?

Separation of slurry is a technical process by which slurry is split up into two or several fractions, different from the original material in terms of dry matter content, composition and concentration of nutrients. There are several techniques (table1) for separating slurry into a nutrient and dry matter rich fraction and a nutrient poor liquid fraction: mechanical screen separators, sedimentation, centrifugation, chemical precipitation, reverse osmosis, evaporation, ammonia stripping etc.

Table 1. Slurry separation techniques (Source: Landbrugets Rådgivningscenter, 2002)

Slurry separation technique	**The technique separates:**		
	Dry matter (fibres)	**Phosphorus**	**Nitrogen**
Strainer	Yes	No	No
Sedimentation	Yes	No	No
Screw press	Yes	Partly	No
Centrifuge	Yes	Partly	No
Ammonia stripping	No	No	Yes
Ultra centrifuge	Partly	Yes	No
Flocculation/chemical precipitation	No	Yes	Yes
Evaporation	No	Yes	Partly
Membrane technology (e.g. reversed osmosis)	No	Yes	Yes

There is a limit of what it can be achieved with such technologies, especially with respect to the fully soluble components. The choice of technology depends of the nature of the problem and the level of abatement sought. The separation efficiency of the different techniques can be defined as the capacity of the technique to separate slurry into a nutrient-rich fraction and a liquid fraction with low contents of nutrients. The total amount of nutrients transferred to the nutrient-rich fraction and the ratio between solid and liquid fraction should be considered when evaluating the separation efficiency. The running costs vary widely, often reflecting the sophistication and efficiency of the technique. Mechanical screen separators and centrifugation are simple, low cost techniques, while evaporation and ammonia stripping are more expensive techniques, used mainly for refining slurry that has been pre-treated by screen separators or centrifuges. With some exceptions, technologies such as membrane filtration and electro-flocculation are mainly at the research stage with respect to applying the technology to the effluents from the farmyard.

Solid-liquid separation

A variety of solid-liquid separation technologies are available on the market (e.g. bow sieve, double circle bow sieve, sieve belt press, sieve drum press, press screw/auger separator, decanter centrifuge etc). Some of them have gained widespread popularity among framers (e.g. decanter centrifuge). Use of chemicals for enhancement of separation is a relatively new approach for treating animal manure, though it has been a widely accepted method for treatment of municipal and industrial wastewater. The chemicals most commonly used for phosphorus removal from wastewaters are alum ($Al_2(SO_4)_3$), ferric chloride ($FeCl_3$), ferric sulphate ($Fe_2(SO_4)_3$)) and lime ($Ca(OH)_2$). For further agglomeration of coagulated particles, addition of polymers may be needed under certain circumstances (Westerman & Bicudo, 1998). Chemical precipitation of animal manure involves addition of chemicals to alter the physical state of dissolved and suspended solids to facilitate removal (Zhang & Westerman, 1997; Westerman & Bicudo, 1998).

The separation efficiency of different equipments showed that separation efficiency for nutrients and heavy metals is highly dependent on both manure type, pre-treatment by anaerobic digestion and the separation equipment (Møller et al. 2002).

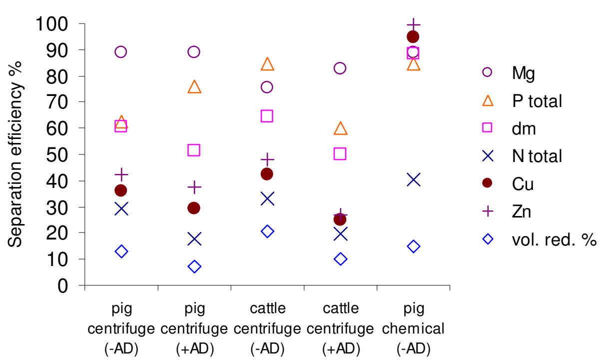

Figure 1. Nutrient and heavy metal separation efficiency by centrifugation and chemical treatment of manure with anaerobic pre-treatment (+AD) and without anaerobic treatment (-AD). (Møller et al. 2002, Møller et al. 2003)

Figure 1 shows that both centrifugation and chemical treatment is efficient in removing nutrients, which are normally associated with particles, like phosphorus and magnesium, while the efficiency is lower for nutrients that are partly in a dissolved form, like nitrogen. Chemical treatment is more efficient than the centrifuge in removing both phosphorus, and nitrogen. Heavy metals like Cu and Zn are also efficiently removed by chemical treatment.

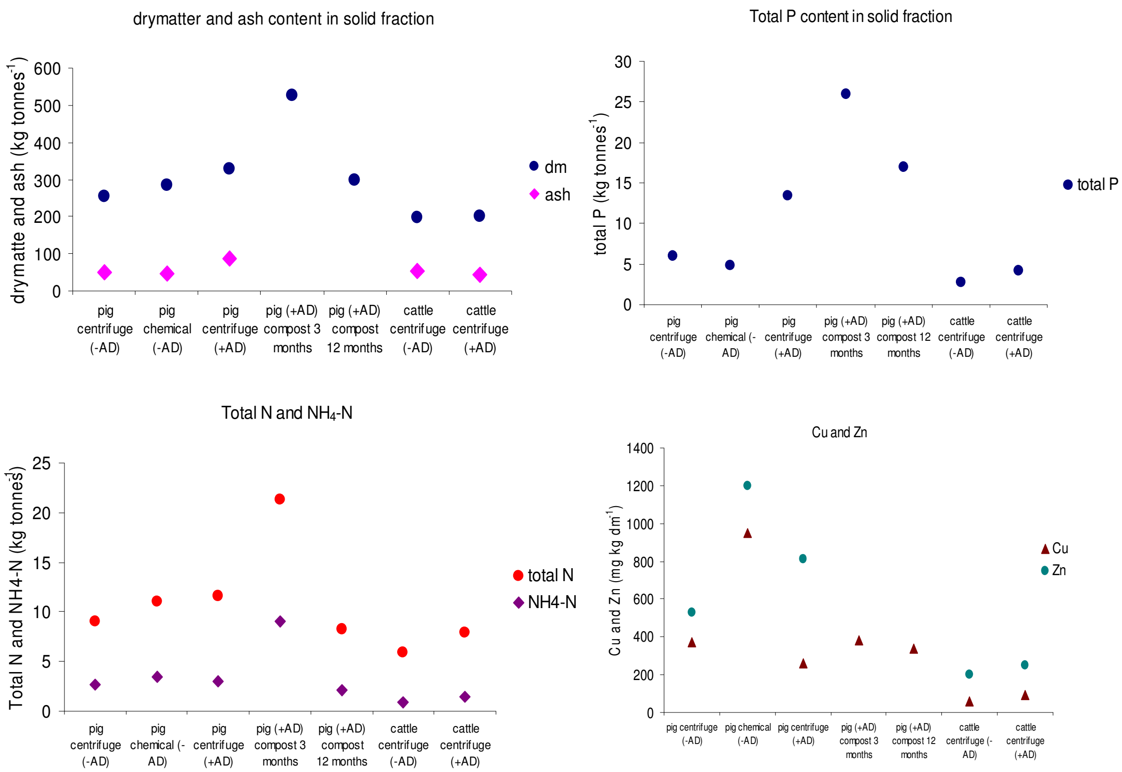

Figure 2. Nutrient and heavy metal concentrations in the solid fractions after separation by centrifugation and chemical treatment of manure with anaerobic pre-treatment (+AD) and without anaerobic treatment (-AD) Composting by passive aeration of solid fraction from pig manure done by storing outside in 2-3 m high piles (Møller et al. 2003).

The transportation costs of the solid fraction in terms of nutrients are affected by the concentration of nutrients. The concentrations of total-N and total P are variable between solid fractions deriving from pig and cattle and it seems that anaerobic digestion results in higher nutrient concentrations in the solid fraction (fig. 2).

The total P content is lower in the solid fractions deriving from cattle and digested cattle slurry than the solid fractions deriving from pig slurry. The solid fractions deriving from chemical treatment have a slightly lower concentration of total N and P than solid fractions from centrifugation.

Composting of the solid fraction is a way to increase the concentration of nutrients in the solid fraction, but also a risk of loosing nitrogen. Outside composting for 3 months doubles the concentrations of both total N and P, while the nutrient content during long term storage (12 months) reduce the concentration to the same level as the starting point, due to dilution with rainwater, thus the dry matter content is reduced from 52% to 35% during 3 to 12 months storage.

Combined processes and slurry separation concepts

Several companies offer different systems for a more or less complete separation of nutrients in concentrated fertilizer products by combining solid-liquid separation with one or more refinement steps. Some of the systems are integrated with anaerobic digestion (figure 3).

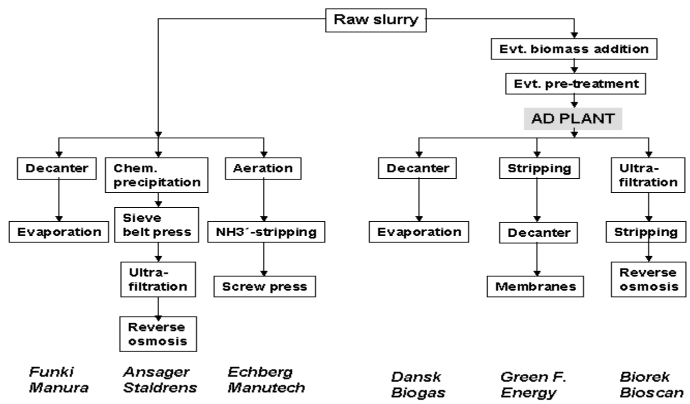

Figure 3. Combined slurry separation concepts.

Centralised co-digestion plants but also farm scale plants handling large volumes of low dry matter biomass would benefit from a volume reduction by separation. A synergic effect is expected to occur from the combination of centralised co-digestion and separation and a number of advantages related to scale and capacity utilisation, energy utilisation, veterinary safety, export and redistribution of nutrients etc. are foreseen. There are few biogas plants in Denmark with separation facilities, but more plants consider establishing such facilities and it is expected that the new established biogas plants will be equipped with separation facilities from the start.

New legislative incentives for separation of slurry

The legislative framework for slurry management

Slurry management become increasingly expensive in Denmark during the last decade, due to strict agro-environmental legislation. The relation between the size of the farm, in terms of livestock numbers, and the area available for manure application is regulated by the “harmonisation requirement”. The requirement defines a livestock unit as a unit of calculation corresponding to a maximum of 100 kg of nitrogen in manure, including the quantity deposited by the animals on the field. The aim of the regulation is to control the input of nitrogen from animal manure.

In parallel, efforts to control the structural development of agriculture translated into a legal requirement of the minimum share of own land for livestock farms, called “area requirement”. This means that an animal farm must purchase land in order to expend the production. The consequence was a very significant increasing of the prices of land in intensive areas, that become a barrier for the further development of the animal farms.

Separation of slurry could unwind from area requirement and harmony rules

Separation of slurry means new investments, operation and maintenance costs. Direct or indirect benefits, to compensate for these costs, such as an alternative to land purchase, are necessary in order to make slurry separation interesting for farmers.

The area requirement stipulates that production units of 0-120 LU must own 25 percent of the harmonisation area, units of 120 –250 LU must own 60 percent of it and for more than 250 LU the whole harmonisation area must be owned. Recent changes in the above legislation bring important relaxation of the area requirement for the farmers that separate at least 75 % of the produced slurry and export the separated nutrients (table 2). The level of dispensation depends on the kind of separation technology that is applied, being of 25 % if the slurry is separated in a low technology installation and of 50 % for a high technology installation. Table 2 shows that the harmony rules must still be kept but the amounts of separated and exported the nutrients can be subtracted from the fertilisation plan and the farmer will get a corresponding dispensation from the area requirement. The dispensation is valid only for farms up to 750 LU. Above this size separation of slurry brings no exemption from initial requirements.

