

# Get fit with anaerobics: The business case for anaerobic digestion

17 Mar 2009 | Author: [Dr Michael Gell](#)



A third of UK food goes to waste

Supermarkets are trialling anaerobic digestion as a way to generate energy and minimise their waste, and soon the biological process could have a far wider reaching application

With a spate of announcements on anaerobic digestion (AD) – from supermarkets using the biological process to handle their organic waste to the building of a national AD biogas network - something seems to be exercising decision makers. Are those bacteria that digest food waste at last going to be harnessed to their full potential? Dr Michael Gell examines the potential for AD to kick-start the building of an integrated biowaste infrastructure and to become one of the star technologies feeding energy into a renewables supergrid.

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**What are the prospects for a renewable gas network?**  
**What innovations might we expect with AD technology?**

**What is anaerobic digestion?**

AD is a natural biological process in which biodegradable waste is broken down by micro-organisms (bacteria) in the absence of oxygen. The process takes place in an airtight reactor vessel, with feedstock put into the vessel and biogas, biofertiliser and waste water taken out. Feedstocks for AD include farm manure & slurry, bioenergy crops (eg maize), sewage sludge, kitchen & catering waste, retail food waste, and food processing waste. Biogas is made up mostly of methane (about 55-70%), the main constituent of natural gas, and it can be used as a chemical feedstock or fuel. The other components of biogas are carbon dioxide (about 30-45%) and traces of hydrogen sulphide.

In the process of being worked on by bacteria, the feedstock material goes through a number of different biochemical processes converting it to intermediate molecules including sugars, hydrogen and acetic acid before finally being converted to biogas. There are a number of different types of bacteria involved in AD each suited to different functions, such as producing acetic acid or generating methane. The amount of biogas produced varies with amount and type of material fed into the vessel, and the rate of decomposition can depend sensitively on conditions (eg temperature) inside the vessel. Although AD is a multistage process, the different bacteria are present at the same time in the vessel and so it is important that the conditions inside the vessel are just right – not favouring one sort of bacteria over another. It is a close-knit bacterial community inside the AD vessel!

**How does AD work?**

In simplified terms, there are four key biological and chemical stages of AD. The first stage is called hydrolysis and is a chemical reaction in which large complex organic polymers in the feedstock are broken into smaller parts through reaction with water. The smaller molecules are simple sugars, amino acids and fatty acids. The second stage is called acidogenesis and through this process further simple molecules are created ready for the third stage. The third stage is acetogenesis and results in the production of acetic acid as well as carbon dioxide and hydrogen. In the fourth stage, called methanogenesis, bacteria work on the intermediate products of the preceding stages and convert them into methane, carbon dioxide and water. It is the methane and carbon dioxide which form the main components of biogas, which can be extracted from the AD vessel. The material remaining in the vessel (after about one to four weeks) which the bacteria cannot feed upon along with the dead bacterial remains make up the digestate.

Conditions inside the vessel affect both what happens in the four stages of AD and also the final products. Important parameters are temperature (the AD vessel is generally kept between 35 and 55°C using recycled heat) and pH (methanogenesis is sensitive to both high and low pHs and occurs between pH 6.5 and pH 8). An important concern is the presence of hydrogen sulphide in the biogas. Hydrogen sulphide, arising as byproduct of sulphur-reducing bacteria in the vessel, is corrosive and care needs to be taken to make sure it doesn't attack the gas-handling and energy generating equipment connected to the AD vessel. One of the benefits of AD is that it allows both a mass and a volume reduction of the input waste. Between 40-60% of the organic matter in AD process is converted to biogas, the rest is left as the odour-free digestate. When an AD process has completed, the vessel is emptied leaving about 10-15% behind which acts as a seed culture for the next batch.

