# Anaerobic Digestion Study

Final Report

November 2011

The Soil Association

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## LIST OF FIGURES

## LIST OFABBREVIATIONS

| | |
|---|---|
| SA | Soil Assocaition |
| WSPA | World Society for the Protection of Animals |
| AD | Anaerobic digestion |
| GHG | Greenhouse gas |
| CH4 | Methane |
| DEFRA | Department for environment, food and rural affairs |
| CO2 | Carbon dioxide |
| kWh | Unit of energy |
| GW | Unit of power |
| AEBIOM | European biomass association |
| Ktoe | Unit of energy (kilotonnes of oil equivalent) |
| MWe | Unit of electrical power output (megawatts electrical) |
| kWe | See above(kilowatts electrical) |
| tpa | Tonnes per annum |
| Ha | Hectare |
| tCO2eq | Unit of GHG emissions (tonnes of CO2 equivalent) |
| NNFCC | National non-food crops centre |
| PAH | Polycyclic aromatic hydrocarbons |
| PCB | Polychlorinated biphenol |
| IEA | International Energy Agency |
| GWh | Unit of energy |
| PCDD | Polychlorinated dibenzodioxins |
| PCDF | Polychlorinated dibenzofurans |
| NFVR | Nitrogen fertilizer replacement value |
| N | Nitrogen |
| P2O5 | Phosphate |
| K2O | Potassium oxide |
| NH3 | Ammonia |
| N | Nitrogen |
| N2O | Nitrous oxide |
| NH4-N | Ammonium |
| WWF | World Wide Fund for Nature |
| Mtoe | Million tonnes of oil equivalent (unit of energy) |
| PAS | Publically available specification |
| LUC | Land use change |

# 1 INTRODUCTION AND SCOPE

1.1 The Soil Association (*"SA"*) and the World Society for the Protection of Animals (*"WSPA"*) wish to investigate the basis of claims made by promoters of large scale industrial farming units regarding the benefits of anaerobic digestion technology (*"AD"*). Claims of environmental benefits and green farming methods have been made in support of the now withdrawn planning application for Nocton dairy, and the current application for Foston Pig Farm by Midland Pig Producers.

1.2 WSPA and SA would like to be informed of the strength of the arguments used to promote anaerobic digestion with industrial farming as an environmentally sound practice. Both organisations believe that there are areas of doubt, and have jointly commissioned this initial investigation into the environmental benefits of AD when incorporated into large-scale industrial farming units. The brief was in the form of five issues to be investigated, as set out below.

1.3 **Issue 1:** *Is there any data which shows the comparative outputs in terms of energy and quality of digestate from different inputs, and in particular, from dairy cattle, pig waste and chicken waste?*

1.4 **Issue 2:** *With reference to AD systems serving 1,000 dairy cows, or 100 sows and their offspring, what proportion of crop material to animal waste is required and how does this vary between different animal waste streams? What crops are typically used, what are the areas of agricultural land required for the production of these co-substrates for?*

*1.5* **Issue 3:** *How reliable are large-scale AD systems? Is there a large variation between different technologies in terms of efficiency, energy output or other ways? What is the actual experience in, say, Germany of running large-scale AD units alongside industrial farming units?*

1.6 **Issue 4:** *What is the value of the digestate as a fertiliser?*

1.7 **Issue 5:** *Have lifecycle assessments been undertaken of AD units that incorporate all the greenhouse gas emissions from an associated large-scale livestock unit? In particular, have the carbon footprints of dairy units including enteric methane production and animal feed/co-substrate production been analysed and accounted for? What proportion of the overall life cycle greenhouse gas ("GHG") emissions are being saved through the use of AD?*

## 2 BACKGROUND

### 2.1 Anaerobic Digestion

2.1.1 Anaerobic digestion is a term that describes the decomposition of organic matter when oxygen is excluded. There are four phases – hydrolysis, acidogenesis, acetogenesis and methanogenesis, and many different protists, fungi and bacteria are involved in the process. In simple terms, the process requires an organic digestible substrate together with the correct environmental conditions for each phase, and will produce biogas and a residue – the digestate.

2.1.2 AD has been used as a stabilisation treatment for wastes such as farm manure and sewage sludge as well as for energy production. National initiatives such as the Danish programme were driven by energy diversification, but significantly influenced by the other benefits derived from digesting waste – waste stabilisation and a valuable energy output that could be used for both electricity and district heating.

2.1.3 A wide variety of substrates can be used for anaerobic digestion, and these are considered in detail in section 3. They range from manure, slurry and animal bedding through to blood, guts, spent apples, animal fat, crop residue, energy crops, medical waste, some degradable plastics, pulp, sewage sludge and the organic fraction of municipal solid waste. Plants can be designed to co-digest a variety of substrates.

2.1.4 The digestion process is typically mesophillic (30-40°C), or thermophillic (50-55°C). Thermophillic processes achieve stabilisation, or hygienisation of the influent inherently due to the higher temperature. Thermophillic processes tend to be used with “risky” feedstocks (those with higher weed seeds, pathogen content etc.). In Germany, mesophillic processes formed 85% of the installed capacity in 2009[1], reflecting their focus on ‘low risk’ energy crops. Where waste (*ie any waste resource such as manure, municipal waste etc. as opposed to virgin crop material*) or riskier products are used in mesophillic processes, an additional treatment stage is introduced to pasteurise the influent/input/substrate prior to digestion.

2.1.5 There are two methods for managing the digestion of the substrate. Processes tend to be either continuous flow or batch flow. Continuous flow processes drain small amounts of digested substrate once or several times per day, and add a corresponding amount of fresh substrate. This ensures constant supply to the bacteria culture, and stable gas production. Retention periods are between 12-25 days.[2] Batch flow processes tend to place a volume of substrate in a hermetically sealed digester for the duration of the digestion. The digested substrate is then cleared out, and the digester is cleaned and the process starts anew with

[1] www.fnr-server.de, accessed September 2011
[2] www.biogasbranchen.dk, accessed September 2011

the next batch. In both instances, the digested substrate is then placed on post-digestion storage. A significant amount of biogas is still generated in this post-digestion storage, and it is returned to the biogas storage facility.

2.1.6 AD is a biological process with many interacting variables and process parameters above and beyond those discussed above. In addition to this, for plants to make economic sense they need control over a significant catchment of feedstock. AD plants cost between €2,000-6,000 per kWe.[3] As a result of these two factors, there are relatively few AD installations (69 in the UK)[4], and a significant heterogeny in system design and operation. This, together with the high capital cost of the plant, contributes to difficulties in rolling out anaerobic digestion technology as a commoditised product. It is also therefore notable that investment in AD is only really viable where control is held over a range of feedstocks prior to the capital expenditure on the plant.

2.1.7 Biogas is typically 60% methane ($CH_4$), and therefore of interest as a source of combustible energy. Where renewable substrates are used, the biogas is considered to be short-cycle carbon, and therefore a renewable energy resource with diverse applications. The five key uses of biogas are:

- direct burning for heat;
- use for power generation;
- combined heat and power;
- upgrading and injection into the national gas grid; and
- use as a transportation fuel.

