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Anaerobic Digestion: maximising the outputs and reducing reliance on subsidies

Chris Rose

June 2019

NUFFIELD UK

This report is written for: farmers, landowners, investors, government policy makers and politicians. In general anyone who has an interest in renewable energy, food/energy security in the UK and the future of the biogas industry worldwide and in the UK

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Nuffield (UK) Farming Scholarships Trust Report

"Leading positive change in agriculture. Inspiring passion and potential in people."

Date of report: June 2019

Title	Anaerobic Digestion: maximising the outputs and reducing reliance on government subsidies
Scholar	Chris Rose
Sponsor	John Oldacre Foundation
Objectives of Study Tour	To investigate potential business models of how AD can be a viable investment in the UK without additional government subsidies . Technical and legislative aspects will be investigated alongside social drivers for change in domestic food, waste and energy production
Countries Visited	USA, Sweden, Germany, France, Switzerland, Poland and Netherlands
Messages	The future for AD is the utilisation of wastes, residues and by-products and a shift to a model with reduced reliance on energy crop production. However, in an economic model with no subsidies every single output has to be maximised, not only the methane produced. Without government financial support AD has the potential to be a profitable working model when there is buy-in from a 'key stakeholder' that can take full advantage of the overarching benefits that AD can bring: this could be a local government, a sister business utilising by-products such as heat, CO2 or the nutrients produced, a utility company or a large corporation that is able to work towards their goals of zero waste and zero net carbon emissions. On a national level, biogas has significant potential to help de-carbonise the domestic heat and transport sectors and requires very little large infrastructure changes. AD is a holistic solution to multiple problems in numerous sectors and should be valued accordingly.

EXECUTIVE SUMMARY

The UK was one of the first major economies to commit to reaching 'net zero' emissions by 2050 in June 2019. Yet, at present ,the UK agriculture industry is a significant producer of carbon dioxide and methane - which is significantly more potent in causing global warming. Anaerobic digestion is a technology that can not only produce renewable energy but can also act as a net carbon sink amongst many other benefits.

The rapid growth, followed by an equally rapid slowdown, in the development of new AD plants is due to the available government subsidies for biogas producers. The purpose of my Nuffield study was to investigate whether it is possible to have a model for anaerobic digestion that does not require government financial support.

It became clear that the use of energy crops in AD had its limitations without substantial government support. However, a model based around wastes, by-products and residues would be more beneficial but is heavily location dependent. The AD plant should be located near the feedstock and not vice versa.

Therefore, my report recommends that collaboration with different stakeholders is key to ensure the many wide ranging benefits of AD are fully captured. Working alongside a business that requires a source of renewable electricity, gas, heat, CO2 or nitrogen/potassium rich fertilisers, is an absolute essential and it is preferable to have a business on board which can realise the economic value of the 'public good' aspect of AD and a desire to reach the status of zero waste and net zero CO2 emissions. To reach such a status will be challenging for many small and large businesses but AD has vast potential to help achieve these ambitious goals.

It must be recognised that AD cannot and will not be able replace all other forms of energy generation, however, the production of biomethane has multi-faceted benefits that can have a realistic part to play in the de-carbonisation of HGV transport and domestic gas heating supplies. AD should not be seen as just another form of electricity production, it is more than that, it is a waste valorisation system and a multiple product stream creator (methane, heat, CO2 and nutrients to name a few).

Finally, the focus by government should not be on the provision of subsidies on gas or electricity production, but on a holistic approach of support for AD developers, taking into account the full carbon cycle of waste, energy crops and organic residues as well as how methane production can best fit into the UK's agriculture and energy system for the maximum benefit of reaching the zero net carbon aim of 2050.

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DISCLAIMER

The opinions expressed in this report are my own and not necessarily those of the Nuffield Farming Scholarships Trust, or of my sponsor, or of any other sponsoring body.

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Nuffield Farming Scholars are available to speak to NFU Branches, Agricultural Discussion Groups and similar organisations

1.Personal Introduction

In 2018 the Nuffield Farming Scholarship Trust, along with the generous support of the John Oldacre Foundation, put their trust in me, giving me the opportunity of a lifetime to investigate a topic to which I have devoted the majority of my career to date. Although my career has involved multiple research projects in the subject area, I had never had the opportunity to travel, speak to practitioners actively working in the field, throughout the world and bring back practical real world suggestions and recommendations for the future of the exciting biogas industry that I work in. It has been one of the most exciting and valuable years of my life and I have learnt a huge amount.