### **AD as a production process**

AD is a process that does occur naturally within a landfill, which accounts for why landfills produce biogas, and is a process that has traditionally been used for waste treatment. Now, however, interest is growing in the use of AD, artificially accelerated in closed vessels, for dealing specifically with organic waste, such as food waste, and the potential for harnessing the biogas and solid biofertiliser. The AD process has been applied to many agricultural and processing wastes as well being an important element in sewerage treatment plants. The nutrient-rich digestate can have a variety of uses, such as spreading on land for agricultural purposes, horticultural uses, and soil cover for landfill sites.

From an engineering point of view, AD can be viewed as a challenge in optimisation and the way that optimisation is done depends on what is required from the production process. The objective may be to optimise for biogas generation as a fuel or to optimise the quality of the digestate for horticultural purposes. There are a number of different process configurations around which AD systems can be designed and engineered. Typical considerations include whether the process is batch or continuous, pretreatment of the feedstock, temperature control, solids content, dry or wet, stirring inside the vessel, and complexity (eg single stage or multistage process). The quality of the feedstock material put into the AD process affects the quality of the end product. In some AD plants, various materials (metals, glass, plastics) are removed from the feedstock.

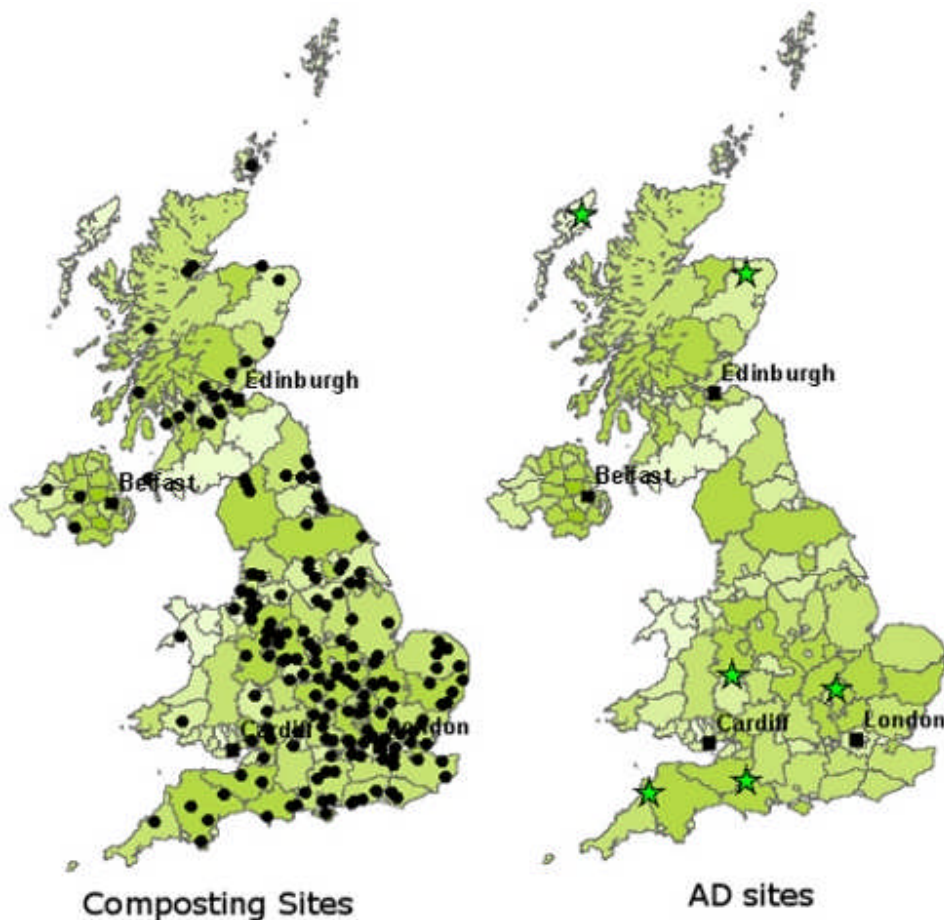
### **How widely is AD being used?**

AD is widely deployed in many countries, both developed and developing. AD

has been deployed extensively in some European countries.