2.1.8 Key properties of biogas as determined by DEFRA's emissions conversion factors are as follows:

- 60% $CH_4$ (methane), 40% $CO_2$ (carbon dioxide);[5]
- Net calorific value of 8.33kWh/kg
- 0.9626 kg/m3
- 0.005 kgCO2eq/kg direct GHG emissions;
- 1.323 kgCO2eq/kg indirect GHG emissions;
- 1.328 kgCO2eq/kg total GHG emissions;

2.1.9 The majority of biogas is burned either for power, heat or combined power and heat. Grid injection and transportation fuels are presumed to remain minor end uses for biogas in the

[3] *These costs assume the full installation of digester and energy generation technology. The terminology kWe refers to the electrical output (in kilowatts).*
[4] www.biogas-info.co.uk/maps/index2.htm, accessed October 2011
[5] *For context: natural gas is effectively 100% methane (CH4)*

medium term as they require further refinement, and additional capital investment on what is already a capital intensive (and largely subsidised) technology.

2.1.10 AD has been used for many centuries. However, its recent development as an energy generating technology started after the oil crisis of the 1970s. High prices for fuel drove some countries to prepare extensive plans for alternative energies to reduce exposure to the fossil fuel markets. Sweden and Denmark are good examples of these. Denmark initiated its AD support programme in the 1970s and by the 1990s had 20 large centralised AD plants operational, mostly run by cooperatives of farmers. Germany has also led on the development of the market and now has more AD installed capacity than any other EU country by quite a margin.

2.1.11 The UK sits second in the installed capacity rankings of the EU 27 of biogas production. However, this comes from landfill gas and sewage sludge treatment. Manure- and crop-based AD output is negligible. The table below shows the biogas production figures from 2009 (excluding landfill and sewage sludge):

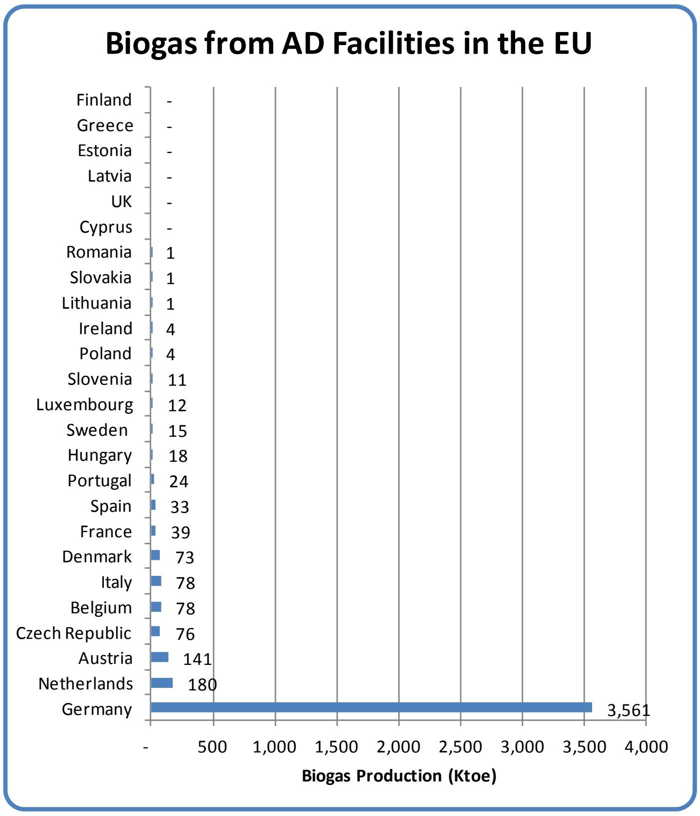


*Figure 1 Biogas Production in EU Countries*

*(Excluding Landfill Gas and Sewage Sludge Gas)*[6]

[6] Source: Statistics Report, AEBIOM, 2011

2.1.12 Germany is the market leader due in the main to the early introduction of feed-in tariffs and the generosity of those feed-in tariffs. The installed electrical generation capacity from biogas is ~3GW , and their peak power demand is 100GW.[7] The current feed-in tariff is quite refined in its level of detail, including differing bonus tariffs on top of the basic subsidy for energy crops, manure, landscape protection, emissions reductions, and CHP. However, Denmark has one of the most mature AD infrastructures through its early implementation of the technology.

2.1.13 The 2011 statistical report from the European Biomass Association (AEBIOM) on the EU27 countries states that biogas has the advantage of reconciling two policy areas: the reduction of biodegradable waste going to landfill, and the production of renewable energy. Interestingly, it also states that the sector is gradually deserting its core activities of waste treatment, and getting involved in energy production instead.

2.1.14 Figure 1 showed that the UK provided a negligible biogas output from non-sewage or landfill gas systems. However, there has been some biogas production albeit at a very low level. AD has been subsidised in the UK through a number of different mechanisms throughout the years including capital grants and the renewables obligation (since 2000). However, the introduction of the Feed-in Tariff in April 2010, and the Renewable Heat Incentive due in late 2011 has created the most financially rewarding period for investment in AD to date. There is now significant interest in the development of AD projects across a number of different market sectors utilising a variety of digestible substrates.

2.1.15 In 2011, DEFRA published its latest national plan for anaerobic digestion. The key findings were as follows:

- There are 54[8] operational plants in the UK with a power output of 35MWe;
- A further 50 have received planning consent, representing a further 70MWe;
- Energy crops may have an impact on food crop displacement, and rising food prices – designers and operators should take responsibility to avoid environmental detriment and unintended consequences;
- Non-waste digestates, including PAS 110 compliant digestates from waste feedstock, can be spread straight to land;
- Digestates that remain waste (ie fail to comply with PAS 110 post-digestion) can only be spread on land according to the safe sludge matrix;
- On 1 August 2011 new higher feed-in tariff rates for AD were introduced following the feed-in tariff fast-track review;
- Renewable heat from AD will be supported;
- 75% of the 1.1mt sewage sludge is used on agricultural land

[7] www.theenergycollective.com, accessed October 2011
[8] *This number is evolving and currently sits at 69.*

2.1.16 Below the key data are set out from two recent examples of the application of AD to planning applications for intensive farming practices in the UK – Nocton Dairy and Foston Pig Farm.

2.1.17 In December 2009 Nocton Dairies Ltd submitted a planning application to North Kesteven District Council (Ref: 10/1397/FUL) for an intensive dairy farming facility. The design and access statement and environmental statement non-technical summary described the key features of the application:

- 3,770 cow unit;
- Design based on Fair Oaks Farm, Indiana; Central Sands Dairy, Nekoosa; and Withgill Farm, Lancashire;
- Livestock are kept in groups of 400-450;
- AD technology included;
    - Batch-processed;
    - Thermophillic (55°C);
    - Stabilisation vessel separately;
    - 75,000tpa of slurry
- A PAS 2050 carbon footprint assessment was undertaken by the ECO2 Project;
    - 57,761 tCO2eq emissions per annum;
    - 3,747 tCO2eq emissions saved by the AD technology;
    - 6% CO2 savings achieved;
- Digestate separated into:
    - 30% DM solids which are redigested or applied to land;
    - 3% DM liquid stored in lagoons and applied as fertilizer replacement for crops;
- 750kWe electrical generation to be installed;
- Application of digestate to meet nitrate pollution prevention regulations (2008);
- Surplus and unused feed would be fed into the digester;
- Heat is used to maintain the thermophillic process (ie parasitic process load);
- The capital cost of the AD plant is estimated at £2.6m using a mid-range price metric;

