Anaerobic Digestion

a technical briefing

for local group campaigners

NOVEMBER 2012

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CONTENTS

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INTRODUCTION - WHAT IS ANAEROBIC DIGESTION?

Anaerobic Digestion (AD) is a biological process in which bacteria digest organic matter in a sealed vessel so it is deprived of air. The decomposition of the organic matter produces biogas. The composition of biogas varies, but typically comprises 55% biomethane, 40% CO_2 and 5% other gases, including hydrogen sulphide (H_2S) and traces of ammonia (NH_3). Within an anaerobic digester this process is contained - which means that the biogas can be collected and used to generate renewable energy.

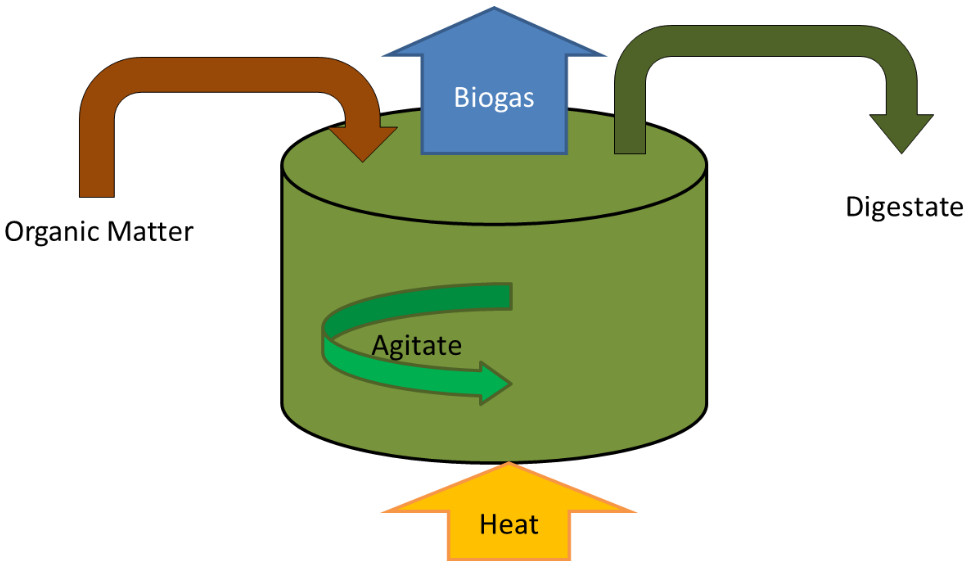
The digester is run to maximise the proportion of biomethane in the biogas.

AD is a natural process that occurs, for example, when you see bubbles coming up in a garden pond. It has been used in the UK since Victorian times for sewage and waste water treatment – sewage gas was used in 1895 in Exeter to light the City's streetlights. The Anaerobic Digestion Portal[1] states there are currently 91 sewage works in the UK using AD.

AD should not be confused with in-vessel composting (IVC), which is an ***aerobic*** process. Both involve bacterial action but the bacteria, processes, feedstocks and outputs are very different. While green garden waste can be disposed of using IVC, the AD process is not suitable for disposing of green garden waste due to the levels of lignates. The regulatory regimes, machinery and risk factors are also different.

General Layout of An Anaerobic Digester

The diagram below illustrates a generic AD plant and the process.



1. A wide range of organic matter can be used, although digesters like stability so consistent supply of material with limited variation is desirable. The organic matter is generally referred to as "feedstock". This is discussed further below.
2. A 50,000 tonnes per annum AD plant might require an 11 metre high cylinder with a base diameter of 30 metres. However, the design of AD plants is changing all the time. Some

[1] See page 19 "Other Sources of Information"

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new and innovative designs incorporate fully recyclable plastic tanks as well as an increased emphasis on low carbon build and operation. More attention is also being paid to the aesthetics – for example some AD tanks are horizontal rather than vertical and these tanks are mostly buried underground, removing the need for 9-12 metre towers.

THE ANAEROBIC DIGESTION PROCESS

3. Once in the digester vessel, the feedstock is stirred or agitated to enable the organic matter and bacteria to mix. There are four key processes performed by different bacteria[2]:
   - Hydrolosis
   - Acidogenesis
   - Acetogenesis
   - Methanogenesis
4. The AD process is not fast. Organic matter can be in the digester for 30 to 60 days (known as the retention time). There are advantages to having as high a retention time as possible (e.g. more gas collected and less smelly digestate), but these are offset by the higher capital costs of bigger tanks. In simple terms this means that doubling the retention time from 30-60 days requires double the tank capacity. Typically, longer retention times apply to slurries where an animal has already digested the material and the AD process is in effect secondary digestion.
5. The other driver of digester size is the volatile solids[3] loading. This varies according to the design of digester and the feedstock.
6. The tank needs heating as the bacteria thrive at elevated temperatures. There are two possible regimes –
   - *Mesophillic*, which thrive at around 39^{o}C and
   - *Thermophillic*, which are happier at 55-60^{o}C. The heat required to raise the organic material/contents of the digester to this temperature is significant, as are the thermal losses. This has significant energy and cost implications. The overwhelming majority of plants operate in the *mesophillic* range.
7. If a digester loses temperature the biogas yield falls as bacterial activity diminishes. If the temperature loss is substantial or protracted bacteria start to die. If the biogas yield falls recovery takes time, possibly months, as the numbers of bacteria have to grow through reproduction. An AD operator is in fact a bacteria farmer – success depends upon being able to provide feed and a convivial environment for the "bugs".
8. To ensure that the various species of bacteria have constant access to nutrients, digester contents are agitated either by mechanical pumps or (increasingly) by bubbling gas through them. Traditional stirring is very energy intensive so the gas based system has the advantage of being cheaper and having no moving parts and is thus more reliable. The very latest agitation technology involves a patented system of using the gas generated to aggressively agitate the digestate, rather than passive bubbling. This technology is said to generate higher gas yields by virtue of the frequency and strength of agitation.