Table 2. Harmony and area requirement without and with slurry separation (Source: Jakobsen and Hjørt-Gregersen, 2002 and personal data)

Nr. LU	**Harmony requirement**	**Area requirement**	**Reduced area requirement by separation**	
			Low technology[1)]	**High technology[2)]**
	Ha	**Ha**	**Ha (25 % reduction)**	**Ha (50 % reduction)**
100	71	18	14	9
250	179	77	58	39
500	357	256	192	128
749	535	434	325	217
750	536	536	536	536
1000	714	714	714	714

[1)] The high technology concepts separate nutrient rich fractions, containing more than 70% of the P and more than 70% of the N, with an average concentration of nutrients at least 2,5 times higher than untreated slurry.
[2)] The low technology concepts must be able to separate rich fractions containing more than 20% of the N and more than 60% of the P, with an average concentration of nutrients at least 1,5 times higher than untreated slurry.

The possibility of reducing the area requirement by separating the slurry is an important element for a wide spreading of separation technologies. The differentiation between low and high technology is not explained in the text of the law, but one of the reasons could be the lower transport volume that is obtained by high technology separation. Although it originates in a structural legislation, the dispensation is the expression of a political will of promoting such technologies, based on environmental arguments (Jakobsen, 2002). The separated fractions must be exported in order to get the dispensation. There is still some uncertainty about the sale prices and the market for separated nutrients and the produced amounts must be high and constant before the fertiliser industry will be interested in purchasing the fractions (Jakobsen 2002).

Conclusions

The intensive animal farming came under increasing legislative pressure during last decades. The cost of slurry management increased due to legal requirements of export and redistribution of the excess of nutrients. The high volume and low dry matter content of slurry made transport over long distances extremely expensive, thus a volume reduction and a separation and concentration of nutrients were considered for some years. The nutrients contained in slurry can be separated by several techniques, of which separation by decanter centrifuge gained popularity among farmers. Several combined technologies and separation concepts were developed in Denmark and abroad, in many cases advantageously combined with co-digestion, of which some are well documented and full-scale implemented while others are still in the developing stage.

The political will to promote separation technologies was concretised into important dispensation from the legal requirements for the farms that separate the slurry. The new legislative incentives can open the way for a massive implementation of slurry separation in agriculture if the market for separated fractions will develop too. It is expected that the technologies for slurry separation will further develop in the future, concurrently with the development of the animal production sector, the biogas sector and the market for separated fractions.

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SEPARATION OF SLURRY – TECHNICAL AND ECONOMICAL SYSTEM ANALYSIS

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Abstract
In recent years considerable interest has been paid to manure separation in Danish agriculture, as incessantly stricter environmental legislation has increased the need of redistribution of manure and the nutrients in it. To some extent the requirements can be met by transporting surplus manure to other farmers. However the idea of separation or refining nutrients in concentrated fractions is appealing to many farmers. Thus several companies in Denmark and abroad have carried out considerable efforts in developing viable separation technologies. A number of technologies are being implemented and tested. An economical analysis on separation systems was carried out by Jacobsen et. al, 2002, and Jacobsen and Hjort-Gregersen, 2003.

Introduction

Rigorous ties between livestock production and ajoining land have lead to significantly increased land prices in Danish agriculture over the last decade. In many areas prices have increased to levels that can not be justified by expected future incomes from plant production.

The aim of the strict legislation is basically to establish or maintain a certain balance between the amount of manure produced and the acreage on which it is finally spread. Until now main focus has been on the distribution of Nitrogen, but it is generally anticipated that a Phosphorus legislation is forthcoming, which may increase the need for manure redistribution. Export of surplus manure to other farmers is one option to comply with the requirements, but in most livestock intensive areas farmers face increasing difficulties in doing so, and thus have to transport it in considerable distances. Another option is concentration of surplus nutrients, which makes the transport cheaper. So far it has been anticipated that separation was only economically attractive when transportation distances were very long. However recent change in legislation may have opened for a break-through for manure separation technology, as livestock/land bindings are loosened if manure is separated and some of it removed. The interest in manure separation was thereby generally reinforced in the agricultural sector. This is indeed true for the biogas sector, as biogas plants are likely to contain a number of advantages when combined with separation technologies.

Biogas and manure separation

The idea of combining biogas plants and separation techniques is not new. Combined systems are operating in many countries, however mostly using simple separation techniques, but more advanced systems like membrane filtration systems are also sporadically found. In Denmark several centralised biogas plants installed screw – press separators hoping to find a market for a compost-like fibre product, unfortunately with limited success. In 1990 the new Linkogas plant included a reversed osmosis separation unit. But due to technical problems the system was never operated on a regular basis and was later dismantled.

In recent years a decanting centrifuge in combination with evaporation, and first-generations of Biorek and Green Farm Energy systems have been implemented on a farm scale basis. Centralised biogas plants have so far been more hesitating in introducing separation technologies. But now they are slowly incorporated in existing centralised biogas systems. Especially new projects in planning pay much attention to manure separation.

A successful technology development of appropriate separation technologies in combination with biogas facilities will indeed enable biogas companies to occupy a new and prominent position as a solver of environmental problems in the agricultural sector. In addition it is a premise for a larger application of the centralised biogas concept in many countries, as the refining and removal of nutrients from manure is the main interest.

Actual technologies

The separation technologies that have been tested in Denmark have been highly variable in technical design and function. Consequently great variation in amounts and contents of separated fractions have occurred, which has made any comparison very difficult, and the preparation of fertiliser accounts more complex.

A number of technologies may be combined with both farm scale and centralised biogas plants in different ways depending on the objectives of the separation.

The separation technologies presented in table 1 are all represented in the Danish market, but not necessarily so far in a biogas context. The table explains how the separation technologies could be combined with a biogas production. In principle al the mentioned technologies can be implemented in both farm scale and centralised biogas plants.

Table 1. Ways of combining biogas plant and separation technologies.

Treatment options	What is achieved	Concept examples
Pre-separationt	Fibre fraction supplied to the biogas plant	Decanting centrifuges Ansager Sep Tek
Post-separation	Separation of digested manure	Decanting centrifuges Funki Manura
Combined systems	Separation of digested manure using surplus heat from biogas plant	Decanting centrifuge/evaporation Dansk Biogas A/S
Fully integrated systems	Pre- and post separation, advantageous for energy production and vice versa	Green Farm Energy Biorek

The on farm ***pre separation*** has always been on the wish list for centralised plants that normally carry heavy costs in slurry transportation. As approx. 95 % of slurry is water, a higher dry matter concentration is generally very attractive to biogas plants. The Ansager Sep Tec concept which uses flocculation and a sieve-belt separator has been introduced for on farm pre separation of pig slurry. The fibre fraction that contains most of the energy potential is afterwards transported to the biogas plant by the farmer. If successful this may minimise transportation costs and the economic dependence on organic waste, which has become increasingly problematic for Danish plants.

Most technologies can be used for ***post separation*** of digested manure. Among these could be found various brands of decanting centrifuge, Funki Manura (evaporation), Echberg Manutech, which uses NH_3 stripping, and membrane filtration systems could also be introduced

Further ***combined systems*** where surplus heat from the biogas production is utilised for evaporation is represented by Dansk Biogas

Finally ***fully integrated systems*** are represented by the Green Farm Energy and Biorek concepts, in which the combination of pre and post separation and biogas production aim at optimising both energy production and separation.

In general technical and economical documentation of combined systems is scarce. Our preliminary analyses show that a very high energy production and very high nutrient sales prices in separated fractions are required if separation cost should be covered by these revenues.

Manure separation affects costs and revenues in the total manure handling system and crop production. Thus, a total system analysis should also include the following utilisation of separated nutrients and other derived effects for farmers. Calculations have been carried out with respect to treatment costs in different separation systems and derived economical benefits for farmers. But unfortunately a thorough system analysis of separation technology in combination with biogas plants has not yet been accomplished in Denmark. Consequently, a biogas plant is not included in the below system analysis on slurry separation systems. Jacobsen et. al. analysed in 2002 two on farm systems (decanting centrifuge and Funki Manura) that might as well be combined with biogas plants for post treatment of digested manure. Calculations are based on the situation for a pig producing farm with 1000 sows and breeding the piglets into porkers, which equals to a total slurry production of approx. 17.300 tonnes per year. In the reference situation there is no upper limit to Phosphorus application and all the manure is consequently utilised on the fields of the farm. Introduction of a Phosphorus limit would create the need of transporting a certain amount of manure to other farmers. In table 2 it is preconditioned that this is possible within a distance of 25 km at the cost of DKK 25 per tonne. So the options are to transport the surplus in the form of slurry or to introduce a separation technology and transport concentrated nutrient fractions with the implication this operation has for transportation costs, nutrient utilisation and so on.

Table 2. System analysis of slurry separation systems

Costs in DKK.	**Untreated Slurry** **A**	**Untreated slurry + Export of surplus** **B**	**Decanting centrifuge** **C**	**Funki Manura** **D**
Slurry per year, tonnes	17.300	17.300	17.300	17.300
Phosphorus application limit, kg/ha	None	30	30	30
Share of slurry or fibre fraction for export %	0	24,2	32,2	30,3
Amount for export, tonnes	0	4648	713	590
Separation costs	0	0	240811	1301199
Separation costs/tonne			13,9	75
Storage costs	327013	327013	343864	147495
Spreading costs	256241	256241	356122	199446
Transport costs surplus [3)]	0	116277	17838	14750
Fertiliser purchase	99920	187711	142527	108608
Nutrient sales	0	0	0	0
Yield effect			28571 [1)]	
Opportunity costs water application				15200 [2)]
Total costs	683174	887242	1072589	1786698
Costs per tonne	39	51	62	103
Extra costs compared to reference		12	23	64
Extra costs at identical phosphorus level			11	52
"Zero point" distance, km [4)]			72	247

1) Yield effect: Extra grain yield due to effect from injection
2) Water fraction from Manura plant must be applied to 7,6 ha grassland from which a revenue is lost
3) Surplus slurry or fibre fraction is transported in a 25 km distance at the cost of 25 DDK per tonne
4) "Zero point" distance is the distance at which export amounts must be transported if separation is equally attractive as traditional handling.

In table 2 the A situation represents the reference situation where no phosphorus limit has been introduced and the actual requirements in regulations regarding nitrogen application can be met. In B, C and D a phosphorus limit of 30 kg/ha is introduced, which may represent a future situation in Denmark. At this phosphorus level 4648 tonnes of slurry must be exported. Alternatively the slurry can be separated either in a decanting centrifuge or at Funki Manura plant, and a concentrated phosphorus fraction can be exported. As the table indicates these options affects storage and spreading costs, fertiliser purchase, but particularly transportation costs for exported fractions are affected in favour of the separation options. However these costs reductions must be related to operation costs of the separation plants to show the full picture. Storage costs are only significantly lower by the Manura plant, because of the large volume reduction. Actually storage costs are higher at the decanting centrifuge, as a double storage system is needed after the separation. Fertiliser purchase is reduced if slurry is separated, as Nitrogen content in exported fibre fraction is significantly lower then in exported slurry, and can be utilised on the farm itself.

However highest total costs are found in D, which is the most advanced separation system. In C costs are lower than D, but still significantly higher than B where untreated slurry is exported. If extra costs of B are compared with the reference A, it is found that a phosphorus limit of 30 kg/ha will lead to increased costs of 12 DKK/tonne for Danish pig producing farmers. A further cost increase would occur if farmers chose the separation option, an additional cost of 11 DDK/tonne by the decanting centrifuge option, and 52 DKK at the Funki Manura option. If transport distance was longer or the phosphorus limit was lower, this would indeed be in favour of the separation options. In addition, increasing land prices, which are not taken into account in the analysis, also favour separation options.

Potential advantages by integrating biogas production and slurry separation.

As mentioned the decanting centrifuge, Funki Manura and other separation concepts may be introduced as a post-treatment facility on centralised biogas plants. But what if separation technologies could be utilised more progressively, and integrated in ways that lead to synergy between biogas production and separation ? Well, separated fibre fractions may be applied to biogas plants as additional biomass, which would lower the actual economic dependence on organic waste application. Utilisation of surplus heat for evaporation could decrease separation costs, and exploitation of economy of scale reduces average treatment costs. Connected to biogas plants small farmers may also have their manure separated and thus make the technology more widely applied. In addition new EU legislation on handling of animal wastes proscribe sanitation of separated manure fractions that are transferred to other farmers. This requirement is prohibitive for manure separation if not set up in combination with biogas plants, which are generally equipped with sanitation facilities. Finally large scale marketing of nutrient fractions could be decisive for a successful market break through

Conclusions
From a farmers point of view manure separation is only interesting in surplus situations where certain amounts of slurry (or nutrients in it) must be exported at a relatively long distance.