2.1.18 Nocton Dairies subsequently withdrew the application.

2.1.19 Midland Pig Producers, part of the Leavesley Group, submitted an application on March 2011 to Derbyshire County Council (Ref: CW9/0311/174) for an intensive pig farming facility. The following data were taken from the associated planning documentation including the design and access statement, the planning statement and the environmental statement, as well as from the MPP consultation website;

- 2,500 breeding sow unit;
- Producing 50,000 pigs for market annually;
- 28Ha site;
- Feed to be contracted locally (wheat, barley and beans), equating to 5,000 acres of land;
- Onsite milling of feed;
- Underfloor heating in the pig lots from the AD waste heat;
- AD technology proposed;
    - 2MWe;
    - 35,000t pig slurry;
    - 45,000t off-farm organic matter to maximise heat and electricity production;

    - Heat could be used for Foston prison (no firm commitment or plans submitted);
    - Technology provided by GHD, a US company;
    - Batch process using hair-pin plug-flow technology;
    - 16 days retention time;
    - Mesophilic process (37°C)
    - Heated to 75°C to stabilise
    - 3 no. 834kWe Jenbacher electrical generation units;
    - 1,000 tonnes per week digestate to fertilise 2,000Ha for autumn and spring;
    - Liquid to be dealt with by traditional aerobic treatment;
    - Emergency flare built in;
    - 30-60% of the heat produced would be used as parasitic process load heat (according to GHD's website);
- £8m capital cost for the pig farm;
- £4m capital cost for the AD plant;

2.1.20 The proposed process for Foston is a plug-flow reactor. The term plug flow derives from fluid mechanics, describing the flow of a fluid in a pipe where there is no back or forward mixing in the axial direction. The fluid flows in discreet disks or plugs in the direction of travel. For plug-flow AD the substrate is added at one end of the reactor – a U-shaped canal. The newly added substrate spends the retention time flowing as a discreet "plug" through the reactor. Each day, new material is added at one end, and digested material removed from the other end. In reality, some mixing does occur.

2.1.21 It is therefore a batch-process, with each plug of substrate remaining discreet and unmixed with the other plugs in front and behind it in the reactor. It requires a high solids content to reduce mixing from plug to plug. The proposed scheme for Foston therefore separates the slurry into a solids fraction for AD treatment and a liquids fraction for water treatment. Advantages of plug flow systems are the low operational cost and high volume conversion rate. Disadvantages are that temperatures are difficult to control, and can result in undesirable temperature gradients.

# 3 ISSUE 1: INPUTS AND OUTPUTS

*Is there any data which shows the comparative outputs in terms of energy and quality of digestate from different inputs, and in particular, from dairy cattle, pig waste and chicken waste?*

## 3.1 Energy Yields

3.1.1 AD is a highly heterogenous technology. Organic matter comes in many forms, and as such, the substrates and the particular ecosystems required for efficient digestion vary significantly. Technology design and operation varies very widely. Local environmental conditions also have an impact. There are therefore many different and varied forms of anaerobic digestion that take place both naturally, and in induced situations.

3.1.2 It is notable that technology development has resulted in a wide range of solutions with markedly different approaches and yields. As a result, the constitution of the resulting biogas and the residual digestate vary significantly.

3.1.3 With regards to UK-based benchmark data, the National Non-Food Crops Centre ("NNFCC") has developed a calculator for anaerobic digestion project developers that calculates the outputs from particular inputs. The latest version was updated in June 2011. It cites as a reference for energy yields the Bavarian State Institute for Agriculture website. The variations noted above mean that in practice, outputs can be significantly different to these benchmarks.

3.1.4 The graph below sets out the theoretical biogas yields from livestock waste substrates, and some key crops also used as substrates. These figures assume optimum retention times to allow full digestion to occur. In practice, retention times are rationalised to reduce the capital cost of the plant.

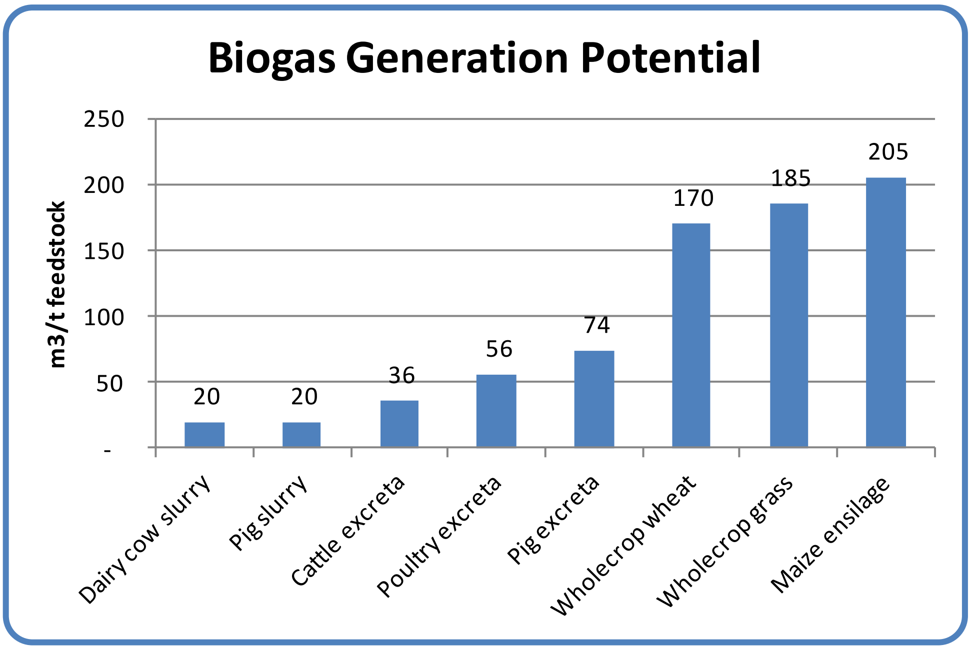


*Figure 2 Biogas Generation Potential from Various Substrates*[9]

3.1.5 To provide a secondary reference for benchmark biogas yields, the German Biogas Association was consulted:

| Substrate | Biogas yield (m$^3$/t fresh mass) | $CH_4$ content (Vol.-%) |
|---|---|---|
| Cattle slurry | 20 – 30 | 60 |
| Pig slurry | 20 – 35 | 60 – 70 |
| Cattle manure | 40 – 50 | 60 |
| Pig manure | 55 – 65 | 60 |
| Chicken manure | 70 – 90 | 60 |
| Maize silage | 170 – 200 | 50 – 55 |
| Rye whole-crop silage | 170 – 220 | 55 |
| Organic waste | 80 – 120 | 58 – 65 |
| Grass cuttings | 150 – 200 | 55 – 65 |

*Figure 3 Biogas Yields*[10]

3.1.6 Figure 2 and Figure 3 show that biogas yields from animal slurries can be just 10% of yields from purpose-grown “energy” crops for digestion.

## 3.2 Quality of Digestate

3.2.1 The issue of digestate quality is considered in detail section 6. In brief, the digestate quality as a fertilizer is closely linked to the fertilising value of the inputs. The digestion process turns solid organic matter into CH4 and CO2, reducing the dry matter volume by circa 25%. The total nitrogen, phosphate and trace element volumes in the digestate remain broadly

[9] Source: NNFCC AD Calculator, NNFCC, June 2011 Version
[10] Source: Biogas, German Federal Ministry of Food, Agriculture and Consumer Protection, 2009

unaltered from the influent (ie the input), although due to the reduction in dry matter, the effluent is a more concentrated version.