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[2] For those particularly interested in the chemistry there is currently (July 2012) a very full explanation of the chemical processes available on Wikipedia.

[3] Volatile solids are the parts of the feedstock that are converted to biogas by the bacteria. The proportion of the volatile solids is different for each type of feedstock. There is a reference list of yields on http://biogas-info.co.uk/index.php/biogas-yields.html

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9. This note is mainly concerned with mesophillic rather than thermophillic digestion as the latter is less common. However there are a number of AD plants using the thermophillic process. One appears to be the Vertal plant in Mitcham which happens to be where about 50% of the food waste collected by Waverley Borough Council is taken. This is not advertised as a thermophillic plant on the Vertal website but the food waste feedstock takes only 3 days to digest so we have concluded that it must be[4].

STABLE ANAEROBIC DIGESTION

10. Keeping the bacteria healthy requires many things. The more obvious are:-

- Maintaining the correct temperature
- Keeping pH within bounds – around pH 7 is ideal for the methanogenic phase, where the majority of gas is produced.
- Providing a constant amount of food, at a rate that all the bacteria can work at. This is more complicated than it may sound. Variation in the loading of Volatile Fatty Acids (VFAs) causes imbalances
- Maintaining the carbon to nitrogen ratio within a specific range

11. If something goes wrong bacteria will quickly die and biogas yields will fall. It is also likely that the composition of the biogas will alter, reducing energy yield and potentially causing ammonia which can lead to an odour issue with the digestate and other problems.

12. While much can be achieved through computer control to stabilize the process, external daily temperature variation, which can be as much as 20^{o}C, also has a significant impact on the process. Some of the most modern digesters incorporate insulation to counter some of the effects of external temperature swings and reduce energy consumption on heating the tanks.

WET AND DRY DIGESTERS

13. One common way of classifying digesters is into “wet” and “dry”. Whether a digester is a wet digester or a dry digester is determined by the feedstock being used. Food waste and cattle slurry are wet, maize silage is dry.

14. In most wet digesters, the feedstock is at a dry matter content of under 20% (more often under 10%) and it is simply pumped into the digester vessel. In a dry digester the dry matter content is over 25%. The feedstock is typically loaded into the digester floor by a loading shovel and left to decompose. The biogas is collected and, when the decomposition is complete, the digestate is removed by a loading shovel. Dry digesters are in fact very similar to IVC plants.

15. Wet digesters are larger than dry digesters with the same yield, but a dry digester is generally more expensive to construct and operate.

16. Wet digesters operate on a continuous process with a constant yield. Dry digesters tend to operate on a batch process with a varying yield.

17. Wet digesters are far more common, not least because most feedstock has dry matter content under 25%, and it is easier to reduce the dry matter content by adding water than reduce it by removing water. This has implications for the volumes and concentrations of digestate.

[4] As a Friends of the Earth local group will be seeking more information on this particular digester as clearly the energy required to heat the feedstock to the required temperatures must be very significant.

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FEEDSTOCK

18. While digesters can use almost any organic material (except lignates) it is useful to classify them into types. Different feedstocks have different handling requirements and fall under different legislation. An AD operator is basically a bacteria farmer. Keeping bacteria healthy is what generates biogas. Digesters cannot process lignates, i.e. woody materials (including straw) as the cell walls are too strong for the bacteria to break down. This is why AD plants do not process garden or forestry waste. Different feedstocks produce different volumes of biogas and mixing feedstocks (e.g. food waste with manure) can make a substantial difference to biogas output. Different feedstocks also require different pre-treatments and come under different legislative regimes.

SLURRY AND MANURE

19. AD requires bacteria and the best source of bacteria is manure. By far the most common manure used in AD is cow manure, usually from dairy herds, with pig manure coming second. The cattle are usually kept in concrete floored buildings, and the manure is removed with a minimum amount of straw in it. If stale bedding (i.e. manure and urine impregnated) is used the straw presents a problem and has to be chopped before being used for AD.
20. Cattle manure yields about $20m^3$/tonnes biogas, or about 5 KWh per tonne. The average dairy cow produces 20 tonnes of manure a year.
21. Generally the pre-treatment required for slurry is simply a macerating pump. If farmyard manure is also used then the chopping load will be higher as it is desirable to remove the straw as this is not digested. The digestate produced from farmyard manure is used in exactly the same way as cattle slurry, under the same spreading regimes.
22. There is some evidence to show that the Nitrogen, Phosphorous and Potassium (NPK) from digestate is taken up better by plants than it is from straight slurry, although the complexities of fertilising soil should not be underestimated[5]. The small number of AD plants operating in the UK means that only a small amount of trial data is available.