Introduction of a Phosphorus application limit will increase manure and fertiliser costs by traditional handling, and the interest and relevance in slurry separation will increase

Long transport distances is favour of slurry separation.

We believe that combinations between centralised biogas plants and separation technologies will prove advantageous for farmers and biogas companies.

Technical and economical documentation of combined systems is much in demand

There are still questions to be answered with regard to the market for separated nutrient fractions.

Further research and technology development is needed in order to find optimal solutions.

The success of these efforts are crucial for the future of centralised biogas plants in Europe

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STATE OF THE ART AND PERSPECTIVES FOR DEVELOPMENT OF AGRICULTURE BIOGAS TECHNOLOGIES IN POLAND

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Abstract
The current state of the art in utilisation of biogas in Poland and perspectives for agriculture biogas utilisation is presented, as well as possibilities to utilise biogas from industrial waste. The analysis of the agriculture biogas technical potential shows that it is significant: *circa* 12,9 PJ. Together with biogas from organic industrial waste it makes 14,6 PJ. The comparison between Polish and German biogas potentials shows big differences, resulting mainly from different structure of agriculture production and utilisation of energy plants for biogas production in Germany.

1. Introduction

Production of agriculture biogas is a very promising technology. Poland has experience in building of agriculture biogas plants, but first installations built in the 1980-s didn't bring expected results and in a way contributed to bad attitude towards this technology. On the other hand Polish agriculture is going to face big changes connected with accession to EU. The structure of animal production has already started to change towards higher intensity and big concerns started to build huge intensive ferms. This trend gives more opportunities to utilize animal manure, but also poses some threats on the environment (such adverse effects are for example a result of American concern Smithfield Food's bad practices- a recently carried out control proved breaking of environmental, sanitary and veterinary regulations in all 16 controled ferms).
At the moment EC BREC is preparing the Strategy of National Fund of Environmental Protection for supporting the development of agriculture biogas plants in Poland. As a result of implementing this strategy first two pilot plants should be built, with finansial support of the Fund. This will open new opportunities for the development of biogas sector in Poland.

2. The current state of utilisation of agricultural biogas

In the 1980's several small biogas installations (25, 50, 100, 150 m^3 of digester volume) were built by the Institute for Building, Mechanisation and Electrification of Agriculture (IBMER). These installations are not in operation any more due mainly to economic problems of farms where they were installed. However, there is a strong interest in building such installations at big industrial pig or cattle breeding farms and several, centralised co-fermentation biogas plants are under design. An example of such is installation is a plant planned in Koczala farm, which belongs to Poldanor Polish-Danish meat production company. The total production of slurry is circa 38 000 tonnes per year. The biogas installation was designed in thermophilic co-digestion with other organic waste like animal fat, fruit and vegetable waste– 2 digesters 780 m^3 each. The biogas production is estimated at 256 m^3/h the installed capacity at 836 kW_e/1010 kW_{th} in co-generation.

3. Perspectives for utilisation of biogas technologies in Poland

3.1 Perspectives for utilisation of agricultural biogas Poland

The estimation of future perspectives for utilisation of agricultural biogas was based on the assumption that it is possible from a technical point of view to install the biogas installations only on farms, which have above 100 LSU (livestock units- animals which weight more than 500 kg). The data is based on information from the national census carried out in 1996 (the next census took place in the year 2002 but the detailed data is still not available). The number of LSU calculated for different animal husbandry is presented in Table 1.

Table 1. LSU for different animal husbandry in farms above 100 LSU [1].

Farms above 100 LSU	**Cattle**	**Pigs**	**Poultry**
Number of animals	667 080	3 281 298	11 210 949
	LSU average as per the herd structure on Polish farms		
	0,73	0,12	0,004
Number of LSU	486 968	393 756	44 844

The statistical data for biogas production from animal waste is presented in the Table 2.

Table 2. Empirical data on biogas production from animal waste [2].

	Cattle		**Pigs**		**Poultry**
	manure	**slurry**	**manure**	**slurry**	**slurry**
Total solids [t TS/t waste]	0,23	0,1	0,2	0,07	0,15
Organic matter content in total solids [t oTS / t TS]	0,80	0,8	0,9	0,82	0,76
Daily production of organic total solids per LSU [kg oTS/LSU/d]	3,0-5,4 average:4,2		2,5-4,0 average: 3,3		5,5-10 average: 7,8
Biogas production [m^3/t oTS]	175-520 average: 347		220-637 average: 428		327-722 average: 524

The biogas production technical potential was calculated as per the following fomula:

$$P\ [m^3\ CH_4\ /a] = LSU\ x\ oTS\ [kg\ oTS/LSU/d] x\ 365/\ 1000\ kg/t\ x\ B\ [m^3\ CH_4/t\ oTS]$$

Legend:
LSU- number of livestock units
[kg oTS/LSU/d]- organic substance per livestock unit
365/ 1000 kg/t- unit conversion factor
B [m^3 CH_4/t oTS]- specific biogas production per amount of organic total solids.

The results for different animal husbandry are presented in Table 3.

Table 3. Biogas production from animal waste.

Farms above 100 LSU	**Cattle**	**Pigs**	**Poultry**
Number of LSU	486 968	393 756	44 844
Annual production of organic total solids per LSU [t oTS/LSU/a]	1,533	1,204	2,847
Methane production [m^3/t oTS]	218	269	330
Technical potential [million m^3 CH_4/a]	162,7	127,6	42,1
Total methane production [million m^3 CH_4/a]			**332,4**
Total methane production [PJ]			**12,9**

3.2 Perspectives for utilisation of biogas from industrial waste

Industry can be a supplier of many waste products, which could be used as substrates in the fermentation process. Two documents were used as the basis for evaluation of waste which could be used for digestion: Statistical Yearbook Environment [3], National Waste Management Plan [4]. Since most of industrial waste is already utilised- calculation of the technical potential was based on the amount of the rest- available waste.

Among waste from food processing industry, the biggest amounts and thus having the biggest technical potential are: beet pulp, beet processing wastewater as well as pomace and slops. In the Table 4 the technical potential for methane production from different industrial substrates is presented.

Table 4. Calculation of methane production potential from digestion of industrial waste [3], [4], [5], [6].

Kind of waste	**Diary product waste**	**Sediments from beet wastewater**	**Slops and pomace**	**Meet production waste**	**Waste from beverage production**
Total amount of waste[t/a]	518800	1396400	514700	269800	552000
Usable amount of Waste [t/a]	4680	688600	28000	42900	11600
Total solids [t TS/t waste]	0,05	0,16	0,18	0,13	0,20
Organic total solids [t oTS/ t TS]	0,86	0,79	0,82	0,88	0,80
Methane production [$m^3 CH_4$ /t oTS]	400	450	345	401	327
Technical potential [million $m^3 CH_4$/a]	0,1	39,2	1,4	2,0	0,3
Total technical potential [mil. $m^3 CH_4$/a]	**42,9**				
Total technical potential [PJ]	**1,7**				

The biogas technical potential was calculated as per the below formula:

$$P\ [m^3\ CH_4/a] = Q\ [t/a] \times \%TS \times \%\ oTS \times B\ [m^3\ CH_4/t\ oTS]$$

Legend:
Q amount of waste [t/a]
%TS- share of total solids in the overall waste production
%oTS- share of organic total solids in total solids
B [m^3 CH_4/t oTS]- specific biogas production per amount of organic total solids.

Currently the biogas is converted to electricity in two sugar factories, still in another one it is used in a boiler for heat production.

4. Summary

The analysis of the agriculture biogas technical potential has shown that it is significant: *circa* 12,9 PJ. If we add all available organic industrial waste we will gain additionally 1,7 PJ, which together makes 14,6 PJ.

An interesting issue can be the comparison of biogas technical potentials between Poland and Germany [7]. As the technical potential depends very much on the national structure of agriculture, industry and municipalities the Figure 1 below shows strong regional tendencies.

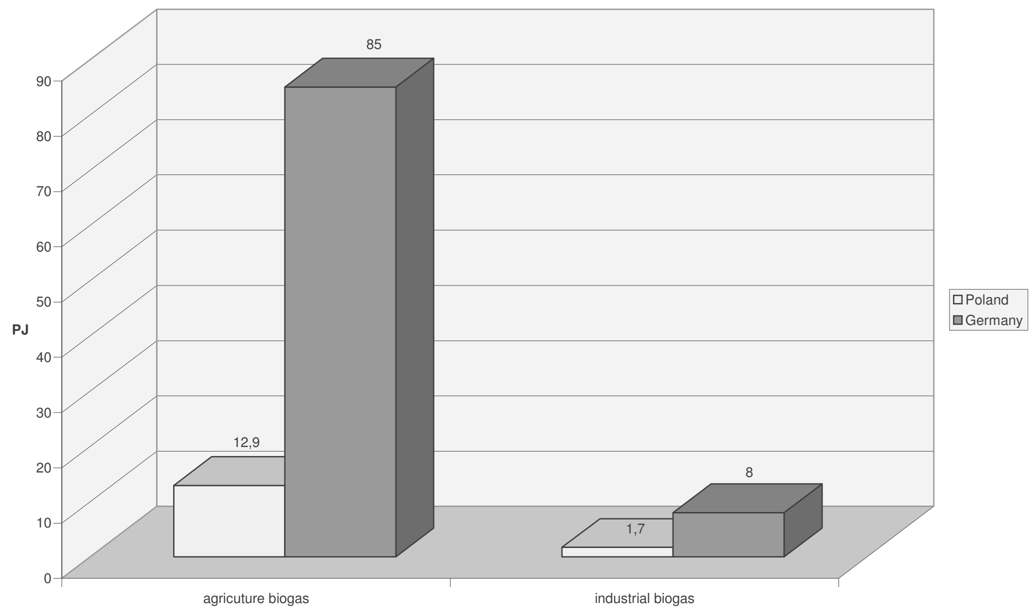

Figure 1 The comparison of technical biogas potentials in Poland and in Germany.

There is a big difference in technical potential of agricultural biogas estimation in Poland and in Germany. The reason for such could be different structure of agricultural production in Poland and in Germany, in Poland small family farms still dominate. The average farm size in 1997 in Germany was 32.1 ha/farm [8], whereas in Poland it was only 6,5 ha/farm [9]. Also the number of livestock was smaller in Poland (2,6 cow farm heads, 16,2 pig farm heads) than in Germany (28,3 cow farm heads, 131 pig farm heads).

Another difference between Poland and Germany is that Germany sees a big potential in production of energy crops as a substrate for co-fermentation with animal waste. The total technical potential for Germany has been estimated at 205 PJ/a. For Poland it has not been investigated as the priority should be first given to fermentation of readily available waste.

For the development of Polish agriculture biogas sector it's important to answer such questions as: should we support agricultural biogas plants on big industrial ferms or on smaller and more sustainable ones? Should we choose Danish or German direction? What is better from economical, ecological and logistic point of view? How to organise utilisation of organic industrial waste for biogas production? There is also a need to collect more accurate data on industrial organic waste- at present we dispose only rough estimations.

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PRETREATMENT TECHNOLOGIES FOR ENHANCED ENERGY AND MATERIAL RECOVERY OF AGRICULTURAL AND MUNICIPAL ORGANIC WASTES IN ANAEROBIC DIGESTION

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Summary
In the light of the goals set of the Kyoto protocol and the new EU-directives on organic waste management, the anaerobic digestion (AD) process is a key player in the recycling and reuse of agricultural and municipal waste. Many efforts have been devoted to apply and optimize the AD process on abundantly produced organic wastes, i.e. sewage sludge, manure and municipal solid waste. Despite the demonstrated efficiency of AD with regard to sanitation and sustainable energy recovery, a pre- and/or post treatment of the waste is needed to meet the recent directives on nutrient management and pollutant and pathogen prevention. Moreover, pretreatment of the waste mostly results in enhanced energy recovery of various waste types and therefore can render AD more efficient.