3.2.2 Different substrates are affected by different pollutants that may affect the digestate quality and market value. These include:

- Pathogens (bacteria, viruses);
- Weed seeds;
- Heavy metals.

3.2.3 Energy crops tend to be low risk, low pollutant inputs, and as a result are often digested in mesophillic processes. Weed seeds could be introduced into the AD system, and if there is no stabilisation or heat treatment stage, they could potentially cause an issue. Maize must be considered as the key energy crop feedstock, and once established, maize outcompetes weeds.

3.2.4 Where pathogens are likely to occur, either waste permitting procedures will be required, or compliance with PAS110 or similar will have been achieved. There are therefore methods in place to deal with pathogen content. However, analysis of digestate is required particularly where it remains a waste product. It may well be the case that in some instances digestate fails to make the grade. With regards to pathogen control, it would be assumed that it could be retreated/redigested to deal with this problem.

3.2.5 Heavy metals and other toxins introduced such as PAHs, PCBs, medicines etc. are a more difficult problem to deal with. The best method is through careful analysis and control of the influent. However, if they get into the system and the digestate failed the various tests, it would be difficult to recover a useable digestate.

# 4 ISSUE 2: CO-SUBSTRATES

*With reference to AD systems serving 1,000 dairy cows, or 100 sows and their offspring, what proportion of crop material to animal waste is required and how does this vary between different animal waste streams? What crops are typically used, what are the areas of agricultural land required for the production of these co-substrates for?*

## 4.1 Optimising Co-Substrates

4.1.1 Animal slurries tend to be waste resources, and therefore zero cost to an AD plant, and often a revenue generator through gate receipts (*revenue received from the waste producers for taking the waste product*). In purely commercial terms, where an organisation has a waste resource and is considering anaerobic digestion, the question of whether and what volume of energy crops should be added is answered by a financial modelling exercise.

4.1.2 As seen in section 3, energy crops create a significantly higher energy output from the AD plant which makes for a higher return on the capital invested in that plant. However, they must be produced, and as such have an associated production cost. In simplistic terms, if energy output is to be maximised, then the energy crops element would be maximised. In practice, resource costs tend to be governed by the proximity of the crops to the plant itself. Deublin[11] states that a sourcing radius of 15-20km is the limit for profitable co-substrates.

4.1.3 In the UK, the key energy crop for AD is maize, as its yields are extremely high. Sugar beet also has very high theoretical yields, but the digestion process for beet is more difficult to manage successfully. "*...silage maize for the biogas production cannot be beaten at most locations*."[12]

4.1.4 This optimisation process has been taking place in Germany where plants originally constructed for animal waste are increasingly being turned over to energy crops to maximise gas production, and revenues.[13] According to the IEA, Germany now has 650,000Ha[14] of land under cultivation for biogas energy crops. These crops provide only 41% of the total mass of feedstock for energy crops (animal wastes provide 43% mass). However, they are responsible for 73% of the energy output (animal wastes provide just 11% of the energy output).[15]

4.1.5 It is becoming apparent that plant operators are indeed switching feedstock from wastes to energy crops to maximise yields. As a consequence, the future direction of policy is likely to

[11] Biogas from Waste and Renewable Resources, Dieter Deublin et al, 2011
[12] Ibidem, pp67
[13] Several sources including: Cropgen Presentation, Deublin et al.
[14] By the end of 2010, this figure was 750,000Ha – AEBIOM Statistics Report, 2011
[15] IEA Task 37 – Biogas, Germany Report, April 2011

review the subsidy mechanism that distinguishes between biogas from waste feedstocks and biogas from energy crops to ensure that the waste resources are used in the first instance.[16]

4.1.6 This is in sharp contrast to the experience in Denmark, where there are 20 centralised AD plants almost all of which rely on an 80:20 split of manure to other organic matter. The reason for this is revealed by the structure and financing of the AD plants. They are all owned by cooperatives of farmers, or municipal authorities. The centralised plants take farm wastes from a number of different farms (up to 70), digests them, sells heat locally to district heat systems, sell electricity to the grid, and sells the digestate back to the farmers.

4.1.7 The AD systems in Denmark were built to resolve their manure management problems in the first instance. Hence, the systems were sized for the local manure volumes. As the systems also supply digested waste back to the cooperative farmers, the plants are so integrated into the local supply and waste chain that displacing manure for higher yielding energy crops would create more problems than solutions.

[16] IEA Task 37 – Biogas, Germany Report, April 2011

# 5 ISSUE 3: RELIABILITY

*How reliable are large-scale AD systems? Is there a large variation between different technologies in terms of efficiency, energy output or other ways? What is the actual experience in, say, Germany of running large-scale AD units alongside industrial farming units?*

## 5.1 Germany

5.1.1 Germany is the leading country in the EU27. By the end of 2010, it had 6,000 plants installed with a total installed electrical capacity of 2.28GW, averaging at 380kWe per plant – half the scale of Nocton, and a fifth the size of Foston.

5.1.2 Most systems in Germany utilise semi-continuous processing, rather than the batch processes proposed for Nocton and Foston. 85% of these are mesophillic. Over 73% of the energy production comes from energy crops grown over 750,000Ha of land.

5.1.3 Using 2009 data, the average capacity factor was 76%, and a primary gas production of 41,414GWh. The UK was second to Germany with a primary biogas production of 20,050GWh.

## 5.2 UK

5.2.1 Reviewing the electricity generation data on existing installations in the UK shows a significantly poorer electricity output per kWe of installed capacity. The average (mean) capacity factor of all the plants is 30%.[17] When normalised for different scales of outputs (the overall capacity factor against the total installed capacity), this number drops to only 8%. In contrast, the NERA/AEA technical report produced in support of the Renewable Heat Inventive mechanism modelled a capacity factor of 100% for AD plants.[18] Further, a recent report by ARUP on the costs of renewable energy technologies for the Department of Energy and Climate Change 2011 stated an assumed load factor of 91.3%.[19] This seems high in the face of the evidence in the UK of actual operational hours achieved.