I grew up in rural Shropshire and spent most of my teenage years either on or around farms in some capacity and continued to work on a wide range of farms during holiday times. The farming industry has therefore always been close to my heart and an important part of my outlook on life and work. I graduated from Exeter University in 2012 before moving on to studying for my doctorate in waste water treatment engineering. My PhD taught me many skills, however, with the primary focus on developing novel methods for the anaerobic treatment of waste water, it made me realise my love for the topic of anaerobic digestion. Since this point I have lived, breathed and worked in the biogas sector. This involved firstly working at a large water utility company anaerobically treating sewage waste and spreading the digestate to land before then moving to work directly in the agriculture industry, focussing on biogas plants fed by crops, manures, agricultural residues and food waste through working at a large agricultural corporate, AB Agri.

In my current capacity I work for an anaerobic digestion services company, Amur, and I am in the UK biogas sector on a day to day basis; visiting multiple different biogas sites regularly and maintaining close links and ties to many landowners and businesses that operate biogas facilities within the UK. From feedstock that is fed to digesters to digestate that is removed from the digesters, from government subsidies to environmental legislation, there is little biogas related topic that I am not involved in in some way in the UK. However, in contrast, my global knowledge of the biogas sector was minimal. In an industry that faces multiple challenges, I was committed to finding out more about the sector to help it grow and prosper in the future and become a key factor in renewable energy, waste management, nutrient recycling and energy security in the UK.

2. Background to my study

The reason I chose to study anaerobic digestion (AD) was simple: the UK biogas sector is in decline and at the current level of technology and industry practice the construction of new biogas plants is heavily reliant on subsidies – subsidies which, in the current political landscape, are in no way guaranteed to continue. It is true that anaerobic digestion presents multiple benefits at local, national and global levels. However, the UK agricultural anaerobic digestion sector is not one without its share of controversy and challenges : its longevity is clearly under threat with a substantial reduction in the number of biogas plants being built in 2019 - limited to only some 20 sites under development in comparison with 2014/15 where over 70 AD plants on farms alone were built each year. Figure 1, below, demonstrates that electrical capacity of AD plants grew steadily from 2013 to 2018 but it is now evident that growth rates have plateaued, and current capacity is likely to remain as it is with little future growth expected.

The decline in the UK AD industry became apparent at an early date in my career: it was clear that if the UK biogas sector was to survive and thrive in the UK then changes had to be made. Technical advances have to be made, environmental policy has to be altered and incentives adjusted accordingly to meet the holistic aims of the country with regards to energy/food security, carbon neutrality, nutrient recycling on farms as well as waste reduction. It is my passion to see the biogas industry flourish and continue into the future – I felt I was well placed to help achieve these factors by exploring best practice around the world – that is what I hoped to achieve and my Nuffield farming Scholarship has helped me uncover many findings that I hope a wide ranging audience will take note of through this report.

Getting to grips with how AD plants can operate without the need for government support is critical at this time. Looking further afield at countries where support has not been as forthcoming is key to learn how innovators have made it work and brought benefits not only to their own farming businesses but the wider environment and community. In addition, it is important to look at countries further ahead of the curve than the UK to see what is happening in these countries both politically and practically and is a key part to explore. In summary, there are a few key barriers that must be overcome for the industry to continue to flourish and reduce its dependence on government subsidies, namely:-

1. Technical advance to reduce operational cost.
2. Increase in financial value of outputs created
3. Cost control of feedstock and digestate
4. Political and corporate drivers to help monetise public good aspects of AD