ENERGY CROPS

23. Leaving the ethics of growing energy crops aside for the purposes of this technical note, from an operator's point of view certain crops are particularly suitable for anaerobic digestion. The most common are maize, wheat and sugar beet. Maize is turned into silage, usually in clamps but bales are more efficient. Wheat is harvested before it is ripe, then baled and wrapped. This then becomes "whole crop" wheat silage. Sugar beet is grown and harvested in the normal way, and then chopped or pulped before being fed to the digester.
24. A comprehensive explanation of the use of energy crops including a comparison of yields can be found in the IEA Energy publication "Biogas from Energy Crop Digestion" by Rudolf Braun, Peter Weiland and Arthur Wellinger[6]

[5] A useful place to start research on this subject is http://www.environment-agency.gov.uk/static/documents/Business/Technical_report_for_anaerobic_digestate.pdf

[6] Biogas from Energy Crop Digestion http://www.iea-biogas.net/_download/energycrop_def_Low_Res.pdf

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WASTE SILAGE

25. The easiest way for a farmer to boost the yield of an AD plant it to put in higher yielding gas feedstocks. The most obvious material to use is silage, which is a well used cattle feed, usually produced on farm and stored close to the cattle sheds[7]. There is a relatively high wastage in clamp made silage, typically 5 -10%, as once the clamp is opened it is vulnerable to attack by the weather and air. For a 750 cow herd, housed for half the year, 5% silage wastage represents 350 tonnes. While this silage waste may not be palatable for cattle, the bugs in an AD plant are less choosy. The alternative, wrapping bales of silage, is not perfect as wrapping is susceptible to damage. Putting an additional 350 tonnes of maize silage through the digester would generate an additional 385,000KWh.
26. Silage however requires more processing than farmyard manure. As well as transporting it from the clamp to the digester, it will need more chopping to reduce fibre lengths (some chopping will have been performed in making the silage). It may also be necessary to add water to control the dry matter content of the overall feedstock, easing pumping and keeping the volatile solids loading within bounds.
27. The digestate produced by using silage can be spread back onto the growing areas under existing systems, thereby recycling at least some of the NPK[8].

VEGETABLE WASTES

28. Many vegetable wastes such as potato peelings and sugar beet pulp are potentially excellent feedstocks, having a high biogas yield.
29. Several vegetable processors are investigating AD plants, and some have been built. These AD plants are usually located on-site or near the vegetable processing company where the waste arises thus saving transport costs. There is also an on-site energy demand and a source of heat.
30. The treatment required for this waste is similar to that for silage (i.e. chopping and dry matter content control). The digested wastes can usually be returned to the farm, often as fertiliser to the vegetable growers supplying the AD plant. Unfortunately it is unlikely that there will be a return load of digestate on the vehicle bringing the feedstock as vegetable production is seasonal but AD plants run all year. This can significantly increases the space required to store feedstock and digestate on site.
31. Alternatively, those operating silage/manure digesters may contract to take in vegetable waste (possibly in place of energy crops). This may or may not add to the transport burden of the vegetable processor.

DAIRY WASTES

32. Dairy products generate waste from the parts of the milk not used. These are excellent AD fuels. Typically the AD becomes part of the waste water treatment at the dairy processing plant.
33. Dairy products also form a significant part of the waste from supermarkets, as once they are out of date they have to be removed from the food chain. While they are an excellent fuel, removing the cartons that they are stored in adds complexity and cost to the AD plant.

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[7] A dairy cow typically consumes 50Kg silage per day. http://www.dardni.gov.uk/ruralni/pub41_dpdb.pdf
[8] Nitrogen, Phosphorous and Potassium (Potash)

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Food Waste

34. The huge advantage of using food waste is that (at the moment at least) processing food waste generates an additional revenue source as a result of being taken out of landfill. This revenue, known as a gate fee, ranges from around £36/tonne to £60/tonne depending upon location and the sort of waste. Packaged food waste attracts a higher gate fee because of the need for more pre-processing and additional equipment. AD plants taking in food waste are subject to higher plant costs, planning issues are more complicated and expensive and they are also subject to more extensive regulation and controls, which again makes the cost of these facilities considerably higher.

35. Food waste comes in a variety of types:

- **Source segregated, unpackaged domestic kitchen waste**. This is collected on behalf of councils by waste collections businesses. Some counties and boroughs have separate waste collections for kitchen scraps, and these are perfect for AD, yielding about 150m^3 biogas/tonne. Others do not collect separately, so the food waste is enmeshed in the municipal waste and is generally not (yet) separated at waste transfer stations. Recent government changes to the Landfill Tax have meant that it is currently unlikely that non segregated waste will be processed through AD facilities. Kitchen scraps are deemed to contain animal by-products – i.e. meat and meat products, which means that any plant processing this type of food waste will fall under Animal By-product Regulations (ABPR) and needs to follow strict rules relating to the receipt and processing of the feedstock.
- **Unpackaged Commercial Food Waste**. Typically collected from restaurants, hotels, prisons, hospitals and schools. It is likely to come in skips or wheelie bins, and may have been bulked up. The collection contracts usually lie outside of local government responsibility and private operators compete for contracts. Little, if any, central data exists on locations and tonnage. Within this category is also the waste from food processors such as bakers. This waste makes excellent feedstock due to high biogas yields, but care needs to be taken by the AD operator to ensure that the feed to the digester remains constant. There can also be problems with pH, preservatives (which may kill bacteria), salt and the like. These issues are not likely to be problematic for commercial scale digesters as the volumes of contaminants are relatively low. However, although the food is unpackaged, there are material issues with contamination with anything from glass to cutlery. It also comes frequently with plastic bags – the biggest problem in recycling, followed by textiles. This feedstock is also subject to ABPR.
- **Abattoir Waste**. There are many AD plants that run on abattoir waste, although in the UK this is complicated by the precautions against BSE – so brain tissue and spinal cords of cattle have to be incinerated and cannot be treated in any other way. Animal blood is an excellent AD fuel, but other parts may need significant amount of processing (macerating and grinding) to make them suitable. Again, any AD processing abattoir waste will fall under ABPR.
- **Packaged Food Waste**. This is almost entirely out of date supermarket food, of which there is a bewildering array including sandwiches, soft drinks, and packed meat. While this is generally a good feedstock, taking advantage of it requires a de-packaging process (which adds at least £200,000 to the capital costs of the AD plant) and the subsequent removal of the packaging from the AD plant also adds to operational costs. Again, the operator has to be careful about maintaining digester stability. This feedstock is also almost certain to fall within ABPR.