This paper highlights the opportunities and drawbacks of existing pretreatment technologies for enhanced energy recovery and sanitation, nutrient separation and the applicability of the end product for reuse purposes (e.g. fertilizer). Besides, integrated AD process designs are defined, which have high applicability for the total treatment of hazardous organic wastes.

From the study, it appears that sequential AD with oxidative low temperature thermal treatment (<200°C) can be a promising approach for complete sanitation of the waste and enhanced energy recovery compared to the conventional AD-aerobic maturation approach.

Introduction

According to recent statistics of the European Environment Agency, about 1.3 billion tons of municipal waste are annually generated within the European Union of which at least 40 million tons are of hazardous nature. This represents a daily municipal solid waste (MSW) production of 400.000 tons in Europe (Mata-Alvarez et al., 2000). The biodegradable fraction often referred to as the organic fraction of municipal solid waste

(MSW), amounts to 107 million tons dry matter on yearly basis. Besides, 700 million tons of agricultural wastes are produced yearly within the EU. Another troublesome waste stream is thickened municipal sewage sludge, of which yearly 9.4 million tons dry matter are to be disposed off by 2005 (Source: European Environment Agency). Finally, grey waste or residual refuse make up a relatively new waste stream for AD and encompass all waste fractions that remain after source separation, e.g. sludge and fibers. These fractions are currently mostly land filled or incinerated. All these abundantly produced waste streams represent a challenge for sustainable and cost-effective disposal. The sum of biodegradable waste streams generated within the EU then constitutes a total sum of 820 million tons of dry matter per year. Based on the calorific value of petroleum (46 MJ/kg) and biogas (21 MJ/m^3) and assuming an average biogas yield of 200 m^3 biogas/ton waste, the theoretical energy equivalent of the total organic waste production within the EU corresponds to about 75 million tons of petroleum equivalent or 250 L petroleum per European citizen per year. Estimating an average petroleum consumption of 2300 Liters petroleum per European citizen per year (Source: EIA), on average 10% of the total European petroleum consumption could be covered by recycling the organic waste by one-stage AD.

Anaerobic digestion (AD) of organic waste is a well-established technology and currently applied at industrial scale worldwide (Mata-Alvarez et al., 2000). It is generally recognized that AD is a much more controlled and sustainable way of treating organic waste compared to other disposal and treatment routes, i.e. land filling and composting. Despite the higher investment and treatment cost (total costs ca. 1.2-1.5 times the cost of composting), AD is expected to gain considerable importance in the near future due to its comparatively low (CO_2) emissions and valuable energy recovery in the form of biogas. Moreover, EU legislation will prohibit the disposal of native organic wastes on landfills in the near future (Gallert et al., 2003). Contrary to land filling, incineration will probably remain a possible disposal route for many solid wastes for the coming years. However, due to the high moisture content (e.g. 5-35% dry matter) of many organic wastes and their concomitantly relative low energy content, incineration has a low efficiency and leads to higher emissions. Therefore, incineration is no sustainable option and will be more and more restricted by stringent emission directives.

AD as such cannot fulfill all requirements imposed by environmental legislation. Sofar, industrial anaerobic digestion facilities have relied upon a short-term digestion phase (typically 15-20 days), followed by a post digestion stabilization of the remaining non-digested solids (Verstraete et al., 1999; De Baere, 2000; Lissens et al., 2001; Van Lier et al., 2001; Liu et al., 2002). Hence, mostly one or more (aerobic) post treatments are necessary to obtain a high-quality digestion product that can be reused for agricultural purposes (Mata-Alvarez et al., 2000). This approach bears the advantage that the digested residue mostly has a very slow biological turnover, given adequate soil conditions (Mata-Alvarez et al., 2000). This way, the soil can function as a sink of highly sequestered carbon. However, a main drawback constitutes the fact that the post-composting step counteracts the advantages of AD in a way that composting is a net energy consumer that moreover impairs high emission of VOC (volatile organic compounds).

Another approach to AD is sequential anaerobic digestion, in which physico-chemical pretreatment and intermittent treatment result in a fractionation of the waste. This route allows higher process yields and better and effective reuse of waste biomass materials and nutrients. Moreover, this approach bears the advantage that post treatment can be omitted and that a complete sanitation can be reached. In this regard, Liu et al. (2002) recently showed that intermittent steam pressure disruption of digested MSW could lead to 40% higher methane yields, leaving a lignin-enriched digester residue with low phytotoxicity to germinating plants without the need for a maturation step. The authors claim that the integrated system provides electrical power and co-generated steam with excess energy available for green electricity (Liu et al., 2002).

This review first discusses investigated pretreatment technologies with emphasis on recently reported low temperature thermal processes (< 200°C). In a second part, sequential AD processes are proposed for selected waste streams, i.e. organic fraction of MSW, grey waste and sewage sludge.

Overview of Described Pretreatment Technologies

Considerable efforts have been made to improve the anaerobic conversion of solid wastes, mostly by means of a pretreatment. The majority of the described pretreatment technologies have focused on the enhancement of biogas yield in subsequent digestion by acting on the first and rate-limiting step of AD, being hydrolysis of particulate matter. Many organic waste streams contain lignocellulose, of which the rate and extent of utilization of the embedded polysaccharides is severely limited due to the intense cross-linking of cellulose with hemicellulose and lignin. Moreover, the crystalline structure of cellulose also largely prevents penetration by enzymes or microorganisms and even by small molecules such as water (Lynd et al., 2002).

Reported pretreatments encompass biological methods (e.g. pre-composting), mechanical methods (e.g. ball milling) and physico-chemical methods (e.g. thermal hydrolysis) as reviewed by Mata-Alvarez et al. (2000). Sofar, the use of biological pretreatments has been restricted to pretreatment with digester percolate, enzyme complexes and thermophilic bacteria (Mata-Alvarez et al., 2000). These methods bear the advantage that they are usually simple and do not require major capital investments. However, the reported increases in biogas yields are relatively low (up to 20%) sofar.

Mechanical disintegration and maceration has been applied to sewage sludge and to fibers contained in manure (Angelidaki and Ahring, 1999). As a rule of thumb, the smaller the fibers (<0.35 mm), the higher the gain in methane potential (up to 20% gain) of the macerated manure. However, the economic feasibility of the techniques was not addressed and can be questioned, seen the relatively low increase in biogas yield relative to the extra investment costs made. The same holds for purely chemical pretreatment methods, generally requiring high doses of acidic or alkaline chemicals and need for costly and unsustainable neutralization steps afterwards. Moreover, acidic pretreatment methods mostly lead to a considerable oxidation of the organic matter to CO_2, which is undesirable in terms of energy recovery and CO_2 emissions.

Many different physico-chemical methods have been explored to enhance the hydrolysis of particulate matter (mostly lignocellulose) as a prior step to the production of biogas, and in particular to the production of bio-ethanol from biomass. These methods can be roughly divided into purely thermal treatments or often referred to as thermal hydrolysis and thermo-chemical treatments, the latter involving the use of dilute acid (e.g. H_2SO_4) or alkaline (e.g. NaOH) addition in the presence or absence of a (oxidative) catalyst (e.g. H_2O_2, O_2). Mostly, temperatures equal or below 200°C and pressures varying from 3-40 bar are applied.

Thermal hydrolysis and steam explosion disruption are the most commonly studied pretreatments prior to biogas and bio-ethanol production (Schieder et al., 2000; Liu et al., 2002). Compared to other thermal treatments, these processes bear the advantage that they do not involve the use of chemicals and that heat recovery from steam is fairly simple. Beside a solubilisation effect, steam processes rely predominantly on a physical disruption of the fibers and higher temperatures (200-220°C typically) are applied than in oxidative thermal treatments, the latter mainly due to the absence of a catalyst. Therefore, these processes are reported to produce significantly higher amounts of fermentation inhibitors such as furan derivatives, which have been shown to be inhibitory to methanogens and in particular to yeast (Bjerre et al., 1996).

Wet oxidation involves the use of air or oxygen under elevated pressure and temperature (typically 0.5-22 bar, 150-200ºC) as a catalyst. The process is been applied in the fractionation of lignocellulosic biomass and also for the treatment of (toxic) wastewaters and sewage sludge (Kolackzkowski et al., 1999; Lendormi et al., 2001). Due to the catalytic action of oxygen, the applied reaction conditions (e.g. temperature, reaction time) are less severe compared to steam explosion processes or hydrothermal processing. Moreover, the presence of oxygen catalyzes a radical-mediated reaction that enhances the formation of low molecular weight organic acids (e.g. acetic acid, formic acid) and CO_2 from liberated sugars and lignin (Garrote et al., 1999). As a result, nutrients are also converted to their highest oxidation state (e.g. sulfur to sulfate, halogens to halides, phosphorous to phosphate) and are predominantly transferred to the aqueous phase forming inorganic salts and acids. At $T < 200$ºC, nitrogen compounds are largely transferred into ammonia while at higher temperatures, more oxidative species can be formed (N_2, NO_3^-, NO) (Kolackzkowski et al., 1999). Therefore, mild wet oxidation is a promising treatment relative to anaerobic digestion because it gives the opportunity to fractionate organic waste into sanitized cellulose rich solids and filtrate rich in solubilized hemicellulose, fatty acids and inorganic salts. Besides, the relatively low temperature (<200°C) does not demand for expensive corrosion-resistant alloys in wet oxidation.

Definition of Integrated AD process designs

Figure 1 shows a sequential anaerobic digestion approach for the conversion of organic waste into biogas by intermittent thermal treatment.

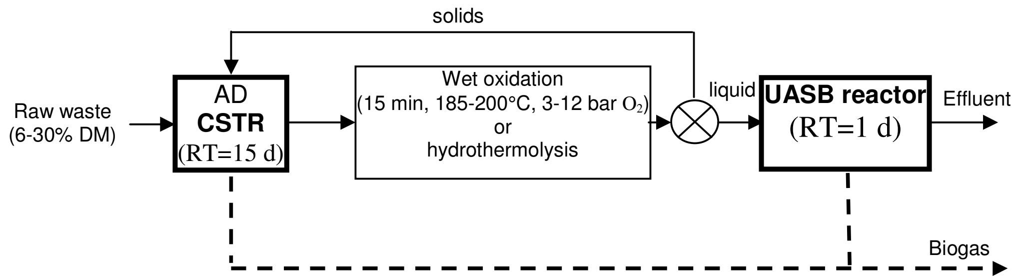

Fig. 1: Integrated anaerobic digestion of organic waste for enhanced biogas recovery and sanitation.

The feasibility of the presented AD process (Fig. 1) will evidently depend on the nature and composition of the raw waste. In particular, the most optimal wet oxidation conditions are determined by several parameters such as the degree of lignification of the fibers and the nutrient and salt content of the waste (submitted work). In this respect, it has recently been shown that oxidative lignin removal (to carboxylic acids mainly) is stimulated at more alkaline pH (7-11 units). Besides, alkaline conditions also largely prevent the production of fermentation inhibitors during wet oxidation. Therefore, the use of wet oxidation as an intermittent treatment bears the advantage that the first digestate has a high buffer capacity with a pH of typically 8-9 units. This approach allows the readily available organic matter to be converted into biogas and only the more recalcitrant organic material (mainly lignocellulose) to be subjected to wet oxidation or hydrothermolysis (no oxygen). The oxygen pressure has been shown to be a key parameter for the oxidation of lignin and is important with regard to lignin utilization during the second AD (submitted work). The solids after wet oxidation, which largely exist of cellulose, can be returned to the main digester for biogas conversion. The wet oxidation liquid will contain the majority of the nutrients and salts, solubilized hemicellulose (xylose), lignin degradation products (e.g. acids) and possible pollutants (e.g. di (2-ethylhexyl) phthalate (DEHP) from MSW). A UASB reactor could subsequently be employed to stabilize the liquid and to convert remaining carbon into biogas or the solids could be recycled to the first digester. The final effluent would be free of pathogens and rich in nutrients and organic salts, suitable for nutrient and salt recovery. The remaining solid fraction would largely consist of humus-like residual recalcitrant matter such as lignin residues and ash, containing considerably fewer carbohydrates compared to the solid fraction after composting.