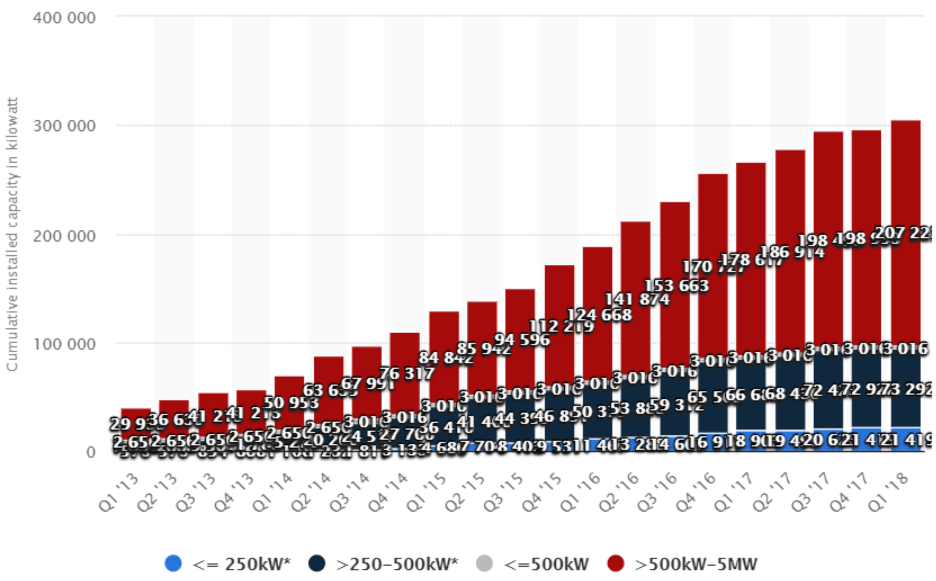

Figure 1. Cumulative installed capacity of anaerobic digestion in the United Kingdom (UK) from the 1st quarter 2012 to the 1st quarter 2018, by tariff type (in kilowatt). This steady growth has now stagnated with few AD plants under development in the UK in 2019, indicating that capacity will remain stagnant at current levels. *Source*: https://www.statista.com/statistics/498683/anaerobic-digestion-installed-capacity-quarterly-uk/

3.Countries visited and why

I chose to visit a wide cross section of countries from those that had either a well-established biogas industry (e.g. Germany), to those where biogas is very much in its relative infancy (e.g. USA),e as well as many in between. Countries were selected based on their outlook and perception to biogas. For instance, Germany is well established as a heavily subsidised industry where the use of energy crops has been commonplace for the majority of its sites. In contrast, in Sweden the market is very much not geared towards agriculture and much of the biogas development has focused on larger scale local authority or government owned/financed schemes. The Netherlands, Switzerland and France sit in the middle ground – much like the UK – with a hybrid of waste/crop fed plants. I chose to keep my travels to higher income developed countries, but not because there is not a biogas industry in lower income countries, indeed there is a significant number of small 'backyard' digesters in countries such as India and China, where there are over 30 million household small scale biogas plants. However, although these work well in rural areas for these countries, there is relatively little relevance to the more centralised urban based UK market.

Country Visited	Current AD capacity (farm/sewage)	Region of country visited
UK	Total 640 digesters. Installed capacity of 730 GwH. Sewage (162 plants), Farm (357 plants), Food waste/industrial (153 plants).	All
USA	Total 2200 digesters. Installed capacity of 977 GwH. Sewage (1,269 plants) Landfill (636 plants), Farm (259 plants), Food Waste/industrial (39 plants)	Texas, Oklahoma, Minesotta, Luisianna, Missipipi, Tennesse, Kentucky
Germany	Total 9500 digesters. Installed capacity 3789 GwH. Sewage (1400 plants), Landfill (400) plants, Farm (7800 plants), Food waste/industrial (250 plants)	Northern and Western Germany
Switzerland	Total 600 digesters. Installed capacity of 1023 GwH). Sewage (463 plants), Co-digestion (26 plants), Farm (89 plants), Industrial (22 plants).	Central
France	Total (336). Installed capacity of 1273 GwH. Sewage (60 plants), Landfill (858 plants) Food /BIowaste (11 plants), Farm (105 plants), Industrial (80 plants)	Mid and Northern
Sweden	Total (200). Installed capacity of 1589 GwH. Sewage (135 plants), Landfill (55 plants), Biowaste 21 plants), Farm (26 plants), Industrial (5 plants).	Southern
Netherlands	Total of 252 digesters. Sewage (82 plants), Landfill (41 plants), Farm (105 plants), Biowaste (11 plants), Industrial (13 plants).	Central

Source : http ://task37.ieabioenergy.com/files/member-upload/Countryreportsummary2013.pdf

4. What is the Biogas Industry: the good the bad and the ugly

4.1 Introduction

This chapter aims to outline some fundamentals of biogas production; such as what anaerobic digestion is, how it is used in multiple applications around the world as well as how many businesses, primarily within agriculture, are profiting from a range of benefits involved in biogas production. This chapter will look at the basics of AD and set the scene for the rest of the report, investigating four key themes that have been uncovered on my travels.