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GLYCEROL

36. Glycerol (also known as glycerine) is a by-product of the bio-diesel industry. It is a very high yielding fuel, (over 500m^3 biogas/tonne) and has the advantage of containing no nitrogen. It is therefore often used by AD operators to maintain the carbon to nitrogen ratio. Most AD plants have the capacity to use a little glycerol.
37. When the biodiesel industry started glycerol was free. It now commands prices of £100 to £400 per tonne as it is a useful industrial chemical so it is not a cheap fuel.
38. Because glycerol is so high powered a fuel, it has to be used with caution as the large amount of volatile fatty acids produced can lead to "foaming" within the AD reactor. Generally levels of glycerol are kept to less than 5% (by mass) of the feed stock.

ENERGY PRODUCTION

39. Any significant AD plant must have a connection to the grid, be it electric or gas, Occasionally there are opportunities for the energy to be channelled through a 'private wire' to a neighbouring facility such as a factory.

40. Hypothetically there is no need for a grid connection if the AD plant is connected directly to an energy user. However in practice the energy user will already have a grid connection and will be unwilling to swap the reliability of the national networks with its multiple power stations for the risk of failure of one (or even two) small generators. As a result in almost all cases the grid will end up acting as a back-up and buffer by accepting surplus supply and relieving surplus demand. This can make for very complicated (and expensive) power purchase agreements (PPA) with the energy purchaser and the grid owner.

ELECTRICITY PRODUCTION

41. The most common use of biogas is to generate electricity by feeding it into a reciprocating piston engine, which in turn drives a generator. The advantages of this process are that it is simple, uses proven technology and produces energy in a form that can either be used locally or sold into the national grid. However, more recently the advent of biogas turbines may improve the cost and reliability of electricity and heat generation.
42. Supply of the resulting electricity into the grid is relatively straightforward, although the grid operators are (anecdotally) generally 'reluctant' to provide new grid connections for small plants. Not surprisingly, domestic grid connections are inadequate. The cost of a grid connection is significant and, if substantial additional power lines are required, can become exorbitant.
43. There are fundamental disadvantages to electricity production from AD:-
    - **Low Efficiency**. Small reciprocating engines driving generators are an inefficient method of producing electricity. Typically less than 40% of the energy available in the biogas is delivered into the grid as electricity. The remainder is converted to low grade heat, in the engine exhaust, the cooling of the engine and irrecoverable heat losses. While some of this heat can be recovered for use in heating the AD process through heat exchangers, these too have inherent inefficiencies. Even if more heat is recovered from the process than is needed in the AD (although this is unlikely if pasteurisation is involved) it is often hard to find a viable use for it.

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- **Low Voltage**. Small generators on AD plants operate at low voltages. This means that to raise the voltage to grid transmission levels requires the use of transformers, a further cost and efficiency loss.
- **Engine Damage**. Biogas contains H_2S and NH_3, both of which attack the oils and indeed the metals of the engine. While this can be contained, a high level of monitoring of the engine oil is necessary. If the digester gets a little out of kilter it can increase the levels of the attacking gases, with concomitant increased wear.
- **Inability to Store the Energy**. As electricity cannot be stored, there will be increasing pressures on the generation of electricity and the ability of the grid system to absorb it at all times.

44. Unlike landfill gas, biogas from AD should not contain significant levels of siloxanes, which increase engine wear.
45. The most efficient electricity producing AD plants are those on dairy farms and food processing plants, where there is use for hot water and electricity within the production process. On a dairy farm there are also plenty of acres to use the digestate.
46. Most food waste processing plants with AD currently generate electricity, there are very few producing gas for grid injection, although this is set to increase. Typically a plant processing 50,000 tonnes/year of food waste will produce about 1.5 to 2 MW electricity, and consume most of the heat produced by the generators in the AD and pasteurisation heating.