5.2.2 The UK on-farm digestion market is summarised in the table below. It is notable the larger units either rely on maize or grass silage, or food waste of some sort. Animal manure systems produce much lower yields and installed power generation capacities. It is expected that without refined incentivisation, this will drive a similar situation to Germany. The current UK policy on energy crops for biogas is to allow the market to decide what is best. It is a hands-

[17] http://www.ref.org.uk/, accessed September 2011
[18] www.decc.gov.uk, accessed September 2011
[19] Review of the generation costs and deployment potential of renewable electricity technologies in the UK, DECC, June 2011

off approach. AD will become increasingly reliant on energy crops to maximise yields. This may even result in the displacement of waste substrates.

| Feed Type | Volume tpa | Power kWe |
|---|---|---|
| Dairy slurry, energy crops | 5,000 | 23 |
| Tomato waste | 15,000 | 75 |
| 250 cattle slurry, poultry, apple | 2,680 | 125 |
| Maize silage | 37,000 | 2,000 |
| Silage and energy crops | 16,000 | 1,000 |
| Business waste, energy crops, slurry | 10,000 | 300 |
| Slurry, manure, vegetable waste | 8,000 | 75 |
| Slurry, manure, silage, whey | 5,000 | 140 |
| Slurry, manure, glycerol (heat only) | 80 | - |
| Manure, maize, grass silage | 25,000 | 1,000 |
| General organic waste | 15,000 | 513 |
| Pig, cow, abbatoir, glycerol, fats | 15,000 | 460 |
| Poultry litter and slurry | 1,700 | 250 |
| Slurry from 750 cattle (heat only) | ? | - |
| Pig, poultry, cattle, maize, grass silage | 18,000 | 250 |
| Cow slurry and manure (heat only) | 480 | - |
| ? | ? | 85 |
| 450t cow manure, 1000t chicken litter | 1,450 | 125 |
| Manure, litter, maize and grass silage | 11,700 | 370 |
| Slurry, maize, grass silage | 20,000 | 500 |
| Cow slurry and manure (heat only) | 190 | - |
| Grass silage, veg waste, by prducts, manure, slurry | 45,000 | 1,000 |
| Slurry and crops | 8,000 | 50 |
| Slurry, maize and grass | 20,000 | 300 |
| Slurry and manure (heat only) | 480 | - |
| Process waste, below par veg | 46,000 | 1,400 |
| Slurry and manure (heat only) | 730 | - |
| Slurry and grass silage | 2,500 | 6 |
| Slurry from 200 dairy cattle | ? | 100 |
| Food, paper, garden, fish waste | 7,000 | 305 |
| Slurry, manure, crop residues | 1,500 | 50 |
| *Average* | *12,089* | *339* |
| Total | 338,490 | 10,502 |

*Figure 4 On-Farm AD Installations in the UK*[20]

## 5.3 Denmark

5.3.1 As noted in section 4, Denmark initiated a series of centralised biogas plants in the 1980s and 1990s, based largely upon the use of manure and slurries from cow and pig facilities. Poultry and mink also provide smaller proportions of waste.

5.3.2 Where the centralised plants accept other organic matter, it must be provided free from inhibitors and contaminants. These systems range from 9,000 tonnes per annum to 182,000 tonnes per annum in scale. Unlike Nocton and Foston proposals, they are almost all continuous digestion processes, 12 of which are thermophillic and the balance mesophillic. Batch processing as proposed for Nocton and Foston is avoided because of the need to maintain stable digestion for stable and good quality gas production.

[20] www.biogas-info.org, accessed September 2011

5.3.3 Most plants have increased their output over the years through a higher fraction of organic wastes from other sources than manure. The digestate tends to have less odour, but the plants have come in for some criticism themselves for odour-related issues.

5.3.4 Financially, the message is mixed. The Danish Biogas Association notes that "*many of the plants are having or have had some serious financial problems.*" Further, it is noted that "*it is not possible to make centralised biogas plants economically viable if they are based on livestock manure alone.*"[21]

5.3.5 The application of combined heat and power ("CHP") in its true sense is most apparent with these centralised Danish systems. The majority of plants feed biogas into CHP units that then feed district heating systems for the local towns. In many other circumstances, the term CHP is applied more liberally where the heat may only be used to achieve a thermophillic digestion (ie it's a parasitic process energy demand), or where it is used to heat animal lots.

5.3.6 The Danish Biogas Association observes that with on-farm systems, gas production levels for manure only systems were much lower than expected.

## 5.4 Netherlands

5.4.1 The picture is similar to that of Denmark. Biogas from manure dominates the current and future projections for their domestic market, providing about 75% of the total biogas production.

## 5.5 Austria

5.5.1 The first Biogas plant for anaerobic digestion in Styria was built in 1978. A significant expansion in capacity started at the end of the 1990s. By 2007 there were 335 biogas plants approved for producing green electricity for the public grid. The average size of the Austrian biogas plants was 315kWe, significantly smaller than those proposed for Foston and Nocton. The gas is typically used in combined heat and power units feeding the electricity grid. Small amounts of heat are used as parasitic loads in the AD process, with any surplus of heat is often used to feed in a district heating system. About 35% are co-fermentation plants, the rest uses only renewable raw material like maize, grass and liquid manure. About 80% of the plants are operated by farmers. [22]

[21] www.biogasbranchen.dk, accessed September 2011
[22] http://www.biogasregions.org/doc/newsletter/newsletter1.pdf accessed October 2011

## 5.6 Canada

5.6.1 Canada has participated in the IEA Task 37 on biogas. Their country report from April 2011 sets out a number of case studies of AD associated with industrial farming facilities, set out below. There are 20 digesters in the country, mainly in Ontario and Alberta. The digestate in each instance is applied to land.

| Substrate | Power | Type | Digestate |
|---|---|---|---|
| 290 dairy cows, waste grease | 500 | Mesophillic | Land applied |
| 230 dairy cows, waste grease | 360 | Mesophillic | Land applied |
| 95 dairy cows,waste grease | 100 | Mesophillic | Land applied |
| 500 dairy cows, waste grease | 500 | Mesophillic | Land applied |
| 650 dairy cows, waste grease | 500 | Mesophillic | Land applied |
| 300 dairy cows, waste grease, grocery refuse | 500 | Mesophillic | Land applied |
| 2700 veal calves, waste grease, grocery refuse | 500 | Mesophillic | Land applied |
| 2000 dairy cows, waste grease | 1,300 | Mesophillic | Land applied |
| 375 dairy cows, poultry waste, off-farm waste | 500 | Mesophillic | Land applied |
| 200 dairy cows, waste grease, biomass waste | 500 | Mesophillic | Land applied |
| Grape pommace, poultry waste, greenhouse waste | 335 | Mesophillic | Land applied |
| Dairy cows, kibble, silage, grape pommace | 250 | Mesophillic | Land applied |
| Waste greeenhouse vines, food process waste | 4,800 | Mesophillic | Land applied |
| 18000 hogs | Heat + flare | Psychrophill. | Land applied |
| 1500 hogs | Site elec. | Meso/thermo | Land applied |
| 5500 hogs | - | ? | Land applied |
| 35000 hogs | 120 | Mesophillic | Land applied |
| 30000 feedlot cattle, co-substrates | 2,500 | Thermophillic | Land applied |
| 1200 hogs | 350 | Mesophillic | Land applied |
| Dairy, poultry, food waste - injected into gas grid | 2,400 | Mesophillic | Land applied |

*Figure 5 Anaerobic Digestion Market in Canada*

5.6.2 The extant systems and those planned are largely based on manure/slurry and other waste co-substrates rather than energy crops. The technology is almost exclusively mesophillic, unlike Nocton which is thermophilic, presumably due to capital cost considerations and funding arrangements. The units based in Ontario were built with money from grants from the regional state. As a result, the outputs are relatively low. The largest unit utilises vine and food waste rather than manure, and is of a different order of magnitude to the most of the manure based systems.

5.6.3 The economics are not particularly attractive. Further, energy policy is a regional rather than federal issue. These issues mean that the industry is growing slowly. The University of Guelph is undertaking research into the value of digestate. Other research programmes are looking into greenhouse gas mitigation. AD remains a nascent market in Canada.

## 5.7 The US and Mexico

5.7.1 AD in the US and Mexico has been utilised, but has not been commercialised to the extent it has been in Germany. However, that is changing, and companies such as Agcert and Camco are developing large AD systems attached to large intensive farms in both countries.