4.2 The basics: What is Anaerobic Digestion?

Anaerobic digestion (AD) is the process of bacteria breaking down organic material (such as crops, manures or food wastes) in the absence of oxygen. The biogas created can be used for heating, electricity generation or the gas can be cleaned and injected into the national grid network. The biogas created is a mixture of methane (CH4) and carbon dioxide (CO2). AD at its simplest is often referred to by many in Germany and the rest of Europe as a 'concrete cow'.

The fundamentals of anaerobic digestion are not new, in fact it was first discovered over 200 years ago in 1776 when scientist Alessandro Volta performed an experiment in which he disturbed the sediment of a shallow lake, captured the gas it released, and, illustrated that it was indeed flammable. Commercial applications followed 100 years later when street lights in the city of Exeter were powered by biogas produced from the anaerobic digestion of sewage. Since then the scientific understanding of the different mechanisms that lead to the production of methane has been undertaken and put into large scale operation successfully. There are numerous resources available online that detail the complex biological process that creates methane gas. However, put simply, AD can broadly be summarised as a 'concrete cow' as illustrated by the image in Figure 2 below.

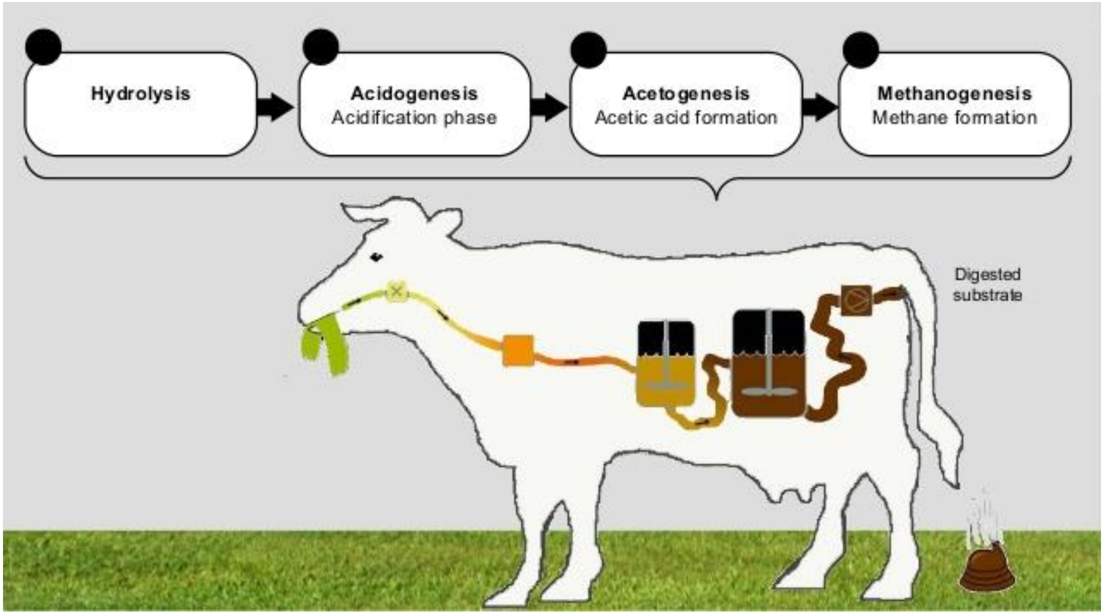

Figure 2.The 'concrete cow'. Anaerobic digestion is essentially a cow in which the feed is optimised to produce methane. *Source : https://www.slideshare.net/eisenmannusa/high-solids-anaerobic-digestion-international-biomass-2013*

Anaerobic Digestion does not just produce biogas, there are also multiple other outputs that can be valorised. In addition to methane, other valuable products are produced such as heat, CO2 as well as nutrient rich fertiliser (digestate). This process is detailed by the infographic Figure 3 below – although the inputs of manures and crops illustrated can be replaced with any organic material, for instance food wastes or organic residues.