BIO-METHANE PRODUCTION

47. The alternative to turning biogas into heat and electricity is to remove the impurities and inject the resultant bio-methane into the gas grid. This has the attraction of avoiding the inefficiencies inherent in changing the energy from gas to electricity.
48. There are a variety of technologies available to remove the CO2, NH3 and H2S from the biogas. The biogas upgrade industry is fledgling across Europe with 3 main types of process – Pressure Swing Absorption (PSA), Cryogenic and Membrane technology. They are expensive and there are differing views regarding reliability and cost of operation. Prices for example for 100 cubic metres of biogas per hour range from c£300k for membrane technology to £900k for PSA. In addition the grid injection costs are added although these are falling.
49. The first challenge is to find a connection in the intermediate pressure gas rid, rather than the domestic one. Laying pipe is expensive, so proximity to the intermediate pressure gas grid is very important.
50. Then there is a specification for gas quality in the grid. Clearly any gas being injected has to meet this. In the UK, where parts of the gas grid are still iron, the specification contains a very low target for oxygen content compared to the rest of Europe (where the gas pipes are plastic). The grid companies are generally helpful in finding ways to achieve the target, but it is not straightforward. Currently, the Health and Safety Executive require a very low oxygen threshold – 0.1%, but are granting exemptions for oxygen content of up to 1% and this is likely to be adopted in the near future as a general standard.
51. Having upgraded the biogas to at least 97% biomethane, the gas has to be injected into the gas grid system. Until very recently, OFGEM would only allow this to be done with injection equipment that is used on North Sea gas interconnectors – there was simply no regulatory framework for biomethane injection. Depending upon the region this injection equipment could cost up to £1.5m per facility, However, OFGEM have now agreed a

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framework for biomethane injection, which will see the price come down initially to around £300,000. There is scope for further improvement but this is a good start.

52. The final piece of complexity can be adjusting what is known as the "Wobbe Index". This requires the addition of varying amounts of propane at the point of injection to ensure that the energy (the calorific value) content of the gas (which varies with pressure and temperature) matches the billing system. Biomethane is very close in composition to North Sea gas, but the latter has additional gases which enhance the calorific value (CV). Biomethane can only reach this CV by the addition of propane, which is both a fossil fuel and adds significant cost. For example, the propination plant can cost up to £200,000 to buy and install and then the running costs are £20-40,000 per annum. However, National Grid in conjunction with Bio Group has established an alternative option for certain areas, where propination can be avoided. In the UK's first AD plant built to put green gas into the grid, the biomethane is first mixed with North Sea gas to dilute it in the system, such that the issue of lowering CV is overcome. This cannot work everywhere, but where it does, it is both environmentally and economically preferable.

53. The gas clean up and injection process does not yield heat for the AD process. This means that the heat for the digester and pasteuriser has to be provided. Either some of the gas produced is burned, or waste heat is extracted from some other source – for example the exhaust from a kiln or industrial process. In a plant in Suffolk, heat is generated in the spring and summer using solar thermal panels to enhance the biogas boiler and maximise efficiency. As a rule of thumb in traditional AD systems, the heating requirement is 30% of the yield. In other words, for every 10KWh of methane produced in the AD, only 7KWh will be injected into the grid, the other 3KWh being used to heat the digester and pasteuriser. Using other renewable sources changes the profile of this. The advantages of co-locating with a heat source are therefore substantial.

DIGESTATE

54. The estimates provided by AD operators of the volume of the original feedstock which will emerge as digestate can vary. One operator puts this figure at 85%. What is beyond doubt is that it is always a very significant percentage and causes transportation and disposal issues. There are also tight regulatory constraints around the use and timing of use of digestate, which is applied to land.

55. A 2MW electrical plant processing 50,000 tonnes of food waste will produce in excess of 40,000 tonnes of digestate containing 120 tonnes of nitrogen. This will require an area in the order of 685 hectares or 1,700 acres of arable land to be spread on. Ignoring woods, towns and other non-agricultural land, that is a circle with a radius of one mile. The more dispersed this land bank is, the further the digestate will have to be hauled (by road) with concomitant increases in cost, congestion, CO_2 emissions etc.

56. Typically the digestate is 10% solids and 0.3% nitrogen, 0.05% phosphorous and 0.3% potash (potassium). Values vary widely, depending on the feedstock. The digestate also contains useful fibre and other trace elements. In a simple world it is a good, possibly excellent, fertiliser. As southern England is said by some to be rapidly approaching pre-desertification, it is very important that organic matter is re-introduced to soils and compost and digestate have an important role in this.

57. Unfortunately this not a "simple world". Most of the farmland in England is in Nitrate Vulnerable Zones (NVZ), and weather complicates agricultural processes of spreading fertiliser on the land. Moreover, all farms already have a fertiliser programme and

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changing to using digestate requires different spreading equipment – which is a cost that most farmers are unwilling to bear. The combined effect of farming cycles and the NVZ regulations mean that digestate can only be put to land around 10-12 weeks of the year.

58. Finally digestate is a waste product, and the Environment Agency requires form filling to enable it to be spread on land, or even moved. While the form filling is not particularly complex, it adds cost and time to a weather dependant process. However, in addition to the forms themselves, various soil samples and product testing has to be undertaken which adds to cost. The processing of the forms and issuance of the appropriate EA permits also takes at least 8 weeks.

59. A solution to this is the PAS110 standard – digestate that conforms to this is NOT viewed as a waste by the EA, and thus spreading it is easier (see below for more on PAS110). At the moment PAS110 does not permit use of digestate as a horticultural fertiliser (so it can't be used on domestic vegetable patches). The list of allowed uses is being refined and developed all the time. However, legislation is being planned in Europe which would reclassify all digestate as a waste – notwithstanding PAS 110, and this would cause massive problems to the traditional AD sector. Again in Suffolk, pioneering work is being done using biomass and capturing the CO2 from the gas upgrade so that the digestate itself is being upgraded to water that can be used in agriculture all year round. Near the Suffolk coast, the area has less rainfall per annum than Jerusalem, so water conservation and sustainability are key issues, and AD can be used as a contribution to the solution.