Alternatively, the wet oxidation process could be applied as a pre-treatment to the raw waste. This option might be particularly attractive for woody waste (e.g. yard waste), as it is known that the anaerobic biodegradability of these materials is severely restricted.

Economical Considerations and Conclusions

Wet oxidation as a pre-treatment or intermittent treatment for the enhanced methane recovery from organic waste is a promising approach. Recent results show that 70-120% gain in specific biogas yield can be reached for raw organic waste and up to 38% gain for primarily digested waste relative to the original waste input.

From an economical point of view, wet oxidation as a pre-treatment is more beneficial for enhanced methane recovery from organic waste than intermittent treatment on primarily digested waste. In all cases, the required capital and operational costs (mainly compressed air/oxygen) for wet oxidation pre-treatment need to be weighed off against the extra gain in biogas production for existing biogas plants. The presented AD approach combined with wet oxidation can be made economically sound since 1) up to 120% increase in green electricity production can be obtained, 2) heat recovery can be realized and 3) process water necessary for wet oxidation can be recycled within the process.

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INTEGRATION OF BIOGAS TECHNOLOGY, ORGANIC FARMING AND ENERGY CROPS

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1. Biogas technology – the missing link in organic farming

Three folded emission reduction
Biogas technology not only contributes to a CO_2 neutral generation of energy in form of electricity and heat. Through the closed anaerobic process a further reduction of harmful greenhouse gases can be achieved: methane and nitrous oxide emissions from open manure storage are substantially reduced, mineral fertilizer savings can contribute directly to fossil fuel savings as 1 kg of mineral N-fertilizer needs the energy content of 2 kg crude oil for production.

Decentralized production of energy
When organic waste is stored under the absence of air a microbial degradation process is started, where biogas is deriving. The process of anaerobic digestion is running at its optimum at a temperature range of 25 to 38°C (mesophillic conditions), but also up to 55°C in the thermophillic range - however more and more unstable with rising temperatures. The produced gas contains 55 to 70% methane, 30 to 45% carbon dioxide and trace gases. One cubic meter of biogas has the energy equivalent of 0.6 l of fuel oil or 6.36 kW/h. Depending on the efficiency of the cogeneration plant up to 2 kW/h of electricity and almost 4 kWh of heat can be produced. When the biogas has undergone an upgrading process the methane can be fed into the public gas grid as "green gas"

Recycling of organic matter and nutrients
Organic residues from the farms own operation and from agro- and food production industry are supplementing the basic substrates liquid and solid manure. Gas production and nutrient recycling can be optimised when energy crops are utilized. The operation of a biogas plant enables efficient nutrient management and therefore enhances the reduction of groundwater pollution. Ecological sanitation of household wastewater and human waste (faeces, urine) can be achieved through treatment and hygiensation in a biogas plant. This means that the loop for nutrient and organic matter recycling can be closed. Such an enterprise is based on the pattern of natural cycles in which all waste is reusable. Through biogas technology organic residues become a valuable raw material.

Strengthening of rural economy and social structures

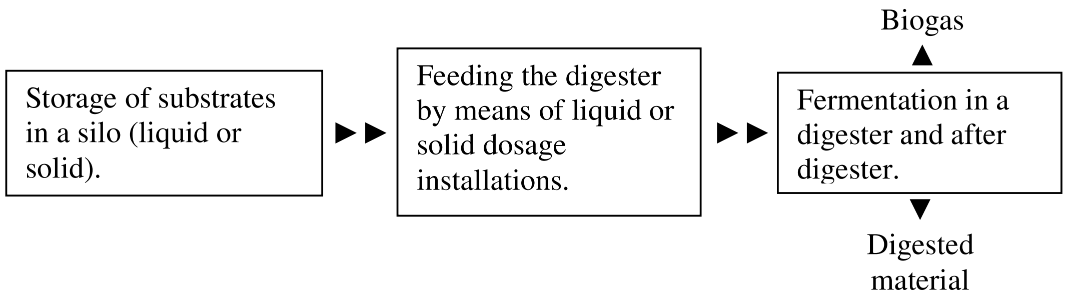
The dissemination of biogas technology will stimulate the local economy, especially in rural areas. Small and medium sized businesses and agricultural machinery dealers can develop a new market with the manufacture, maintenance and sale of biogas units. Farmers who use their biogas plants for co digestion of organic residues from households and communities acquire a new role in housing policy planning, while boosting their own economic position. The exchange of codes of good practice amongst operators of biogas plants can improve the social and economic conditions in rural communities.

2. Statements for Development:

- The size of biogas plants in Germany is increasing to bigger dimensions.
- In the pioneering phase of biogas technology half of the biogas plants were installed on organic farms mainly for improving of the fertilizer, even the main organic farming associations were against using degassed manure.
- Nowadays investors in biogas technology are less environment orientated and more profit orientated, therefore economical energy production is very much in the foreground.
- How to guaranty the requested amount of feeding material for the biogas plant is an essential criterion already in planning phase.
- There is not possibility for organic farmers to utilize organic waste from outside the farms nutrient cycle for energy production in biogas plants. Even so there is already a serious competition on organic waste, which makes the availability very difficult with falling gate fees.
- Research work has been done on different energy crops and their gas yields since 1993 and increasingly used in practical biogas plants since 1998.
- The technology developments are mainly taking place in the digester intake technology of solid and liquid energy crops.
- Liquid manure is a cheap substrate and stabilizer during the fermentation process, but looses importance for future biogas plants.
- In order to increase energy output and fertilizer production on organic farms only energy crops from the farms own cycle can be used.
- Legal, political and economical frame conditions have an increasing impact on the commercial decision-making process, therefore the only viable way is to stabilize the investment conditions.

3. Fermentation of agricultural energy crops

3.1. Digestion process



3.2. Parameters of agricultural energy crops

Item	**Maize Silage**	**Grass Silage**	**Grain**
Dry solid content	30 – 35 %	35 – 38 %	88 %
oDS content	90 – 97 %	85 – 89 %	90 – 98 %
Methane content	55 – 58 %	57 – 59 %	54 – 55 %
Gas yield	0,6 – 0,73 m^3/kg oDS	0,5 – 0,6 m^3/kg oDS	0,7 – 0,8 m^3/kg oDS
Retention time	50 days	50 days	20 – 30 days
Degradability	60 %	55 %	70 – 80 %
Problems	Floating crusts	Floating crusts, dirt	Low methane content
Specific weight	650 kg/m^3	650 kg/m^3	700 kg/m^3

4. Comparison of organic waste and energy crops

4.1. General requirements:

Organic waste	**Energy crops**
Technique: Dry fermentation, one or multi stage wet fermentation Indoor reception of substrate	Land needed for feedstock cultivation or contracts for substrate delivery Mostly one phase wet fermentation
Thermal treatment in order to meet hygiene standards	Simple plant technique (no thermal treatment required)
Direct/indirect process control	Inter-storage of fermented substrate in liquid manure tanks
Analysis of heavy metal contents	Application on fields using conventional manure spreading techniques
Preparation of the fermentation substrate regarding disrupting material in a pulper	Use of set aside areas for energy production
Aerobic post-treatment / composting	
Membership in quality association	
Only 200 tons dry matter substrate spreading per hectare within 3 years	

4.2 Comparison of economical aspects:

Organic waste	**Energy crops**
Generates income through waste disposal fees and sale of energy	Expensive cultivation of special plants at 6-8 Cents per kWh
Higher technical input, higher investment costs	Silo storage space required
Complicated approval process	Competition with food production
No additional subsidies	Economical dependency from set aside premium payment from EU
Restricted spreading conditions	Higher feed-in tariffs needed for smaller installations
	No problems with application of digestate
	Concept of closed loop – nutrients recycled
	Simple approval conditions
	Plans for crop rotation for high yield of biogas production

4.3. Economy of Biogas plant with 300 LU

Substrates	Liquid manure [1]	Liquid manure + maize silage [2]	Liquid manure + kitchen waste [3]
Production			
Gas yield (m3/year)	186 150	367 950	502 950
Electricity production (kWh/year)	429 904	924 741	1 264 027
Heat production = (net, kWh/year)	399 292	789 253	899 023
Costs			
Invest: (digester, manure storage, Manure equipment, CHP, other (€)	274 926	374 210	557 920
Federal subsidy (€)	15000	---	---
Net investment (€)	**259 926**	**374 210**	**557 920**
Payback period 15 years (€/year)	17 328	24 947	37 195
Interest, 4,2% of ½ net investment (€/year)	5 458	7 858	11 716
Maintenance, operating costs, incl. CHP and dual fuel costs, (€/year)	16 319	31 252	43 414
Manpower (€/year)	2 500	4 400	13 800
Corn on set aside land (€/year)		18 000	
Total costs per year (€)	**41 605**	**86 457**	**106 125**
Benefits			
Electricity sale (€/year)	42 990	92 474	126 402
Heat substitute (6000 l oil, 40 c)	2 400	2 400	2 400
Gate fee for waste treatment (30 €/t kitchen waste)			43 200
Set aside premium for maize (€/year)		6 660	
Fertilizer value (€/year)	3 300	4 000	5 000
Benefits total (€/year)	**48 690**	**95 734**	**177 002**
Profit (€/year)	**7 085**	**9 277**	**70 877**

1) Digestion of farm liquid manure, digester volume: 900 m3, generator capacity 56 kWel.
2) Digestion of farm liquid manure, 7 ha maize from set aside land (202 m3 Biogas/t maize) digester volume: 1000 m3, additional storage 450 m3, generator capacity 110 kWel.
3) Digestion of farm liquid manure, 1440 t kitchen waste (220 m3 Biogas/t per year) digester volume: 1200 m3, additional storage 1440 m3, generator capacity 150 kWel.

The above calculation is based on the practical experiences of several biogas plants in the different regions in Germany. Through the intensive exchange of experiences it was possible to make these calculations. The experiences show that the viability of biogas plants is only reached through cofermentation, but the limit of that market is probably almost reached by over1600 existing plants. Increasing the amount of biogas plants the gate fees of digestible organic waste would significantly drop and new laws (e.g. biowaste ordinance) make the financial return even smaller.

As a result a further dissemination of agricultural biogas plants can only take place, when the farms own residues (manure) and biomass (maize, rape, fodder beets, grass, intermediate crops) are utilised for digestion. This is the basis for the following calculations. Under the frame conditions of today biogas plants only have a sufficient return, when there is a high demand of thermal and electricity as well as cofermentation is being done. Without cofermentation the viability of a biogas plant can only be reached, when the remuneration according to the feed in law is risen to higher level. The following calculations are also showing, that the operator of a biogas plant without the income of a gate fee for cofermentation can only reach a sufficient level of income, if a lot of the building work is done by himself and if the farm operation is paying the fixed costs for the production of biomass from the field.

5. Summary

- ✓ Organic waste requires specially constructed and approved biogas installations.
- ✓ Strong limitations on application of fermented residues on agricultural land, if derived from organic waste.
- ✓ In order to achieve an economical operation result, an elimination fee for organic waste must be introduced/paid.
- ✓ High production costs for cultivation of energy crops.
- ✓ "Closed loop economy" if nutrients are recycled and applied again on agricultural fields.
- ✓ Demand for higher feed-in tariffs for agricultural substrates.
- ✓ If energy crops are used, state subsidies for building and set aside area are generally available.

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SOCIO-ECONOMIC ASPECTS OF AGRICULTURAL BIOGAS PRODUCTION

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Introduction

Socio-economic considerations of renewable energy production have become a trendy new standard, particularly in the field of biomass utilisation. No other renewable energy than biomass is so closely linked with mankind, nature and therefore with the climate and offers a wide playfield for socio-economic discussions. Energy crop has at the same time a high potential to create new jobs and introduces high-tech applications into rural areas thus offering options to keep trained people in rural villages.