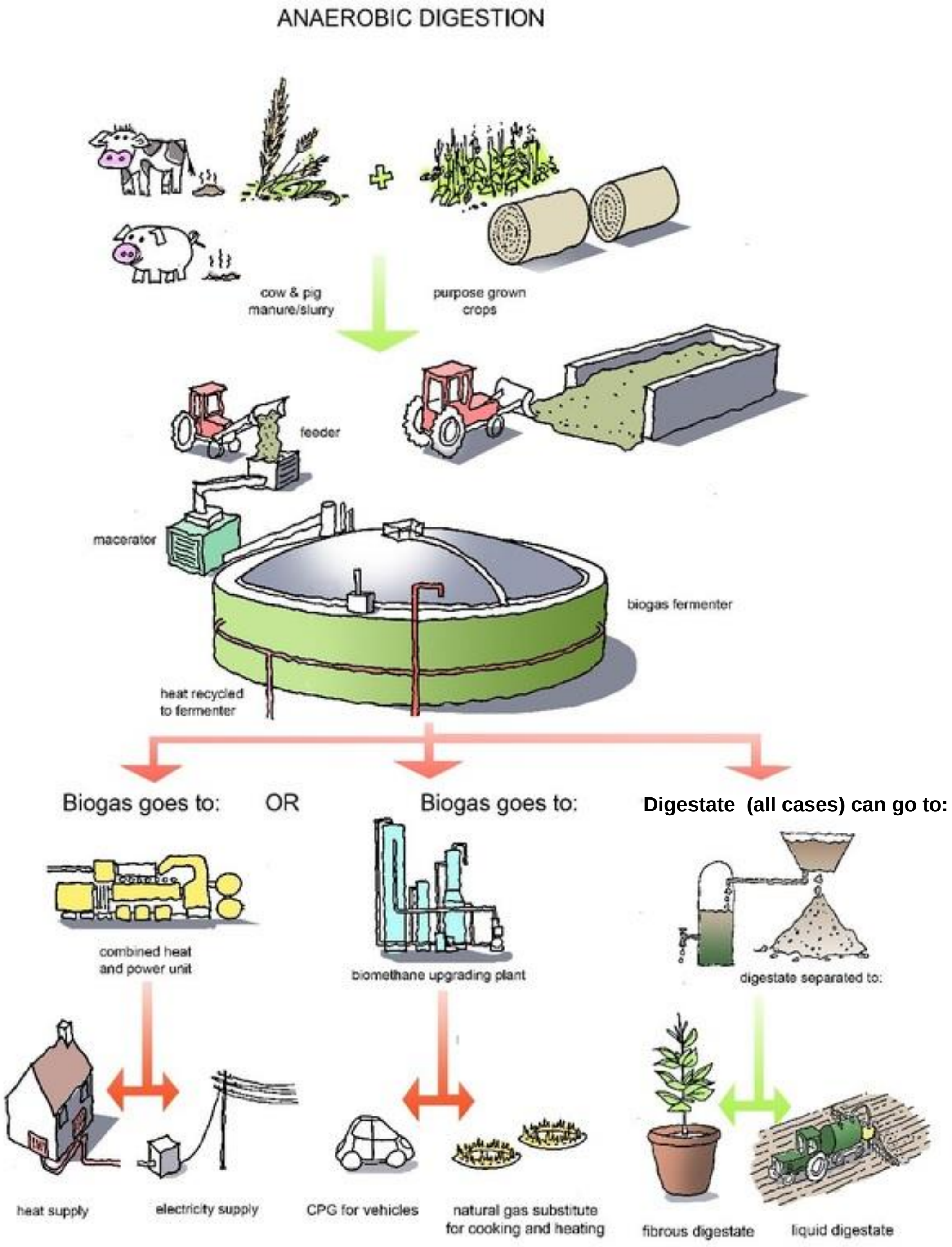

Figure 3. Diagram to show the basic flow diagram of an AD plant.