NITRATE VULNERABLE ZONES (NVZ)

60. Historically the enthusiastic application of nitrogen based fertilisers to farmland caused elevated nitrate levels in waterways. This affected the biology of the waterways, to the detriment of many fish species. The solution to this has been to limit the application of nitrogen in areas where this is a problem, and these are known as nitrate vulnerable zones[9]. NVZs have been successful in improving water quality and aquatic life, but they make digestate disposal more complex.

61. In a NVZ there is a limit to the amount of nitrogen that can be applied. For grassland it is 250Kg/Ha, for other agricultural land it is 175Kg/Ha. There are also constraints on proximity to water courses etc. Nitrogen fertiliser can only be applied between January and September[10] and if the land is to be grazed by cattle there is a block ban on grazing after an application of slurry, typically 2-6 weeks.

62. The AD plant needs access to a substantial land bank to spread its digestate. A 22,500 tonne/year AD plant will require around 750 acres of grassland or 1,000 of arable land. This is not a problem for slurry and energy crop plants (where the land is being used to produce the feedstock), but is a significant challenge for food waste plants. Spreading costs (which are borne by the AD plant operator) rise dramatically with distance that digestate has to be hauled. There are thus strong arguments for building food waste processing AD plants in rural areas and many farmers welcome the opportunity to reduce their chemical costs through the use of digestate.

63. The application of low nitrogen content fertiliser is protracted and complex. It must be integrated into the rest of the farm management. Many farm fields cannot be worked by tractors in late winter as the ground is too soft. If the field is a hay or silage field, applying in late spring will damage crops. This means that in practical terms there are probably

[9] The extent of NVZs can be seen on http://defranvz.adas.co.uk/a4website.pdf
[10] There is some local variation on this.

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only 3 or 4 windows of opportunity in any 12 month period to apply digestate to any one field.

64. During the non-application season all digestate will have to be stored (other than when the new technology referred to above is applied). For a 22,500 tonne/year plant this could require storage for 10 million litres of digestate.

ANIMAL BY-PRODUCTS REGULATIONS (ABPR)

65. ABPR are run by DEFRA, and they control the treatment of any waste (including food waste) that contains or might contain animal by-products. In practice, all food waste falls under ABPR.

66. The rules are complex. The most significant requirements are:
    - That all operations involving food waste have to be conducted in air tight buildings with bio-filters.
    - All the digestate must be pasteurised before it can be released for use as a fertiliser. The success of the pasteurisation is monitored by DEFRA, who test digestate for certain specific types of bacteria, including salmonella. Until the test is passed, the batch cannot be released, which further complicates the storage of digestate.

67. The practical effect of ABPR on the design and operation of the AD plant is as follows:-
    - A pasteuriser has to be included as part of the plant - this has to be capable of raising all digestate to a given temperature and holding it there for a required period of time. For instance a temperature of 68^{o}C would need to be held for an hour and the waste has to have a particle size of less than 12mm.
    - The heat load is significantly increased – although this can be mitigated through the use of a heat exchanger to recycle heat from the digestate as it exits the pasteuriser to that coming in
    - The site operator tests outputs on an agreed basis with the EA and has digestate samples tested at independent labs. The operator maintains records and self regulates on an ongoing basis, with the duty to re-process batches which fail the testing procedure. These records are audited by the EA as part of their regular inspections.

GROUND DAMAGE AND COMPACTION

68. Current nitrogen fertilisers are typically 35% nitrogen by mass. Sufficient fertiliser for one hectare for a year weighs a total of 714Kg. Applying the same quantity of nitrogen from digestate at 0.3%N requires 8,333Kg of digestate i.e. almost 12 times as much weight. The potential impact is 12 times as much ground compaction during spreading and, in the early season, the potential for substantial wheel ruts. It also requires 12 times as much energy (and therefore cost) to spread the digestate.

69. The ground compaction and wheel-rut problems can be solved, in part, by using low ground pressure machinery. While this exists it is expensive, still relatively rare and also unlikely to be in use on the farms close to the AD plant. It is therefore entirely possible that an AD plant operator will have to buy their own digestate spreading equipment.

DIGESTATE DE-WATERING

70. One way to improve digestate's utility as a fertiliser is to remove surplus water. At the AD plant to be built at Selborne Brickworks in Hampshire the proposal is to use a process

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called 'reverse osmosis' to get the water to a suitable quality to meet EA licence standards.

71. Separating solids from the digestate is relatively straightforward. The first step is to use a mechanical belt or screw press. This removed the larger solid components, typically at 25% dry matter (i.e. for each Kg of solid, there is also 3 Kg of water). The second step is to pass the liquid component through the reverse osmosis process, which will remove around 80% of the water, and that water will be close to potable[11]. The remaining matter is a thick liquid with a relatively high level of nitrates.

72. Unfortunately a de-watering plant is expensive, typically costing between £250,000 and £500,000. Its performance is largely dependent upon the feedstock's composition and the retention time of the digester. The plant is not cheap to operate either, requiring significant power and regular replacement of filters and membranes. It may even be necessary to add an aerobic digestion stage.

PAS110

73. A standard for digestate has been defined, it is called PAS110. Digestate meeting this standard is not a waste, and can therefore be transported and spread without further reference to the Environment Agency or DEFRA. The Soil Association has recently accepted PAS110 digestate as an organic fertiliser.