5.7.2 Cornell University has published a case study on a farm-based AD system at Twin Birch Farm in New York State. It is based on the same type of technology to be employed at Foston Pig Farm – a hair-pin plug-flow reactor. The scheme was primarily driven by manure management requirements in a sensitive area. It consisted of nearly 2,000 cattle, and was designed to produce 180kWe.

5.7.3 The initial design was poor, and biogas leakage and poor generation technology selection prevented successful operation. Construction was commenced in 2001, but final commissioning was not until 2006, and the first power generation was in 2007. The capital cost was almost three times the original budget, and in the end, the farm disposed of the underperforming design contractor and took on the design themselves.

# 6 ISSUE 4: WHAT IS THE DIGESTATE VALUE AS A FERTILIZER?

*What is the value of the digestate as a fertiliser?*

## 6.1 Background

6.1.1 The value of digestates as fertilizers depends on the make-up of the digestate, and its classification in waste terms. The chemical make-up is strongly determined by the particular nature of the inputs. Bioavailability of different nutrients can also be affected by the digestion process.

6.1.2 Often, the solid component of AD digestate is separated out, composted and sold. The quality of anaerobic compost only has slightly lower contents of salt and nutrients to aerobic compost. The liquid fraction is normally applied to land.

6.1.3 When harmful inorganic substances (e.g. heavy metals) or organic substances (PAHs, PCBs, PCDDs or PCDFs) are present, land application of the digestate may not be possible. The presence of these pollutants derive from the inputs – ie the feed for the livestock, any co-substrates and in some cases, medicinal treatment of the livestock. Other harmful components of digestate can be toxins to animals, humans and plants, and injurious weed seeds.

6.1.4 PAS 110 has been developed by the industry as a voluntary specification for quality digestate, compliance with which mean that the digestate is not waste, and is therefore exempt from waste treatment legislation. However, there remain wastes that do not comply with PAS110, which must be treated as wastes, with the appropriate permitting or exemptions as appropriate.

6.1.5 The UK AD Strategy makes the following points about the use and application of AD digestate:

- *Waste-derived digestate which meets the end of waste criteria set out in the Quality Protocol for Anaerobic Digestate can be used as a non-waste product.*
- *However, waste-derived digestate which does not meet these criteria continues to be classified as waste and can be used only under the terms of an environmental permit or a registered permit exemption where appropriate.*
- *Plants that use waste as feedstock require a standard or bespoke permit, go through an exacting planning process, and would need to comply with waste permitting requirements as well as authorisation under the Animal By-Products Regulations (ABPR) where appropriate. Generally, feedstock pre-treatment technology is required to remove packaging and homogenise the feedstock before it is added to the digester. Because of this, capital and operating costs tend to be higher than those plants where feedstocks require lower levels of treatment, but income can be generated through charging a gate fee for waste coming in.*

- *Generally speaking, where AD plants are treating animal by-products, including waste food, they will need an approval from the Animal Health Veterinary Lab Agency (AHVLA) under Animal By-Products legislation. Regulation (EC) 1069/2009 on the handling and use of animal by-products permits the use in AD of low-risk animal by-products which are essentially material passed fit for purpose, but no longer intended for human consumption. High-risk material such as dead/fallen stock cannot be used in AD. Permissible AD plant treatment and hygiene standards are set out in the Implementing Regulation (EC) 142/2011. The EU rules are administered and enforced in England by the Animal By- Products (Enforcement England) Regulations 2011 (SI 2011/881). There are certain limited exceptions where AD plants treating animal by-products, including food waste, will not need to have an approval from AHVLA. These include AD plants treating food waste on the premises of origin, and there is a small list of animal by-products that can be used in AD without needing an AHVLA approval, including manure, milk and milk products and colostrum.*
- *Digestate derived from AD plants treating animal by-products and approved by AHVLA is subject to a grazing ban once the digestate is used on land. Livestock must not be allowed access to the land during this time period.*[23]

## 6.2 ADAS/SAC Report Findings

6.2.1 In 2007, the Scottish Agricultural College undertook a review of existing research on digestate quality, and made studies on two AD plants in Scotland.

6.2.2 With regards to the nutrient value of digestates, the SAC and ADAS report (2007)[24] indicated a general lack in data due to the focus on analysing energy performance rather than nutrient performance: "*...there have been few well controlled comparisons of the impact of digestion on slurry analysis, [and] there are even fewer data where crop response has been assessed.*" The premise of the study was to investigate the strong body of opinion that believes that the nutritional value of effluent is improved by the digestion process.

6.2.3 The key findings from the research data review were as follows:

- A significant reduction in solids content (up to 25%);
- An increase in pH;
- An average increase of 26% in ammonium-N content, but a caveat that this is highly variable and depends on the retention times;
- Danish studies reported an increase in slurry N-efficiency of 15-30%, although results were inconsistent;
- Short-term NFRV (nitrogen fertilizer replacement value) was increased for digested slurry, but the first year benefits were offset through longer-term disbenefits;
- No clear findings on improved crop recovery or utilisation of slurry N as a result;
- Comparatively, lowest losses of N were associated with digested, separated slurries, reflecting the quicker infiltration into the soil due to the lower dry matter content;
- Small and inconsistent changes to total N, P2O5, and K2O, in line with expectation that these are conserved during the digestion process;

[23] UK Anaerobic Digestion Strategy, DEFRA, 2011
[24] Nutrient Value of Digestate from Farm-Based Biogas Plants in Scotland, ADAS UK Ltd and SAC Commercial Ltd, July 2007

- A likely increase in availability of phosphate through increased orthophosphate (the result of the solubilisation of some organic P through the digestion process), but recommendation for further studies;
- There were no clear effects of slurry digestion on the annual emissions of N2O (raw slurry vs digested slurry in land application).

6.2.4 Having then undertaken an assessment of two installations, a number of observations about digested slurries were made:

- Solids are reduced substantially;
- Mineral nitrogen content can be increased, but digestate should not be considered as a mineral fertilizer solution;
- There is a risk of increased NH3 emissions in storage, but it remains controllable;
- Danish studies have shown a reduction in NH3 emissions following land application. Low emission application processes are recommended for digested slurries;
- Increased mineral N content does not guarantee improved crop recovery;
- There is strong evidence for an increased availability in phosphate.

6.2.5 The ADAS/SAC thesis indicates that there is not a significant body of evidence supporting the general claims that digested slurries are more valuable than non-digested slurries. However, implicit in framing an investigation in those terms is that digested slurry is as valuable as non-digested slurries. Circumstances that may mean that the digested slurry would be less valuable would be where toxins from non-slurry feedstocks had contaminated the slurry.

6.3 Other Sources

6.3.1 The Danish Biogas Association sets out the advantages of digestate as compared with raw substrate as follows:

- The product is homogenised, allowing accurate chemical and biological analysis and certification of content. This in turn allows for accurate calculation of application rates and a reduction in mineral fertilizer (less propensity to over-compensate having applied slurry of unknown nutritional value);
- Sanitation occurs either as part of the process (thermophillic), or as an additional treatment stage (mesophillic), reducing occurrence of weed seeds, and pathogenic bacteria and viruses;
- NH4-N is 25% more biologically available;
- Liquid digestate is easy to spread, odours are reduced, and soil humus is improved.
- By implication, the homogeneity of the digestate and accurate analysis should also allow it to command a premium over less homogenous undigested products. [25]

6.3.2 While the SAC research showed limited nutritional benefits of digestate over raw substrate, the point made by the Danish Biogas Association regarding the homogeneity of the product allowing higher displacement of mineral fertilizer is an important one.