The field of socio-economy is not new. It has often been used for agronomic studies. As long as 15 years back Wellinger et al. [1] have published a detailed survey on the financial and social constraints of anaerobic digestion (AD). Today, the method is standardized and hence accessible for modelling. Traditionally, socio-economic implications of biomass production and utilisation are measured in terms of economic indices such as employment and monetary gains, but in effect the analysis relates to a far higher number of topics including lifestyle, cultural and environmental aspects. The socio-economic group within IEA Biomass talks about "techno-ecolo-socio-economy" and includes social aspects, macro levels (security of supply, regional development, etc.), supply side (productivity, regional growth) and demand side (employment, income and wealth) [2]. And yet the factors to be considered are still growing with the continuing pollution of the world. Today, we have to include (ground-) water protection and aspects like CO_2 sinks or CO_2 markets, etc.

The driver behind the growing European interest in social integration of energy technologies is the Kyoto protocol, the decision of the Commission to promote bioenergy and to introduce the CO_2 trade by 2005. According to the white paper, biomass should roughly cover 74% of the renewable energy production.

A fair amount of work has been done over the last five years allowing to introduce socio-economy as a descriptive element for a project decisions. However, the approach to use socio-economy as a tool to predict or even guide a development of a technology like agricultural biogas production is still a little bit like reading the cards or the coffee-grounds. Economy has one clear goal for years already that is to make money. Society on the other hand changes its goals or priorities increasingly fast and consequently induces changes of the political framework. Agricultural biogas has a young history of some sixty years. Within this short period of time the social driver to produce biogas has changed several times [1]. If we really want to influence the development, we have to take those instable factors into consideration.

Factors influencing the biogas dissemination

The major factors influencing the biogas development in Europe may be subsumed in the following fields:

- Society.
- Politics.
- Energy.
- Environment.
- Climate.
- Economy.

Influence by society

By far the most important factor stimulating or hindering the promotion of renewable energy is the society. Unfortunately its priorities are changing quite frequently in function of the economic situation, weather extremes (green house effect), accidents of oil tankers, etc. and before all in function of other worldwide developments like war, refugee movements, health cost, education (Pisa study), etc. Over the recent years the topics of energy and environment have lost their top rankings in the charts of important preoccupations they had during the economic boom years in the nineties. But there are still enough events broadly covered by the press like tanker accidents or storms (Lothar or El Niño) to maintain in the population a certain interest in the climate and ultimately in the renewables. There is a good chance that after a scientific interpretation of the 2003 summer heat period peoples opinion will even more strongly switch back to the support of the renewable energies.

In Denmark or in Switzerland politicians have tried to use the decreasing interest in renewable energies to cut them out of their political agenda and to claim the savings achieved as an economic success. There is a good chance that they have misinterpreted the situation. A survey in Switzerland of the second half of August 2003 which was done in the framework of wiping out the renewable energy programme in Switzerland has shown a distinctive difference between the parties opinions and that of the parties' voters [3] (Table 1).

At first, the Swiss government wanted to fully stop the energy and climate programme called "Energy Swiss". Finally they decided to mention it with one third of the money which means that it die gradually.

The population's opinion is obviously quite different. They ranked savings in the Energy Swiss budget at the ninth place only. In fact, 39.6% opted for an increase of the budget and only 8.6% for a decrease (Table 1). This was the fourth best ranking after education, social security and day care centres.

Table 1. Debate on economies in the state budget: Top rankings (ranking 1= highest savings)

Budget position	Parliament's Ranking	Population	
		Ranking	% for a change[1)]
Immigration	1	3	- 34.6 + 10.4
Support for homes	2	7	- 14.1 + 21.3
Day care centres for children	3	11	- 8.1 + 41.3
Development aid	4	6	- 17.0 + 24.3
Renewable energy Climate programmes	5 (64% reduction)	10	- 8.6 + 39.6
Military	6	1	- 57.4 + 5.9
Support for alpine areas	9	9	- 9.3 + 29.4

1) The percentage indicates how many % of the population is opting for an increase (+) or decrease (-) of the respective budget position.

Influence of politics

During the seventies and later during the nineties of last century the political opinion of the different parties remained fairly stable. Basically all where convinced that the renewable energies had to be supported because within a few generations there would be no other energy sources available. The few Million Euros were willingly spent because the stock market was booming and the money available for renewables was still factors of ten lower than the money spent for nuclear power. "Let them do research then they don't do any harm" was the generally accepted opinion of the right wing parties.

But all the sudden the research yielded usable products at reasonable cost and the dominance of environmentally sound politicians throughout Europe led to the introduction of dissemination programs. This was the kick off for a European programme of the commission. In the White Paper they set the target that renewable energy should cover 12% of the total energy consumption by the year 2010. Biomass should cover 74% thereof.

Unfortunately, the world market undergoes some difficult times. It is therefore no surprise that in countries where the right wing parties gained power like in Denmark or in Switzerland, the renewable energy and environmental programmes have been cut or will soon be. Politicians would claim that they saved tax money and would hope that the climate will not strike back until the next elections, i.e. remain stable. Basically they do not care about the environment because they still think that climate change is a fairy tale.

Thanks to the re-election of the socialist party, at least Germany continues strongly to support the renewable energies despite the very critical financial situation. The German government is in the comfortable situation that even the conservative farmers including their union are strongly supporting the renewable energy programme. Their pressure was so strong and the wave of building biogas plants and wood stoves so high that even the Christian Democratic party (CDU) promised during the 2002 campaign to continue with the supportive programme if ever the were elected. This is a very important observation and has to be kept in mind for future developments.

There is one thing for sure: The dissemination of renewable energy plants is strictly proportional to the subsidies paid which is proven by all European countries. In that sense the opinion of and the measures taken by the politicians is extremely important. Jungmeier and Spitzer [4] have shown that the cost of greenhouse reduction with Bioenergy is in the order of 13 €/t CO_2 to 330 €/t CO_2. This is far higher than the actual prices paid for CO_2-trading in the order of 1.5 to 2.5 € per ton. Under very optimistic assumptions trade prices might rise up to 8 € per ton. Without political support, even with all optimistic premises the target of 12% renewable energies is difficult to reach [5]. We definitively need political support, i.e. laws and regulations.

Influence of environment and climate

Until a few years back experts believed that energy will be the limiting factor in the development of a higher social standard throughout the world. Nowadays it is generally accepted that in the developing world water will be the most limiting good endangering peoples lives and creating wars. Dryness and diminishing water tables become more severe every year. Not only quantity is a problem but even more though quality. Most of the ground water is polluted due to anthropogenic (industrial) activities. The dryness is enhanced through the continuing rise of the temperature.

Hence, climate does not fulfil the hopes of the politicians. The world's surface is heated up much faster than scientists have expected. The worldwide average increase over the last century was 0.6°C, in Switzerland even 1.6°C. The ten year mean values give an impressive reflection of the current situation [6]. From 1991 to 2000 there were 22 months with elevated temperatures. Whether this increase is due to the green house effect (that's what scientists tell) or for other unknown reasons is not of relevance. Mankind and before all, politicians can not wait to react until full proof is given, it's definitively too late by then. The consequences of the temperature shift are severe by just looking at this year's weather data (the hurricane season has not fully started yet):

- Heat wave in Europe (42°C in Lisbon, 41°C in Switzerland)
- Heat wave in India (48°C) followed by a heavy monsoon with inundations
- Extreme heat in China (42°C in Shanghai)
- Heat wave in the Emirates (45°C) with sand storms
- Wood fires in Europe (Portugal, Spain, France, Switzerland and Italy), Canada, USA
- Thawing of perma frost
- Massive fish dying due to high water temperature in Switzerland
- Extremely heavy snow storms in New Zealand
- Cold wave in South Africa (with minus 9°C; 12° below average wintertemp.)

Effect of socio-economic parameters on biogas production

Having discussed a number of parameter, the question has to be specified: How do these factors influence the dissemination of biogas plants? Table 2 lists a few of the major factors and tries to give a measure of importance on the biogas development.

Table 2. Factors influencing agricultural biogas production in Europe

Influencing factor	**Rating**
Greenhouse effect	+++
CO_2-Trade	++
Joint implementation projects (Kyoto)	- -
Shift to right wing parties (new economy)	- - -
New EU-laws and regulations	+++
Increasing food overproduction	++
Willingness to pay higher electricity prices	- -
Production cost of biogas	- -

Conclusions

The promotional and hindering effects of the parameters compiled in Table 2 on biogas dissemination are more or less in balance. In other words, there is a risk that without intensive lobbying the actual situation will not change much. Renewable energies will continue to increase slowly but will not reach the goal set by the Commission. There will be an increasing competition between the different renewable energies, the technology with the lowest production prices will predominate. There are clear advantages for hydro- and windpower, PV will be the looser. Biogas will have a fair chance however, production cost should be reduced.

How can we improve the situation? The development can be strongly influenced by existing associations and international working groups. They can act conjointly on three levels:

Politics: The energy production from biomass has to become a standard technology like nuclear power, i.e. a (even small) market has to be established as soon as possible. Nuclear power is an expensive way to produce electricity beside all the environmental problems. None the less, it is so well established that even conservative politicians do not ask for comparable cost anymore.

Germany can serve as a leading country. But "one country is no country". The good example has to be spread out to other countries which are close to optimal solutions. For example the U.K. could intensify its encouragement followed by Sweden and Hungary. The latter is important because it's huge surface of set aside land has a tremendous potential for energy crop. Biomass associations and working groups should coordinate their lobbying and focus on the proposed countries or others which are to be specified. The break through has to come fast as long as the commission is still convinced about its goals set.

It is important that there is no competition between the different uses of biomass (incineration, gasification, biogas) and even more in between the different biogas processes. There should be a different support for those plants which are accepting waste materials and those digesting agricultural crop only. The Austrian ElWOG might serve as an example [7] where co-digestion of industrial or communal waste reduces the feed-in price by 25%. Independent of the input material, the quality of the compost should be equally high if we don't want to face the sewage sludge problem in the near future.

Population: The public opinion is very important but at the same time the most difficult to influence. The opinions are changing constantly under the impression of the daily news. There is no network thinking. It is a one reason, one reaction behaviour for example: BSE leads to an increase of chicken meat consumption; dioxin in chicken leads to an increased pig meat consumption; a virus epidemic in Holland drives to fish; etc.

It is extremely important to stay out of the trap by avoiding ecological sins, which is more difficult with the increasing number of biogas farmers. Early biogas producers where most often organic farmer. With increasing ecological viability there are all sorts of farmers with "Euro signs in their eyes". So far we were lucky. Only one case of polluted industrial waste application in Germany became public which is still tolerated.

Verbally the large public is supportive for renewable energy. However, when it comes to money the message is simple: Renewable energy yes, but not at a higher price than fossil solutions.

In EU countries that use quotas of renewable electricity such as Germany and Austria, the high feed-in prices are sustainable over a long period of time. In other countries subsidies to support electricity from biogas might be whittled down to nothing at any time. There is only one long term solution: A real market has to be created. Associations together with power companies have to convince people to by labelled green electricity.

We therefore have to be open for unconventional solutions. In Switzerland for example, the second largest retail store has pushed up products from organic farming from somewhere below 2% up to over 8% of their food sale thanks to clever marketing. Since summer 2003 they started selling green power addressing the same target group as for the organic products.

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IMPORTANT SOCIO-ECONOMIC ELEMENTS OF CENTRALISED CO-DIGESTION IN DENMARK

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Introduction

The development of biogas technology in Denmark has been widely encouraged by the government over the last 15 years. The overall reasons for government concern is the increasing awareness that centralised biogas plants contribute to solve a range of problems in the fields of energy, agriculture and environment. To achieve an evaluation of new centralised biogas plants equipped with best-known technology, Risø National Laboratory and the Danish Research Institute of Food Economics, c/o University of South Denmark, have carried out a thorough socio-economic analysis for the Danish Energy Authority.

Externalities

Conventional economic analyses and corporate investment analyses of projects do not take into account so-called externalities. Externalities or external effects do neither imply expense nor income elements for the corporate or private investor. However, externalities are important economic effects seen from the point of view of the society.