74. PAS110 limits the uses of digestate, specifically excluding horticulture and thus the retail market. There are plans to extend its application, but these are progressing slowly. In any case, the price of a 25Kg bag of compost is around £2.50 (or £100/tonne). Allowing a margin of 50% for the retailer and transport costs of £25/tonne leaves the AD operator £25 to bag, label, palletise and load one tonne of separated digestate. Operators maintain this is not financially viable.

OTHER ISSUES

LICENSING AND REGULATION

75. Operating an AD plant requires licensing. The administrative burdens of operating even a simple AD plant are significant. The licenses required depend upon the plant type and location.

76. The simplest is the purely agricultural plant. The farm will already be regulated by the Environment Agency and (if it has livestock) DEFRA (although there are restrictions on the processing of ABPR waste on cattle farms). The existing licenses will need amending, but this is not a major problem. Similarly an industrial plant will have existing licenses, and all that is required is to amend them.

77. A food waste processing plant taking animal waste has to obtain and maintain ABPR approvals through regular Animal Health inspections if the plant is to run under ABPR.

78. Waste management permits are not hard to get, but the process is complex. The process can take 6 months and cost £15,000 or more. The annual charges for the license will vary depending upon the site, but are substantial. The application cannot be submitted until planning permission is granted.

[11] Submarines use reverse osmosis to make their drinking water. The RO membrane is impenetrable by bacteria and larger molecules.

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79. In the case of an AD plant producing electricity, the energy grid operators will regulate the connection from the plant, possibly using third party contractors. They may well also monitor the actual performance of the plant in terms of efficiency and availability.

80. Other regulators involved are likely to include the Health and Safety Executive, District and County Councils, Environmental Health, OFGEM (which regulates the energy connections and markets and pays subsidies) and DECC.

SIZE OF OPERATING PLANT

81. At its simplest a digester comprises two or more large storage tanks, one of which is the digester vessel. Most digesters are cylindrical, and there are trade-offs between height and diameter. For a 10,000 tonne/year plant the digester may comprise one 25m diameter vessel, 8m high with a further 5m high gas holding membrane on top. Digestate storage would require another two vessels of similar size. New innovations include burying tanks, using recyclable materials and minimising visual intrusion.

82. If the plant is processing food waste it will require a feedstock processing building, which will also contain the pasteurisers and dewatering equipment. This will be at least 1,200m of floor area, with an eaves height of 8-10m and can have a ridge height of 12-15m.

83. The buildings are similar to modern agricultural buildings and an AD plant is a substantial construction, particularly when you add in offices, weighbridges, generators, and in some circumstances gas holders, flares and access roads.

LOCATION OF AD PLANTS

84. There is much debate about where best to site AD plants. There are a number of sometimes conflicting requirements. For straightforward agricultural plants growing and digesting energy crops there is a fair amount of flexibility. For those plants disposing of food waste the issues are more complex.

85. In general terms the key requirements for a successful and efficient AD plant are:

- on site access to the energy grid - an intermediate or high pressure gas grid connection being the preferred option – see above
- proximity to a bank of agricultural land to dispose of digestate – see above
- in the case of food waste plants, access to the road network
- a complimentary activity e.g. a manufacturing or agriculture or forestry process

COMPLIMENTARY ACTIVITIES/CO-LOCATION

86. For environmental (resource efficiency), financial and operational reasons it is desirable that the AD plant be co-located with complimentary activities. These will usually be energy users with a requirement for electricity, gas or low level heat.

87. The most appropriate type of complimentary activity probably depends on whether the AD plant is near a gas grid connection or will be using the biogas to produce electricity for the electricity grid.

88. A very example of a good complimentary activity for an AD plant with a gas grid connection is a brickworks. An AD plant adjoining a brickworks can produce biogas for

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use in the brick kilns. The brickmaking process will itself then produce a lot of surplus heat which can be captured to warm the digestate. As previously explained, all AD plants require some heat to warm the digestate and they usually take some of the energy they are producing to do this. This is what is called the 'parasitic load'. In the case of a brickworks, which obviously requires very high temperatures to make bricks, there may be more surplus heat than is required to heat the feedstock. Other possible users of low level heat could be for wood drying (for sustainable biomass) or to provide the heating for commercial greenhouses.

89. In the case of an AD plant on the electricity grid the best fit may be to co-locate with a heat producer because the surplus heat can be captured to warm the digestate and reduce the parasitic load.

90. However there may be operational and safety reasons, such as fire hazards, which mean that an AD plant cannot be included on certain sites.

91. In our experience the planning system currently lacks sufficient flexibility to be able to recognise the best sites for heart producers and heat users including AD plants. In the case of AD plants the current system is geared towards on trying to fit them into existing waste facility sites which often offer no opportunity for co-location or processes and result in energy being wasted.

ACCESS TO THE ROAD NETWORK

92. 25,000 tonnes of food waste in 20 ton loads (i.e. articulated tippers) represents 12 round trips per working day as not all tippers will be full. Disposing of the digestate is another 8 round trips per working day.

93. For planning purposes it is a requirement that any plant be located close to the HGV network – essentially the "A" road infrastructure. Typically the required proximity is 2Km.

ODOUR

94. Today well run AD plants are virtually odourless on the exterior. There can be a very faint odour when you are within a few feet of a plant but what you can smell is actually the biogas. However some of the early plants, through a combination of inappropriate design and bad operation, have a well-documented history of odour problems[12].