In Germany and Austria, for example, thousands of anaerobic digestors are used for generating electricity. Biogas can be used to generate electricity through a generator (eg CHP unit). Alternatively the biogas can be cleaned and used in other systems, such as compressed natural gas for transport or feeding into a gas distribution network. In the French city of Lille, most of the city's buses and refuse lorries are running on biomethane generated by domestic household waste and sewage.

In the UK the water industry is a major user and treats about two thirds of the country's sewage sludge using AD. The UK water industry plans to generate about 0.8 TWh/yr of electricity from AD by 2010. In the waste and farming sectors in the UK, however, AD is still under deployed. In the UK there are about 20 on-farm systems, with less than 0.1% of livestock manures treated by AD, and only a very small number of centralised AD systems that serve many sources of waste (see [WRAP location maps](#) featured below, comparing centralised composting sites to centralised AD systems).



## **Recognising the potential for AD**

AD has been recognised as having great potential as part of an integrated waste management system, because AD reduces the emission of greenhouse gases (GHGs) from landfill. Last month the UK's Department for Environment, Food and Rural Affairs (DEFRA) set out a ['shared vision'](#) for AD in the UK, with the aim of making the process an established technology by 2020.

Rather than continuing to send organic waste to landfill each year, DEFRA hopes to use AD to produce a renewable gas, helping to reduce fossil fuels, as well as generating digestate. As well as reducing the reliance on landfill, which is becoming a scarce resource in itself, the heat and power generated through AD could be used to run more than two million homes. An ability to process waste on a commercial scale without using slurry has been demonstrated as part of a £30 million trial in Ludlow, Shropshire, by Greenfinch, an engineering firm working with government backing, in partnership with South Shropshire District Council.

Are there alternatives to AD? There are but they each have drawbacks or limitations. For example, aerobic digestion requires energy and more land, composting produces low grade heat, incineration produces heat that may be utilised but has various environmental issues, and gasification requires dry wastes to generate fuel gas. AD also has its drawbacks. In general terms AD plants are more expensive than aerobic composting systems. AD also is not good for breaking down cellulose and lignin (in wood).

## **Turning waste into useful products**

AD has received significant UK government support as a waste treatment option. In terms of electricity generation, the use of AD attracts double Renewable Obligation Certificates (ROCs), although there is disquiet in some quarters that electricity-from-AD is favoured over heat-from-AD. In terms of the digestate, a Quality Protocol (PAS 110) has been established and addresses the uncertainty over when waste is fully recovered and ceases to be waste (within the meaning of Article 1 of the Waste Framework Directive 1975). The Quality Protocol clarifies when waste controls are no longer required and gives users of the digestate the certainty that the product conforms with a standard.

If AD digestate does not fall within the scope of the Quality Protocol, the producer must comply with the appropriate waste management control for the digestate's transportation, storage and use. A range of other regulations may apply to AD facilities depending on their throughput (for example, planning permission, environmental assessment, waste management licence, pollution prevention and control (PPC) permit, surface water discharge consent, building regulations, fire regulations, ATEX). Despite this complexity, what we are seeing through the

Quality Protocol is an example of how the economy is moving to transform waste into product and how the regulatory environment is being adapted to encourage this smarter use of resources, give confidence in the use of the product, and encourage the development of new infrastructure and markets. PAS 110 has been drafted specifically with two end-markets in sight (agriculture and land restoration) and illustrates an emphasis on biological solutions to waste problems.

### **What are the environmental benefits of AD?**

AD also has an important role to play in the fight against climate change. There are four ways in which AD of food waste, for example, can be used to reduce GHG's.