Source: https://nerissaferguson.weebly.com/

4.3 What are the current financial models for AD plants

With the exception of the USA, all the other countries I visited on my travels provided fiscal incentives of some form, either through payments on a) the production of electricity b) heat production or c) methane gas produced for gas network injection of transport fuel. In Europe these subsidies are given on top of the wholesale gas or electric market price and will be discussed in greater length in subsequent chapters. The overall business model of most crop-fed AD plants is to feed as little energy crops as possible in order to produce the amount of gas (decided upon by a government 'production cap') in which additional subsides are paid, nothing more or less. In Germany, Holland, and Poland operators of energy crop-fed plants repeatedly informed me that, if there was no subsidy or premium on the energy they produced, then the cost of the AD energy crop feedstocks would not be greater than the cost of producing the energy crops themselves, meaning they would be better of simply not doing anything at all as, unless the costs of maize production were to reduce it, would not be viable. Therefore, the greatest cost in running a solely energy crop fed AD plant is generally feedstock and this, along with the subsidy tariff will generally determine how profitable the AD plant is.

Food waste fed AD plants, however, have a different business model. Food waste feedstock is generally lower in cost than energy crop feed . However, there is generally more investment needed upfront in de-packaging equipment and in greater staffing requirements needed to secure feedstock contracts with waste suppliers, as well as increased operations and maintenance issues due to the greater complexity of feeding non-uniform waste materials. It became clear on my travels that many food waste AD plants in Germany, Holland and the UK were no longer getting paid a gate fee (a payment made to the AD plant in order to dispose of organic material) in order for them to take material but were, instead, having to purchase feedstocks in order to secure the supply of the types of waste streams that gave the largest gas production. AD plants often had to bid against other rival AD plants in their locality in order to hold onto high gas yielding feedstocks or lucrative waste removal contracts, meaning there was a switch from being paid to take feedstocks, to having to pay to receive feedstocks.

The split between energy crop AD models and food waste AD models was not as clear cut as this. There were many businesses that I visited, particularly in France, Switzerland and Germany that operated a hybrid model between these two feedstocks. Also, no particular reference to slurry/manure management has been made in these classifications: in general, it can be said that most smaller AD plants (<1 mW) added slurry and manures to their energy crop mix, this was especially the case in Germany. However, the larger energy crop fed plants in Poland and Eastern Germany tended not to bother using animal manures due to the relatively low gas potential. An exception to this rule is in the southern states of the USA where most of the biogas plants that I visited were situated on the back end of a large pig or cattle enterprise and primary goal was manure management and fertiliser cost savings.

4.4 Subsidies and incentives

4.4.1 USA

The European nations primary business model is taking advantage of government fiscal incentives for energy production. In contrast, my pre-conception before visiting the USA was that renewable energy was not heavily, if at all, subsidised. Upon talking to many, it became clear that this was far from the case for many states with subsidised corn based ethanol production for instance as well as lucrative tax breaks for solar and wind farm operators throughout the country. For this reason, to investigate this further my travels took me to Georgetown, north of Austin in the state of Texas. Here the mayor of the town had pronounced the town's electricity production100% renewable. In Texas, the largest crude oil producing state in the USA, I was intrigued to find out more. Sure enough, in order to secure such substantial investment in windfarms there have been significant fiscal incentives – tax breaks such as a federal Production Tax Credit (although this is now no longer available), Investment Tax Credits, and Texas property tax abatements which also sit alongside other funding and stimulus introduced during Barak Obama's era. All these incentives combined have actually produced an intriguing phenomenon of potential net negative power prices! A Texan farmer explained to me the extreme lack of need for electricity at certain times in the state of Texas by a simple live scenario that had been reported in the local paper one month previously: a windy night in the West Texas plains meant that there was a high supply of electricity being produced, and this combined with a low load of required electricity demand due to everyone being asleep with air con units off, led to a situation on the electricity spot market pricing system that the price paid for electricity went lower and lower before eventually going into the negative point for several hours before rising again. A crazy situation, but a scenario that can be learnt from in the electricity island closed loop electricity system that Texas is. Electricity and energy production have to be flexible. This is something that the Biogas producers can learn from – biogas does indeed have the ability to be flexible and it is this benefit that should be emphasised.