95. Odour problems in general only arise if waste is stored in buildings for several days and/or the odour treatment is insufficient. Food waste will always smell and it is how this is controlled and treated that is the key – the operation of a plant is key in this regard. Friends of the Earth local group members who have visited large AD food processing plants say that other than internally in the main food waste reception hall odour was not noticeable. If the AD process itself causes odour then this means that the sealed process is leaking, or that it is not digesting and undigested waste is being taken out of the back end of the plant.

NOISE

96. Most AD operations are relatively quiet and the noise is controlled by planning permission. Building design and mitigation measures can render the noise negligible at the site boundary (which is where it counts). AD plants built on existing industrial sites probably have an advantage as there is already a high background noise level.

[12] Holdsworthy Farm and Ludlow being good examples of this.

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97. Flaring of gas is not essential. Flaring is a back up and can be used to avoid the need for gas holders as temporary storage devices. Where it is used, bottom down flares – essentially upside down patio heaters – are used, so there is no visible sign of flaring. The emissions are not problematic and although undesirable when flaring does take place it is a green gas not a fossil fuel. Bio Group has developed a system that does not require either a flare or a gas holder in its new plant in Stockport.

BIO-AEROSOLS

98. Although there is no evidence that they are a problem with anaerobic digesters, residents often worry about the potential health impacts of bio-aerosol. This concern can arise because residents find reports on the internet of problems with bio-aerosols on open composting sites where bio-aerosols can be released when the compost windrows (which are in the open) are turned by a digger. There is extensive guidance on bio-aerosols at composting sites[13] [14] and the research concludes that at a distance of 100m to 200m even from an open composting site bio-aerosols are at background levels.

99. There is less planning and environmental guidance on bio-aerosols at AD plants. The Environment Agency permitting regime appears to have added to public confusion and concern. If there is a sensitive receptor (which includes a dwelling) within 250m of an AD plant it will require a "bespoke" EA license which involves a higher level of monitoring and regulation - but this requirement has been interpreted by some members of the public as meaning that the EA does not permit any receptors to be located within 250m of an AD plant, and that is simply not the case.

100. AD plants using food waste as a feedstock will have a closed processing building, running at under-pressure and exhausting its air through a bio-filter. Some operators treat air emissions from within the reception hall with ozone. This process deals with odour, and thus will also deal with spores and bacteria (which are many, many times larger than a single molecule).

101. In addition AD plants also fall under Health and Safety regulations.

BIOSECURITY

102. The regulatory regime reflects the significant concerns about the risk of food waste getting back into the food chain. Any livestock farmers adjoining a proposed AD plant are also likely to be wary. While the extreme fear is foot and mouth, any decomposing food that ended up on grazed land is a potential source of (at the least) bacterial infection. The regulations governing the transport of food are very tight, but one problem is that there is a low faith in the efficacy of government regulation (particularly in the farming community which is well aware that the last Foot and Mouth outbreak was actually caused by the DEFRA laboratory near Pirbright in Surrey).

THE SAFETY OF AD PLANTS

103. Everyone knows that gas can explode, and those that read up on the subject will also find that H_2S is about as toxic as hydrogen cyanide. In the past there have been fatalities at

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[13] http://publications.environment-agency.gov.uk/PDF/GEHO0809BQUO-E-E.pdf
[14] http://www.hse.gov.uk/foi/internalops/sectors/manuf/03-10-11/index.htm

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AD plants arising from both explosions and gas poisoning. More recent innovations mean that tanks are sealed and therefore not accessible and regulations on equipment and operations with regard to gas are tightly monitored in the UK.

104. Today the safety is designed into the plant from the outset as the plant has to meet specific regulations that are equivalent to building regulations for gas plants. The planning application will have to cover the safe operation of the plant and will in some part cover this. In addition there are requirements for gas producing plants to have specific gas safety training before for example the National Grid will allow connections.

105. The reality is that the biogas in an AD plant is at a very low pressure, typically well under 10mb which is less than a tenth of the pressure of a domestic gas supply. Moreover, the biogas is at least 40% CO_2, and there is no air present (by definition). It is therefore impossible for it to explode within the system. If there is a leak, the amount leaking is small and is more likely to diffuse than ignite. Biomethane is also more difficult to ignite than petrol, because of the way it behaves.

Carbon Emissions

106. Estimates of the contribution to carbon emissions reduction for every ton of food waste treated by anaerobic digestion vary over quite a large range and estimates of the savings also vary! We are doing further research into this and hope to expand this section in the form of a short addendum to this briefing note at some point.

Other Sources of Information

Wikipedia – Anaerobic Digestion currently (August 2012) contains a detailed explanation of the process

For relevant EA and EU legislation on waste Houses of Parliament POSTNOTE Number 387 September 2011 'Anaerobic Digestion' is useful.

The main dedicated policy document relating to AD is the Anaerobic Digestion Strategy and Action Plan published by DECC in 2011

There is a website dedicated to AD developed with support from DECC and DEFRA (but claimed to be independent of both) to help all sectors interested in development AD see http://www.biogas-info.co.uk/

A trade body called the Anaerobic Digestion and Biogas Association has a useful website http://www.adbiogas.co.uk/

For a good guide to community AD see the website of Plan Local www.planlocal.org.uk and the short films they have produced (these are better and more realistic guides to AD than the one on the Local United website).

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