- preventing the uncontrolled emissions of methane from landfill (methane is a GHG which is 25 times more potent than carbon dioxide). For example, if digested, rather than sent to landfill, capturing the biogas from one tonne of food waste will save between 0.5 and 1 tonne of CO<sub>2</sub> equivalent.
- displacing agrichemical fertilisers through the use of biofertiliser thereby reducing the need for carbon-intensive mineral fertiliser
- reducing the transport of waste to centralised landfill sites, especially as a network of decentralised AD facilities gets built
- production of renewable electricity, fuel and heat

The UK produces over 100 million tonnes of organic material per year that could be used to produce biogas. The majority (about 90 million tonnes) is agricultural material such as manure and slurry, about 12-20 million tonnes is food waste (approximately half of which is municipal waste collected by local authorities, the rest being hotel or food manufacturing waste), and nearly 2 million tonnes is sewage sludge.

In addition to reduction of GHGs, AD has other benefits, some of which are environmental and others economic. On the environmental side, the deployment of AD improves air quality (through odour reduction) and reduces emissions of ammonia and oxides of nitrogen and reduces pollution of water from nitrates and pathogens compared to aerobic digestion. The digestate is easier to handle and also does less damage to crops.

### **Economic opportunities with AD**

On the economic side, incentives for AD will stimulate the development of a new infrastructure, based on biosystems.

An integrated infrastructure has the potential to develop synergies between municipal solid waste disposal, agricultural waste disposal and renewable energy generation. There are opportunities for businesses to work with each other and their supply chains. Similarly, local authorities will need to consider where anaerobic digestion can contribute to achieving their waste management, recycling and low carbon emission goals.

This will lead to the creation of new jobs, requiring new skills. By producing renewable energy, AD offers the opportunity for farmers, water companies and companies with large volumes of food waste to reduce their energy bills and disposal costs while, at the same time, reducing their environmental footprint.

The sale of surplus energy and digestate (treated material from anaerobic digestion plants) offers a potential additional revenue stream and valuable diversification for rural businesses. From the point of view of national energy security, the use of local organic waste to produce energy locally means that there is less reliance on gas imports.

### **What is driving the surge in interest in AD?**

There are several drivers for the interest in AD. Legislation is an important factor, with the EU Landfill Directive, UK WET Act and LATS, UK Landfill Tax, targets for recycling and recovery, Animal By-products Regulations, and Renewable Obligation Certificates (ROCs). Renewable generators can sell ROCs to Power Companies. In the background there is also the EU Draft [Biowaste](#) and Soils Directives.

On the international scene, there is the [Methane to Markets Partnership](#), the International Energy Agency [Bioenergy Implementing Agreement on biogas](#) (Task 37), and various collaborative programmes on sustainable agriculture.

The EU Landfill Directive, in particular, has been influential because AD is an excellent technology for diverting organic waste away from landfill. Regulations, introduced by the Environment Agency, require all businesses to demonstrate treatment of their own waste in either a physical, thermal, chemical or biological process, while landfill operators must also demonstrate they are not accepting waste from business without it being treated.

The emergence of legally binding long-term frameworks to cut carbon emissions and adapt to climate change in various countries will without doubt strengthen interest in AD as a climate change mitigation technology. For example, the UK Climate Change Act, which became law on 26 November 2008, commits the UK to reduction of GHGs by at least 80% by 2050. Similar legislation is being considered in other countries.

## **Who are the key stakeholders for a national AD infrastructure?**

DEFRA's shared vision identifies some of the key stakeholders in a national AD infrastructure and their plans for AD.

Food and Drink Federation (FDF) members will seek to send zero food and packaging waste to landfill from 2015 and AD will make an important contribution to achieving this. The Milk Roadmap sets out the vision for the dairy industry towards 2020. This sets targets of 30 dairy farms piloting on-farm AD by 2010 and 3 centralised anaerobic digesters at processing sites by 2015. Dairy UK is working with its members on AD feasibility studies.

National Farmers' Union and other representatives of the agriculture sector will lead the use of 1,000 anaerobic digesters by 2020. At present there are estimated to be only about 20 in existence.