[25] www.biogasbranchen.dk, accessed September 2011

6.3.3 This experience is backed up by anecdotal evidence in the WWF and FCRN report 'How low can we go?': "*The actual realisation of the benefits of AD may arise through unexpected consequences. One of the authors heard a farmer talk about his experience of involvement in the Holsworthy centralised AD project in Devon.*[139] *His initial scepticism was overcome by his experience of having a uniform digestate to apply, rather than heterogeneous manure. Because of the waste management regulations, all loads of digestate arrived with analysis tickets, including NPK. That was the critical factor in enabling the farmer to raise the efficiency of nutrient use*."

# 7 ISSUE 5: LIFECYCLE ASSESSMENT

*Have lifecycle assessments been undertaken of AD units that incorporate all the greenhouse gas emissions from an associated large-scale livestock unit? In particular, have the carbon footprints of dairy units including enteric methane production and animal feed/co-substrate production been analysed and accounted for? What proportion of the overall life cycle GHG emissions are being saved through the use of AD?*

## 7.1 Existing Studies of Livestock Units

7.1.1 The Nocton planning application incorporated a lifecycle assessment of the dairy greenhouse gas emissions that was PAS2050 accredited. The study considered CO2, CH4 and N2O emissions from all potential sources associated with the milk production, rather than the emissions associated directly with the AD plant. It is assumed therefore that it does not consider the impact of the co-digestates as these are not relevant to the final emissions per litre of milk. An emissions assessment of the biogas plant may be a relevant exercise, considering the GHG impacts of the co-substrates.

7.1.2 The carbon benefit of the anaerobic digestion facility was estimated to save 6% of the total emissions. This was checked using the NNFCC calculator, which indicated only a 3% saving from the volume of slurry anticipated. Presumably, the balance is from the waste feed that is due to be digested also. The majority of emissions came from enteric $CH_4$ (41%), and the feed for the herd (34%). The breakdown is set out below:

| | | |
|---|---|---|
| Fertiliser | 749 | tCO2e |
| Lime | 57 | tCO2e |
| Pesticide | - | tCO2e |
| Herbicide | 100 | tCO2e |
| Farm machinery | 1,346 | tCO2e |
| Farm electricity | 741 | tCO2e |
| Lime application | 579 | tCO2e |
| Fertlizer application | 526 | tCO2e |
| Animal manure mgmt | 4,183 | tCO2e |
| Sewage and crop residue mgmt | 3,519 | tCO2e |
| Atmospheric deposition | 139 | tCO2e |
| Land N | - | tCO2e |
| Enteric fermentation | 23,534 | tCO2e |
| Manure CH4 | 6,368 | tCO2e |
| Feed use | 19,646 | tCO2e |
| Straw and bedding | 20 | tCO2e |
| Carbon credit/deduction | - 3,746 | tCO2e |
| | 57,761 | tCO2e |

*Figure 6 Nocton GHG Impacts*

7.1.3 There remains work to be done on analysing the associated substrate feedstocks. If a similar trend to Germany is expected, then maize is likely to dominate as a co-substrate as a means to maximising biogas production, and revenue generation. This needs to be accounted for, together with land use change impacts. As noted previously, the UK policy is currently to let the market decide what is best. It is likely that the market will aim to maixmise revenues.

7.1.4 Other studies include Xergi's 2007 report on the lifecycle assessment of biogas from maize silage and animal manure and other biofuels (NB. Xergi are an AD technology supplier). LCA is a comparative study process, and shows the environmental consequences of making biogas instead of the alternative use of the substrate. The key findings were:

- Biogas from manure has very high reductions in GHG gases and very high fossil fuel savings compared to conventional storage and soil application of the manure;
- Environmentally, manure should be used for biogas prior to application to land;
- Manure-based has much higher GHG reduction compared with energy-crop based biogas, and should therefore have higher priority;
- Comparing biocrops and end-use, biogas from maize, and heat and power from willow have the highest GHG savings and land use for energy crops should prioritise these two energy crops above others.

## 7.2 Land Use Change

7.2.1 The WWF and Food Climate Research Network report 'How Low can we Go?', an assessment of greenhouse gas emissions from UK food, states that "*land use change (mainly deforestation) driven by agricultural expansion is a hugely important source of emissions attributable to the global food system...*" and that "*the UK food system is part of the global food system contributing to the underlying forces.*"[26]

7.2.2 It is a reasonable extrapolation from this that energy crops also contribute to land use change for the same reasons. In 2008, 2.03mHa, 17% of Germany's arable land, was used for energy crops. In 2010 750,000Ha was used for biogas crops alone. The land use change component of energy crops for biomass is therefore an important consideration. In a presentation by Jens Bo Holm Nielson of the University of Southern Denmark, he talks about the viable potential of energy crops using 20% of Europe's arable land. This has the potential to provide 182Mtoe of energy. This compares with a realistic potential of pig and cattle manure across the EU of just 19Mtoe – a factor of 10 difference. Noting Xergi's lifecycle assessment findings that AD is the best use of land for biogas, the impact of energy crops is an important factor in the future of biogas.

7.2.3 DEFRA Report FO0404 was reviewed as part of the research into this project. It notes the following: "*Land use change (LUC) can have major effects on GHG emissions from crops, especially if tropical rain forest is converted to cropland. PAS 2050 specifies a method to use,*

[26] Audsley, E., Brander, M., Chatterton, J., Murphy-Bokern, D., Webster, C., and Williams, A. (2009). How low can we go? An assessment of greenhouse gas emissions from the UK food system and the scope to reduce them by 2050. WWF-UK

*which is clear for some situations, but not for all. The uncertainties associated with LUC are also large.*" It also states "*This work was done to test PAS 2050, not to produce values that represent an average for UK production. Therefore, results should not be interpreted as benchmarks.*" Bearing that in mind, the benchmark for maize was stated as 0.18kgCO2eq/kg.

7.2.4 Other benchmarks relevant to the scope of this study were derived from report ISO205 that are relevant to the scope of this report:

- Forage maize – 0.577 kgCO2eq/kg
- Soya – 1.3kgCO2eq/kg
- Milk – 1.06kgCO2eq/litre

## 7.3 Carbon Savings from Anaerobic Digestion

7.3.1 The carbon savings from AD for Nocton were calculated to be 6% of overall emissions of the end product. The slurry component is estimated to provide only 3% savings. Those from Foston have been estimated to be in the region of 15%, taking account of manure substrate only.