This finding began my search for people who were using this flexible approach to electricity production to take advantage of the peaks and troughs in the electricity market. As electricity is notoriously difficult to store, it seemed an interesting perspective to only generate electricity at time in which it was needed most.

Figure 4. Windfarms in West Texas. Although much of the wind in Texas comes at night (when electricity demand is at its minimal) at least it compliments solar energy well! *Author's own photo.*

4.4.2 Germany

Germany has over half of the biogas production within the EU economic area. Germany was a fascinating place to visit for multiple reasons. It is best described that the German biogas market is very similar to that of the UK, except that it is a) a great deal bigger and b) approximately 5 years ahead of the UK's. For this latter reason, many of the initial subsidies are approaching the end of their 20 year commitments and the German government is increasingly focusing on unsubsidised, market-driven electricity production. Germany introduced subsidised electricity generation tariffs in 2008 with a guarantee of 20 years given to the biogas plant operators. In the following years, alterations made to government policy made it strongly incentivised to grow crops for the use in AD plants. Since 2016 a limit was placed on the amount of energy corps that could be used within new biogas plants coming online. This was placed at 50% - a move which the UK introduced shortly afterwards.

Despite being 5 years ahead in the 'curve' than the UK or others I visited such as Poland, the German farm AD model is very reliant on energy crop fed plants. There is a relatively high level of subsidy on the electricity produced, however, coupled with this is a higher cost of production for the feedstock. Purpose grown energy crops such as maize and rye grass are relied upon, and those biogas plant managers/owners with their own land/expertise/climate conditions to grow these crops were more resilient than those who relied upon local contractors This factor became apparent on my visit to Eastern Germany in the late summer of 2018. Growers had been hit by severe spring and summer droughts, some maize crops were completely written off (see Figure 5 below) and one farmer/AD operator, Leon Weber, said that he and two of his neighbouring farms with biogas plants were considering stopping production completely in the autumn due to a lack of feedstock. He explained that the financial model would no longer work if forage maize had to be bought in at the then current prices (upwards of 80 Euros/tonne). This reliance on grown energy crops shows the fragility of the system when exposed to extreme weather events. Although it must also be highlighted that it had been one of the driest spring/summers since records began for this and many other parts of Germany. Leon and other German operators also pointed out that such financial problems are not confined to biogas production, with the animal feed market drastically affected when there was a 40% reduction in maize production in Germany.


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Figure 5. Maize production severely impacted by European drought.

A poor maize crop in the eastern German state of Brandenburg as a result of a severe in 2018. Maize crops like this were commonplace on land contacted by AD operators. This poor maize harvest led to a shortfall in maize in 2018/2019 leading to numerous AD plants having to scale back production due to high feedstock costs. Source *Author's own photo*:

4.4.3 Other European nations

Within the UK there are several fiscal incentives for biogas production; these include Renewable Obligation Certificate (ROC), Feed-in Tariff (FiT) and/or Renewable Heat Incentive (RHI) regimes. Either all, or a combination of these schemes can be claimed for by an eligible AD plant. However, the tariffs eligible to be claimed have reduced sharply and continue to do so with the current RHI scheme scheduled to come to an end in 2021. Many AD operators within the industry say that perhaps this is a justified market correction and AD plants, especially waste fed plants, are now too numerous and there is not enough organic waste to go around which has led to a race to the bottom in gate fees that can be charged. However, many other AD developers that I spoke to during my Nuffield investigation felt that this was not the case and that there is still an opportunity for farms to invest in anaerobic digestion as a source of sustainable gas, electricity, heat and nutrients. These mixed views were largely echoed by operators in Poland and Holland, when the subject of future ADs being built in the areas was addressed. Many operators such as Jan, who ran a small farming estate in the west of Poland, expressed their fears of increased competition for wastes and residues that they were using successfully but he did admit that this was natural in all good businesses, the fear of competition!

4.5 Perceived positives and negative attitudes in UK

To summarise the overall sentiment towards AD in the UK is difficult. It was highlighted by an AD operator in the UK that although 60% of AD plants are based on farms (excluding the water industry) within the farming community AD often has negative connotations (summarised in the table below). I was intrigued by this factor, as usually opposition to aspects of farming comes from outside the industry from the wider press and public. However, AD in the wider public's eyes is largely seen in a positive light. So, I was keen to explore farming as well as public perception in the countries I visited to see if this indeed was the case elsewhere and what could be done to improve PR of the biogas industry.