The digesters are expected to make many farms self-sufficient in electricity. Any excess could be passed on to the national grid. The water industry will be an important part of a national AD infrastructure as well as National Grid.

## **Carbon footprints in the food waste chain**

About 20 per cent of our GHG emissions are related to the production, processing, transportation and storage of food. According to WRAP, a third of the food we buy in Britain ends up being thrown away, which amounts to about 6.7 million tonnes of food each year. What are the carbon footprints associated with the food waste chain and what reductions could be achieved through the use of AD?

The supermarkets have an important role to play in helping to reduce food footprints and their CSR reports and websites are a useful source of statistics. With a few approximations, the waste generated in the UK supermarket sector is about 1.4 Mtonnes, of which about 0.9 Mtonnes is recovered waste (mostly packaging) and 0.5 Mtonnes is disposed of waste. In terms of the disposed of waste, assuming that it is mostly food-related waste, fruit and veg is roughly about 30% and other foods (bakery, meat, fish, etc) is about 70%. Our estimates of the carbon footprints of these waste streams are fruit and veg waste 0.3 Mtonnes CO<sub>2</sub>e other food waste 1.8 Mtonnes CO<sub>2</sub>e.

These should be taken only as indicators of waste-based CO<sub>2</sub>e at the supermarket point in the food waste chain. Once food waste goes into landfill, there are further emissions (eg of methane) which need to be taken account of. Using the numbers above for supermarket food waste, and assuming that 50% of the carbon in food material going to landfill contributes to the formation of landfill

gas, the methane given off by supermarket waste food as it decomposes in landfill sites, is the equivalent to about 1 Mtonne CO<sub>2</sub>e. Going through similar calculations for all of the food waste in the UK, the amount of methane from landfill would be about 13 Mtonnes CO<sub>2</sub>e. This footprint should be added to the carbon footprint associated with embodied emissions in the food, before it became waste, and that amounts to some 28 Mtonnes CO<sub>2</sub>e. Thus, the UK generates approximately  $13 + 28 = 41$  Mtonnes CO<sub>2</sub>e each year through its activities in wasting food.

If waste food were to be diverted to AD, our calculations of AD biogas production indicate that (each year) the supermarket waste food would generate in the region of 0.08 Mtonnes methane (assuming 100% collection of food waste for AD) and the UK waste food would generate in the region of 0.3 Mtonne methane (assuming 50% collection of waste for AD). These are significant amounts of renewable gas to inject into a national gas infrastructure, and that is just from food waste.

### **What are the supermarkets doing?**

So far, there are only a handful of commercial-scale AD facilities in the UK, although the technology is attracting considerable interest from both farmers and food waste producers. The EU ban on sending former foodstuffs – cooked foods containing meat, fish or animal derivatives – to landfill, an extension on 2003 ban on sending raw meat and fish wastes to landfill under the Animal By-Product Regulations, as well as the drive to reduce carbon footprints is encouraging the supermarkets to explore the use of AD.

Supermarket chain Waitrose has started a trial to use food waste from five of its stores. Food waste is collected from stores in Northamptonshire, Bedfordshire and Cambridgeshire and taken to the Biogen AD plant in Bedfordshire, where waste is treated in 42,000 tonne capacity plant which has been in operation since 2005. Electricity generated at the AD plant goes into the national grid and currently has the capacity to provide the power requirements of over 500 homes.

Marks & Spencer is encouraging its suppliers to build AD plants on their farms, to process waste such as grass and manure, and is offering contracts to purchase the renewable electricity they produce. Sainsbury's, whose 800 stores send 60,000 tons of food waste to landfill sites annually, has indicated that some of its waste will be taken to AD plants instead. Sainsbury's has been running trials of AD systems with London-based Axion Recycling and technology provider Greenfinch. The supermarket is planning to build up to five £8m regional anaerobic digester plants by 2010, in order to process all of the food waste from its nationwide supermarket chain.