7.3.2 Where co-substrates are based on energy crops, maize is likely to dominate. The figures below consider the orders of magnitude involved where biogas is used to generate electricity for sale to the grid, assuming the energy crops are responsible for direct land use change.

| | | |
|---|---|---|
| Maize carbon footprint (excl. LUC) | 0.180 | kgCO2/kg |
| Yield | 205 | m3/t |
| Net cal val | 7.50 | kWh/m3 |
| Energy potential | 1,538 | kWh/t |
| Energy potential | 1.54 | kWh/kg |
| Conversion to electricity efficiency | 35% | |
| Electrical output per kg maize | 0.538 | kWh/kg |
| Displacement electricity carbon saving | 0.525 | kgCO2/kWh |
| Carbon savings | - 0.283 | kgCO2/kg |
| GHG impact excl. LUC | 0.180 | kgCO2/kg |
| Net GHG impact | - 0.103 | kgCO2/kg |
| | | |
| Maize yield | 18.0 | t/Ha |
| LUC (unknown origin) | 37.0 | tCO2e/Ha/yr |
| LUC impact | 2.1 | kgCO2e/kg |
| GHG impact incl. LUC | 2.236 | kgCO2e/kg |
| Carbon savings | - 0.283 | kgCO2/kg |
| Net GHG impact | 1.953 | kgCO2/kg |
| | | |
| LUC (UK grassland conversion, historic) | 7.0 | tCO2e/Ha/yr |
| LUC impact | 0.389 | kgCO2e/kg |
| GHG impact incl. LUC | 0.569 | kgCO2e/kg |
| Carbon savings | - 0.283 | kgCO2/kg |
| Net GHG impact | 0.286 | kgCO2/kg |

*Figure 7 Indicative Net Benefits from Energy Crops in Biogas Production*

7.3.3 NB – the land of unknown origin approach no longer applies under recently published revision PAS 2050: 2011.

7.3.4 When land use change is accounted for, there is generally no net benefit when using the grid electricity carbon factor of 0.525kgCO2/kWh. There are other figures that may be used depending on the marginal grid loads displaced, but the above provides an order of magnitude. What it demonstrates is that where there is uncertainty over the origin of the energy crop, the impacts are potentially highly adverse in climate change terms. Where more local energy crops are used, but they cause land use change from grassland to cropland, the net benefit is significantly adverse also. Only where LUC is ignored, or not an issue can energy crops provide a small climate benefit when used in AD for power production.

7.3.5 Pas 2050: 2011 does not yet account for indirect land use change emissions. For example, energy crops grown in the UK on historically arable land would not create direct land use change, but in the gloal land market, would have an impact. These impacts are not accounted for due to the ongoing evolution in suitable calculation methodologies. Future revisions of the document will take this into account. Further, the document notes that soil carbon is not accounted for unless supplementary requirements exist.

# 8 KEY FINDINGS

8.1.1 This study provides context for understanding the environmental benefits of AD in industrial farming practices. It is apparent that different countries have adopted widely varying approaches to AD. Where take-up of AD technology is significant, it is as a result of national financial support programmes. The drivers for such programmes have been varied and include strategic energy diversification, manure management, waste stabilisation, greenhouse gas savings, and the promotion of renewable energy.

8.1.2 The value of the energy generated from AD is the most important revenue stream for the viability of the technology. The comparative data regarding energy output makes it clear that the energy value of manure-only systems, and therefore the commercial value, is very limited. Manure tends to have a biogas potential which is only $1/10^{th}$ of an energy crop.

8.1.3 This has resulted in two different approaches. In Denmark, manure is collected from farms and taken to a central plant. This achieves a critical mass of input, and allows significant quantities of heat and power to be generated. In Germany, the global leader in AD, energy crops have been incentivised and now account for 73% of the power generated from AD. Indeed plants in Germany originally set up for manure digestion are changing to energy crops to maximise the energy output and feed-in tariff revenue.

8.1.4 The mixing of co-substrates tends to be driven by the availability of waste streams to the plant operator, the optimisation of biogas output, and the price of the substrates. It is not primarily driven by a requirement for balancing manure with crop material for biological considerations.

8.1.5 Maize tends to be the dominant crop, and research is ongoing into energy-specific varieties that maximise digestible content. The higher end of maize yields are 18t/Ha. AEBIOM notes that maize is a controversial energy crop due to its high water footprint, and the inputs required for successful growth. UK policy is currently non-specific regarding energy crops for biogas, leaving the market to decide what creates the best return on investment.

8.1.6 The proposals for Foston pig farm propose the co-digestion of a range of other substrates together with the manure. The mix proposed is 35,000tpa pig slurry, and 45,000tpa other substrates. If the other substrate comes to be dominated by maize, the land area required would be 2,500Ha for the energy crops. This is in addition to the 2,000Ha required for the pig feed. The proposals are currently non-specific in terms of where the co-substrate will be derived from.

8.1.7 The reliability of AD technologies seems to vary significantly. The market leaders – Denmark in manure-based systems, and Germany overall – favour continuous and semi-continuous feed systems rather than batch processing. Both Foston and Nocton are proposing batch processing. Germany and Denmark also state the importance of a stable and consistent substrate that allows the digestion to stabilise and maximise gas outputs. Controls and analysis of the substrate prior to digestion are essential for this. In Denmark, almost all systems have had their financial difficulties. In Germany, the capacity factors average at 75%. In the UK, the average capacity factors are between 8% and 30%. Modelling assumptions in recent work undertaken for the Department for Energy and Climate Change use a load factor of 91.5%, which seems high in light of the UK and German experience to date.

8.1.8 There are numerous anecdotal instances of AD technology under-performing. Manure-only systems have suffered from outputs well-below what was predicted by designers, and other plants have suffered from poor design. Designs and technologies tend to vary significantly as there many varying factors in the biological processes of AD, and many different opinions on the best type of design. This heterogeny is partly symptomatic of an immature industry, but also perhaps a result of trying to control a biological process using a wide variety of different substrates.

8.1.9 The AD process tends to stabilise wastes and kill pathogens and other living contaminants such as weed seeds if controlled correctly. The raw substrate and the digestate differ mainly in carbon terms – the nutrients are largely retained, and increase in proportion as carbon is lost to the production of biogas (CH4 and CO2). Some nutrients have higher bioavailability according to studies undertaken. The major benefit of digestate over raw slurry though is in the fact that it is homogenous, and can be analysed with precision. Increased accuracy in analysis leads to reduced 'contingent' fertilisation from mineral fertiliser – ie avoiding the need to 'be on the safe side' when calculating supplementary fertilizers. In Denmark, the digestate comes with an NPK label. There are more complex questions about the associated N2O emissions of raw fertilizer vs digestate. This study is unable to draw conclusions regarding this issue.

8.1.10 With regard to lifecycle assessment, there have been some studies, but it is a very difficult area in which to generalise. The standard methodology, PAS 2050:2011, does not yet account for indirect land use change, nor soil carbon issues. Each and every AD plant would have its own considerations. The Nocton proposal undertook its own footprinting exercise. Extrapolating in the absence of any commentary on the results, it would seem that the AD plant has the potential to save 6% of the emissions associated with the milk production. This number has been sense-checked by running the NNFCC calculator on the proposed 75,000 tonnes of slurry – it suggests the slurry component would only contribute half of this saving (3%). A basic calculation regarding Foston would indicate savings of approximately 15%.

8.1.11 Considering maize energy crops alone for AD energy production, there is a minor benefit where direct and indirect land use change is not caused. This is considered unlikely in global land markets. Where direct land use change is accounted for in the UK, there is a net impact rather than a benefit. Indirect land use change would also have associated emissions, but these cannot be quantified under the current methodology. The considerations for soil carbon and different agricultural systems are also not accounted for under PAS 2050, but may be a significant consideration in terms of both animal feed and energy crops for AD systems in industrial farming practices.

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