The socio-economic analysis looks at the project or activity in question from the point of view of the society in its entirety. A project may inflict burdens or contribute gains for the society relative to the reference activity, which must be taken into account when evaluating a project from the point of view of the society. Many actors and sectors in the economy may be influenced from the project.

Biogas projects have implications not only in the agricultural sector, but in the industrial and energy sectors as well, and among the environmental consequences, mitigation of pollution, green house gas (GHG) emission reduction and reduced eutrophication of ground water etc. are important external effects.

Approach

The present socio-economic analysis is carried out at different levels, where the levels in succession take into account still further of the external effects related to the biogas scheme. Four levels have been chosen for the analysis. Termed Result 0,1,2,3 these differ according to which socio-economic elements and externalities that are included in the analysis. Analyses at higher levels include all effects from lower levels. This hierarchy is shown in Table 1 below.

Table 1 Socio-economic aspects included split on levels of the analysis.

Socio-economic analysis of biogas plants				
Level of analysis: / Aspects included:	Result 0	Result 1	Result 2	Result 3
Energy and resources:				
Value of energy production (biogas, electricity)	R0	R0	R0	R0
Capacity savings related to the natural gas grid	R0	R0	R0	R0
Environment				
Value of GHG reduction (CO_2, CH_4, N_2O-reduction)			R2	R2
Savings related to organic waste treatment		R1	R1	R1
Value of reduced N-eutrophication of ground water:			R2	R2
Agriculture				
Storage, handling and distribution of liquid manure:		R1	R1	R1
Value of improved manurial value (NPK)		R1	R1	R1
Value of reduced obnoxious smells				R3
Investments and O&M-costs:				
Investments. Biogas Plant	R0	R0	R0	R0
O&M of Biogas Plant , incl. CHP unit for process heat	R0	R0	R0	R0
Investments and O&M for liquid manure transport	R0	R0	R0	R0

As seen from Table 1 "Result 0" do not include externalities in the socio-economic analysis, and benefits concern the energy production from the plant only. Analyses at the higher levels, however, take externalities into account, and further cost and benefit elements enter the analysis. Thus, the socio-economic levels of analysis are characterised by:

- *Result 0*: Energy production (biogas and electricity) from biogas plants. Externalities are not included.
- *Result 1*: Benefits in agriculture and industry are added to the analysis.
- *Result 2*: Environmental externalities concerning GHG emission (CO_2, CH_4, N_2O-emission) and N-eutrophication of ground water are furthermore included.
- *Result 3*: A monetised value of reduced obnoxious smells from digested biomass is moreover included in the socio-economic analysis.

The aspects included in Table 1 are quantified for the analysis. Considerable effort has been put into the assessment of biogas scheme externalities (see ref.1). However, due to lack of data important further external effects have not been quantified and monetised for the analysis. Among such aspects can be mentioned: Increased flexibility at farms associated to biogas plants; effect for the security of energy supplies; veterinary aspects; employment effects and effects for the trades and industries.

Monetised externalities

Expressed in specific units (EUR/ton of biomass) monetised externalities included in the analysis are shown in table 2. The results shown apply for a biogas plant outlined for a treatment capacity of 550 ton/day.

Table 2 Monetised externalities.

Monetised externalities:	**Results based on biogas plant:**	
Socio-economic value per ton biomass	Biogas plant size: 550ton/day	(20% waste)
Agriculture	**Monetised**	
Storage, handling and distribution of liquid manure:		
Storage savings for liquid manure	**0.13**	EUR/ton liquid manure
Transport savings in agriculture	**0.07**	EUR/ton liquid manure
Value of improved manurial value (NPK)	**0.73**	EUR/ton degassed
Value of reduced obnoxious smells	**0.67**	EUR/ton liquid manure
Industry		
Savings related to organic waste treatment	**16.82**	EUR/ton org. waste
Environment		
Value of GHG reduction (CO_2, CH_4, N_2O-reduction)	**3.01**	EUR/ton degassed
Value of reduced N-eutrophication of ground water:	**0.39**	EUR/ton degassed
Liquid manure	0.37	EUR/ton liquid manure
Org. waste spread on farm land in reference case	1.64	EUR/ton org. waste
Org. waste not spread on farm land in reference ca	-3.03	EUR/ton org. waste

A quantification for the 550 ton/day biogas plant of the monetised externalities is shown below in Table 3. The table shows the annual costs and benefits taken into account at the four levels of the socio-economic analysis. A socio-economic rate of calculation of 6% p.a. has been used, and the analysis covers the period 2001-2020. Values shown are in year 2000 price level.

Table 3 Annual costs and benefits. Results based on biogas plant outlined for treatment of 550 tonnes per day.

Socio-economic results	**Results based on biogas plant:**			
Annual costs and benefits	Biogas plant size: 550ton/day			(20% waste)
	Result 0	**Result 1**	**Result 2**	**Result 3**
Costs (levellised annuity)		mio.EUR/year		
Investments, operation and maintenance:	**1.481**	**1.481**	**1.481**	**1.481**
Benefits (levellised annuity)		mio.EUR/year		
Energy production:				
Biogas sales	0.526	0.526	0.526	0.526
Electricity sales	0.061	0.061	0.061	0.061
Agriculture:				
Storage, handling and distribution of liquid manure		0.032	0.032	0.032
Value of improved manurial value (NPK)		0.186	0.186	0.186
Value of reduced obnoxious smells				0.097
Industry:				
Savings related to organic waste treatment		0.675	0.675	0.675
Environment:				
Value of GHG reduction (CO2, CH4, N2O-reduction)			0.605	0.605
Value of reduced N-eutrophication of ground water:			0.079	0.079
Sum:	**0.588**	**1.481**	**2.165**	**2.262**
	Result 0	**Result 1**	**Result 2**	**Result 3**
		mio.EUR/year		
Surplus as annuity: Benefits - costs	**-0.893**	**0.000**	**0.684**	**0.781**

It is seen from Table 3 that the biogas scheme is not attractive under Result 0, where it has been assumed that benefits only concern energy production from the plant. Result 0 shows a socio-economic deficit of about 0.89mio. €/year. However, taking into account agricultural benefits, and industry cost savings in waste disposal, Result 1 shows socio-economic break-even.

If the described environmental benefits (GHG emission reduction and reduced N-eutrophication of ground water) furthermore are included, result 2 shows a surplus of about 0.68mio. €/year. And including the value assumed for reduced obnoxious smells from degassed liquid manure on fields relative to the reference the socio-economic surplus adds up to about 0.78mio. €/year. Thus from an extended socio-economic point of view, under Result 3 assumptions, the biogas scheme is highly attractive.

GHG emission reduction costs

The relevant Green House Gasses (GHGs) affected by biogas plants are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). The GWP_{100} (Global Warming Potential) or the strength of CH_4 as an GHG in the atmosphere is 21 times higher than the same amount (in weight) of CO_2, and for N_2O this relative strength is 310 times the effect of CO_2. The detailed analyses show that CO_2, CH_4 and N_2O contribute about 44%, 48% and 8% respectively to the total GHG reduction achieved for centralised biogas plants.

In Table 3 above GHG emission reduction has been assigned the external value of 33.6 €/ton CO_2 equivalent reduced (or 250 DKK/ ton CO_2 equivalent). The Danish Energy Authority has used such value in a recent study. Below the analysis is reversed, and break-even GHG reduction costs achievable are calculated for centralised biogas schemes of best-known technology.

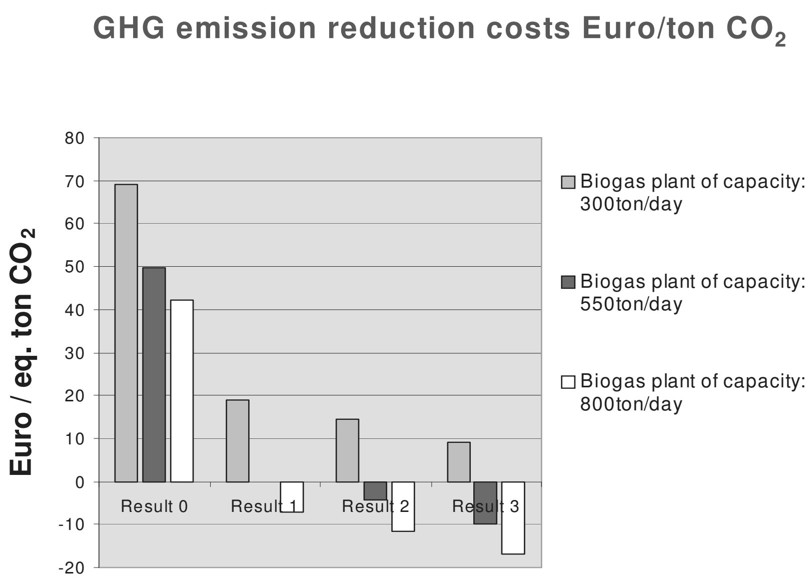

Figure 1 Socio-economic GHG reduction cost achievable from biogas plants outlined for treatment capacities of 300, 550 and 800 tonnes per day.

In Figure 1. the equivalent CO_2 reduction costs are presented for three biogas schemes. Results of the socio-economic analysis expressed by this key-number allow decision-makers to interpret results based on diverse CO_2 reduction cost aims. To illustrate economies of scale regarding the size of plants, the figure presents equivalent CO_2 reduction costs achievable via biogas plants with treatment capacities of 300, 550 and 800 tonnes biomass per day.

From Figure 1 it is seen that GHG reduction costs based on Result 0 assumptions are in the order of magnitude of 50 €/ton CO_2 equivalent. The economy of scale shows gains for larger plants, indicating that the increased transport costs and transport fuel consumption for the larger plants are counterbalanced by the overall benefits.

Result 1, 2 and 3 show socio-economic GHG reduction costs below zero. Thus showing, that larger biogas projects may contribute important GHG reduction while concurrently generate considerable socio-economic gains.

Main conclusions

The main conclusions of the socio-economic analysis of centralised biogas plant are:

- Based on Result 0 assumptions, none of the plants are attractive. Thus, the socio-economic value of the energy production, covering a 20year period, can not justify the deployment of biogas plants.
- However, based on Result 1 assumptions, where agricultural benefits and benefits in industry concerning treatment of organic waste are included in the analysis, this picture changes, and in particular larger plants are favourable for the society at large.
- If furthermore the benefits from environmental externalities are taken into account (Results 2 and 3) the utilisation of biogas plants in the configurations considered becomes very attractive from the socio-economic point of view.

A further result is, that admixture of organic waste from industry is very important both for the corporate economy and for the socio-economic result. For the socio-economic result, admixture of organic waste contribute important combined benefits concerning e.g. increased production of biogas and income hereof, savings related to organic waste treatment, improved manurial value (NPK) and increased CO_2 reduction.

As mentioned already, a number of aspects relevant for the socio-economic analysis have not been included in the analysis, due to lack of data. These aspects would mainly contribute positive effects for the socio-economic analysis, however some negative veterinary effects may include socio-economic cost elements.