## **Is AD commercially feasible?**

Capital costs for an AD facility range from about £0.3 to £0.8 million for on-farm AD plant up to about £2.5 million for more complex systems capable of handling many thousands of tonnes of food waste each year. The high costs derive from requirements for safe gas handling, to provide good gas seals to prevent air getting into the vessels, internal environmental controls and sensing and monitoring systems, such as the detection of low levels of concentration of hydrogen. Clearly access to funding could be an issue for many businesses, although the potential to establish integrated biosystems suggests the potential for many collaborative ventures across sectors.

Given the high capital costs it is important therefore for incentives to encourage the development of an AD infrastructure. These can be both legislative and financial, such as the opportunities for businesses to generate new revenue streams. There are various income streams available for an AD operator and these include income available from generated electricity and heat as well as gate fees for taking waste. Revenue can also be generated from selling digestate.

Capital grants, low-interest finance, or project development support could usefully be used to stimulate take-up at the smaller on-farm scale. The wider supply chain may also have a role to play in overcoming the capital cost of AD, particularly when it comes to product differentiation.

The NFU believes that future deployment of AD technology in the UK is likely to involve on-farm digesters and larger centralised AD plants. Centralised AD plants might be located on rural industrial estates or close to food processing facilities, and could perform a role in localised treatment of municipal wastes, e.g. at the scale of a market town. These could also be located on farms. Centralised AD plants are likely to be more profitable than single-farm plants, although they will have longer design and planning lead times.

## **What are the prospects for a renewable gas network?**

National Grid has called for a multi-billion pound investment in AD and gasification facilities to turn biodegradable waste streams including food waste and wood waste into biogas to heat up to half of the UK's homes. The National Grid study suggests that a UK-wide biogas network could be developed at a cost of around £10bn and that by 2020 waste streams including food waste, biodegradable waste, food waste and agricultural waste could be used to meet up to 18% of the UK's total gas demands, and up to 48% of its residential gas demands. At a cost of about £10bn, a biogas network would be highly competitive with other forms of renewable energy, such as wind power, and will provide a domestic replacement for declining North Sea gas reserves.

The [report](#) calls for an overhaul of renewable heat policy and a new incentive scheme to encourage renewable gas producers to inject biogas into the gas grid rather than generate electricity from it, as they are currently incentivised to do under the government's Renewables Obligation scheme. It also calls for a new regulatory framework to clarify the roles and responsibilities of the gas transporters who will have to provide renewable gas connections and continued financial support for R&D into renewable gas production and upgrade technologies

### **What innovations might we expect with AD technology?**

Owing to the complexity of the AD processes, key challenges with the technology revolve around how best to manage mixed waste streams and optimisation of the plant to maintain consistent yield of biogas. Digesters for food waste tend to be more complex and expensive as they must recover bacteria in the effluent (eg using a down-flow filter bed or an upflow sludge blanket), involve more operator training, and are also prone to acidification and failure. Increasingly AD plants are having to handle more complex feedstock and varying volume streams. Although requirements in terms of reliability, stability and robustness are significant such plants can produce a high yield of biogas of a high quality, and this may incentivise investment.

On the technical side, AD offers many applied research challenges and therefore scope for partnership between R&D oriented and commercial waste enterprises. Some of the challenges that need addressing relate to standard operations and tradeoffs (eg temperature, reactor size, flow rates, sensitivities, yields, costs) of reactor performance because these translate directly to business performance (of the waste management service provider) and investment performance. From an investment point of view, it is useful to note that integrated biosystems and their supply chains are scaleable, and investigation of options for such systems is another area of active investigation.

AD offers a promising opportunity to harness a technology for producing renewable energy, diverting materials away from landfill, reducing greenhouse gas emissions and producing biofertilisers. In addition there is the potential to improve energy security as well as create new jobs. That is an opportunity the UK government, if it is serious about a 'green new deal' for the economy, may not want to miss out on.

### **Respond:**

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