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THE PRESENT AND FUTURE OF BIOGAS IN EUROPE

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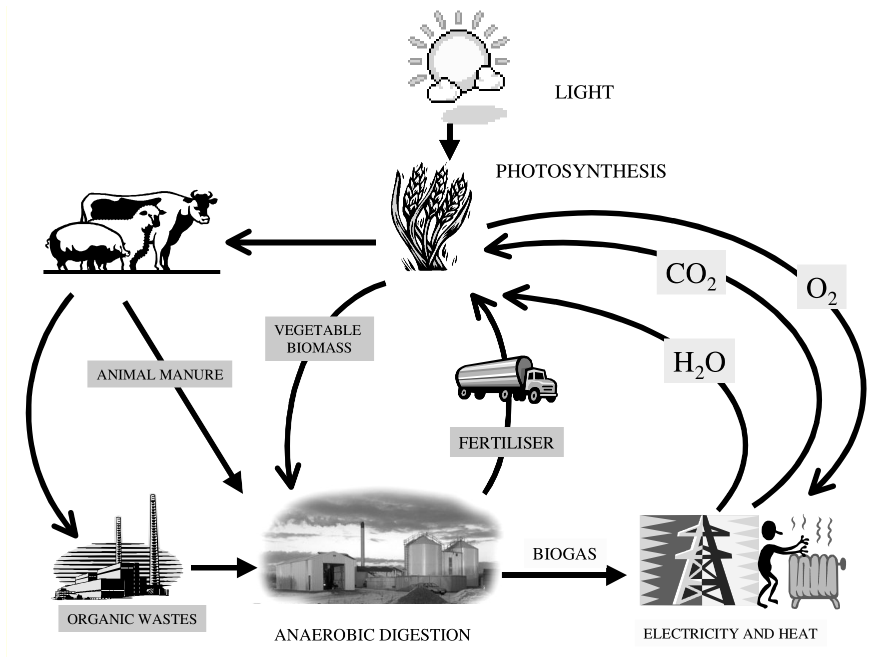
The accomplishment of the goals of the Kyoto protocol and the EU directives concerning nutrient management, human and animal health and food safety as well as the overall pollution prevention issues increasingly require a sustainable agricultural sector. Pre- and post treatment technologies for animal manure, combined with anaerobic co-digestion of biowaste play an increasing important role.

Wet organic waste streams have a constant pollution potential and a negative impact on water environment all over the world. To prevent leaching of nutrients and organic matter directly or indirectly to natural water environment it is necessary to close the chains from production to utilisation and recycling. This is also the case of biomass based renewable energy systems and the aim is to diminish the environmental pressures to the lowest obtainable.

Integrated anaerobic digestion – biomass energy processing plants contains some of the most promising technology solutions for all kinds of biomass recourse and waste streams. There are still many challenges to be solved, but biogas production and utilisation are on the move in a quite promising direction, which contains sustainable solutions for lowering air and water pollution pressures from the societies on the natural environment. Technology for balancing from by-products.



B.H. Jacobsen and K. Hjort-Gregersen Figure 1 Schematic representation of the sustainable cycle of anaerobic co-digestion of animal manure and organic wastes.

Biogas production potentials, feedstocks and biomass resources:
Biogas can be produced from nearly all kind of biological feedstocks originating from organic waste streams from the entire society. In order to deal with these kind of feedstock strict precautions and quality control are needed if the final sludge, fibres and nutrients are going back to the food chain via the cropping systems at farmland. In this category are as well wastewater treatment plant sludge and other grey wastes, with restrictions and banning of utilisation on farmland. In the future there will be a split between complete treatment with or without recycling of nutrients and other products.

Anaerobic co-digestion of manure and organic waste from industry is very important both for the corporate economy of the biogas plants and for the socio-economic result. For the socio-economic result, admixture of organic waste brings important combined benefits concerning e.g. increased production of biogas and energy sales, savings related to organic waste treatment, improved fertiliser value (NPK) and increased CO_2 reduction (L.H. Nielsen 2002).

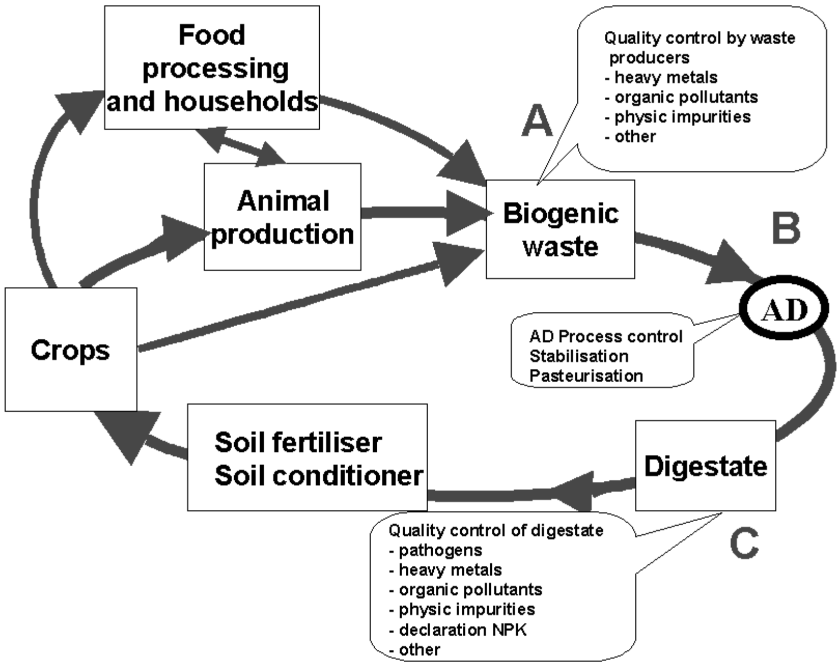


Figure 1. Schematic representation of the closed cycle of anaerobic digestion of biogenic waste and the three main steps (A, B and C) of the quality management of digestate. (Source: Al Seadi, 2000)

The major source of feedstock originates from the primary agricultural sectors. Until now the largest resource have been animal manure and slurries from animal production units, mainly cattle and pig farms and at some level various manure types from poultry, fish, fur and other animal production. In Europe there are produced more than 1000 mill. tons per year of this kind of feedstock. If untreated or managed poorly at the farm level, these feedstock are regarded as a major source of pollution and environmental pressure.

Table 1: Status of digestible biomass in the 15 EU-countries.

	Cattle manure	Pig manure	Total manure	Population (humans)	Municipal waste generation		Sewage sludge	Industrial org. waste
	(1993)	(1993)	(1993)	(1993)	Total waste (450kg/capita)	Org. waste (30% of total)	(1990)	Digestible <35%DM (100 kg/cap)*
	mill. t	mill. t	mill. t	mill.	mill. T	mill. t	mill. t	mill. t
Austria	25	8	32	7,7	3,5	1,0	**2,3	0,8
Belgium	35	14	49	9,9	4,5	1,3	0,7	1,0
Denmark	22	22	44	5,1	2,3	0,7	1,3	0,5
Finland	14	3	17	***5,1	***3,1	0,7	0,1	0,5
France	211	26	238	56,5	25,5	7,6	0,6	5,7
Germany	167	51	218	62,7	28,2	8,5	1,8	6,3
Greece	6	3	9	10,0	4,7	1,4	-	1,0
Ireland	66	3	69	3,5	1,6	0,5	0,6	0,4
Italy	80	15	95	57,6	25,9	7,8	**3,4	5,8
Luxembourg	2	0,2	2	0,4	0,2	0,02	0,02	0,04
Netherlands	48	28	77	14,9	6,7	2,0	0,3	1,5
Portugal	14	6	20	10,3	***3,4	1,0	-	1,0
Spain	53	37	89	38,9	17,5	5,3	10,0	3,9
Sweden	19	5	24	8,6	3,9	1,2	0,2	0,9
U. Kingdom	125	16	141	57,3	25,8	7,7	1,0	5,7
Total EU	**887**	**237**	**1124**	**348,5**	**156,8**	**46,9**	**22,32**	**35,04**

*Estimated figures, based on fixed data from Denmark, Finland and the Netherlands, ** 1994 data, *** 1996 data. Source: Holm-Nilsen, J.B. & Al Seadi, T. (1997): The Future of Biogas in Europe. Altener Programme, Final Report Phase II.

Energy crops are considered an AD feedstock with a lot of potential, coming on the agenda in this decade. We are talking here about grain crops, grass crops, raps and other crops. The land resource are in a slightly movement towards energy production due to EU CAP reform and the WTOs negotiations effect on price levels for food production worldwide. Recently, EU has supported energy crops with a slight higher hectare support level that grain production, stimulating the production of green electricity in specific European countries and making biogas production from energy crops a new possibility. The leading countries in this area are Sweden, Germany and Austria. Crop based biomasses are available in all countries as by-products from primary food- and feed production and form environmental cropping systems for the management of the natural conservation areas.

Biogas upgrading and utilisation

Biogas can be utilized by various ways, according to different national policies and options. Due to different taxation, prizing- and support systems there exists different development routes in European countries. The liberalisation of the energy market and more fee trade of energy commodities aside the international Kyoto mechanisms will be likely to be harmonized goals in the future. A diversification and decentralisation of such mechanisms will be in favour of biogas based energy systems.

The further utilisation of biogas means that it must be upgraded. Biogas upgrading is an integrated solution today. The produced biogas is first of all dried and drained for condense water and biological or chemical cleaned for H_2S, NH_3 and trace elements. Further upgrading steps to increase the CH_4 content, membrane separation of CO_2 and pressurising the biogas can be taken depending on the utilisation purpose.

The utilisation of biogas can be set into five categories. The ranking below begins from technology of yesterday towards future converting technologies.

- Biogas converted by conventional boilers for heating purposes at the production plant (house heating, district heating, industrial purposes).
- Biogas for combined heat and power generation.
- Biogas & natural gas combinations and integration in the natural gas grid.
- Biogas upgraded and used as vehicle fuel in the transportation sector.
- Biogas utilisation for hydrogen production and fuel cells.

Biogas from anaerobic digestion is an important tool for sustainable management and treatment of wet organic waste streams and the protection of water environment in Europe.

Efficient biotechnological treatment technologies including pre- and post treatment by physical and chemical separation are today available, in order to recover and recycle. By this waste can be regarded as waste only until the right treatment takes place. The technologies are economically and technologically well proven, documented and the environment gets value for money. So in the medium to long-term run, there are no waste products but valuable resources.

For the main part of the integrated projects where biogas is one of the core technologies, the goals are to establish facilities for the treatment of biowaste and manure, able to convert organic residues into valuable products. These final products are on one side the renewable energy as green electricity, heat for many purposes, and vehicle fuel and on the other side digested biomass, able to be converted into concentrated nutrient fertilizers, fibre products and water for reuse as process water or irrigation water.

Human and veterinary safety and sustainable recycling of end products (digestate, fibre and nutrients) in crop farming.

The recycling of the end products on agricultural land is affected by cross-sectorial EU legislation. The overall aim is to be able to provide a safe recycling of Ad products from the point of view of human and animal health (R. Braun 2002).

The European biogas actors appreciate veterinary measures and regulations and wish to use them to promote sustainable waste and by-product management principles. The regulations are to be used to support the recycling of biowaste in all cases when possible and suitable. Sanitation treatment and other pre or post treatment steps have to be set into operation upon documentation, in accordance with the health rules for recycling of animal by-products, for as many waste and by-products streams as possible.

Biogas from anaerobic digestion - an integrated system and an important tool for mitigation of global warming and air pollution.

Co-digestion of various biomass substrates has a high value for improving and stabilizing the biogas production and makes biogas a strong and cheap tool for mitigation of green house gas (GHG) emission.

Biogas externalities including environmental, human and animal health benefits must be quantified and integrated in the socio-economic analysis in order to highlight biogas from co-digestion as a very attractive solution from a socio-economic point of view.

Sustainable solutions are needed to deal with the increasing environmental pressure from methane emission and odours at and around the farms and food processing industries. Reduction and control of methane gas emissions via establishment of closed animal production chains is a great challenge for the future.

Conclusion

Biogas can contribute substantial to the sustainable energy recovery from agriculture and the organic fraction of wastes. The amount of agricultural and municipal organic wastes currently produced but not utilised for energy production is very large.

Apart from waste treatment biogas plants, there is also a huge potential for "clean" energy recovery biogas plants, mainly based on energy crops, that are under constant development in this decade. (Köttner, Graff & Rakos) The EU energy policy provides the basis for a much broader future application of biogas from anaerobic digestion as a renewable energy technology, based on energy crops.

According to the EU renewable electricity directive renewable energy sources must be increased from a current level of 13.9 pct to 22 pct. in the year 2010. Biogas not only can be used for electricity and heat production, but also for general substitution of fossil fuels, especially in the transport sector. Biogas has definite advantages over other renewable alternatives, since it can be distributed through existing infrastructure and used in the same applications as natural gas.

Biogas has an increasingly important role to play in Europe and worldwide, integrating many sectors for a higher degree of sustainability, energy recovery and resource preservation.

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