Agricultural Outlook on AD	
Perceived Positive	**Perceived Negatives**
Avoiding loss of methane to atmosphere – reducing net farming contributions to global warming	Heavily subsidy reliant industry, the effective double subsidies AD operators get (i.e. getting subsidised for energy crop growing as well as the energy production in AD).
Creating a renewable energy source that can be stored or injected into the gas network	Use of valuable land resources to grow energy crops
A non – fossil fuel energy generation method	Residues that could be animal feed are being used for energy generation – pushing up prices increasing feed imports
Recycling of valuable nutrients and organic matter to farmland	Land rental values increased especially in proximity to AD plants
	Negative connotations of maize cultivation. Soil damage/bare fields over winter
	Ethics of growing fuel vs food
	Pollution incidents, over application of digestate and plastic contamination of fields

Wider Public Outlook on AD	
Perceived positive	**Perceived Negative**
Creating carbon neutral or net negative gas	Reliant on government subsidies
Renewable energy reducing reliance on fossil fuel – mitigating global warming emissions of CO2	Increased road transport of 'waste' in and out of sites
Reducing waste going to landfill	Odour and localised traffic issues
Increased energy security for UK	Planning concerns of un-sightly digesters on landscape
Management/processing of manures	Smell and high traffic in local areas

Figure 6. perceptions of AD by the farming sector and the wider public

My travels to numerous different countries confirmed to me that the biogas industry in general suffers very little public opposition and most of the opposition comes largely from those within the agriculture sector who see some of the more in-depth pitfalls; for instance, the land for food vs fuel debates (very common place in Germany) as well as mis-management of digestate on agricultural land (a problem that is mostly only seen by those working in the arable sector). The wider public support throughout the world for biogas is definitely a plus for the industry. The relative simplicity and easy-to-explain nature of renewable fuel means engagement with the mainstream wider public is easy to achieve. There were many examples of this throughout my travels: for instance, a biogas company sponsoring an Indy Car race in the USA state of Alabama was the latest move by the American Biogas Council to help gain the support of the wider public when I visited in March 2019.

Figure 7. Biogas hitting the mainstream in the Indy Car Series in Alabama, USA.
Source : http ://biomassmagazine.com/articles/16063/biogas-groups-sponsor-2-teams-at-honda-indy-grant-prix-of-alabama

4.6 Key learnings

- The biological AD process is not a new technology. It is a well-known and researched process. However, its commercial application around the world in relation to purpose grown energy crops is relatively new, largely due to lucrative government subsidies.
- Most AD plants have some form of fiscal incentive involved, no matter where in the world
- Energy crop-fed plants are at the mercy of government incentives due to the high cost of production of growing energy crop materials such as maize.
- Energy crop-fed plants' greatest risk is ensuring enough feed is available year round at a commercially viable price. The drastic climatic or market changes that affect the wider animal feed sector will also affect AD plants
- Waste fed AD plants are more resilient, provided that the market is not saturated with too many competitors vying for the same waste streams.
- AD has a bad reputation only within agriculture: the wider public as well as government bodies are largely supportive of biogas operations

5. CO2, heat and nutrients the golden ticket for making AD viable?

5.1 Introduction

This chapter aims to address key findings on my travels addressing three key areas: CO_2, heat and nutrients.

It was a common viewpoint throughout my travels that AD was still a developing market and one for which much more technical innovation was required in order to make it a profitable enterprise. This was particularly the case in Germany, in which the circa 9500 biogas plants were largely built on the back of lucrative government subsidies for electrical input up to 2012. These plants were, as their owners frequently confessed, put up in a hurry, by construction firms that often went bust in the immediate aftermath when the number of plants built dropped sharply. Since the construction of these AD plants, there has been little innovation in the sector and the predicted increases in operational efficiency haven't taken place like they have in similar renewable energy sectors, for instance wind and solar, which now largely operate without the substantial government support that the biogas sector receives in Europe. Indeed, it is the government's aim in almost every country to support an industry initially to encourage innovation and technological advances at scale before withdrawing this support when technology reaches a state when it can operate on its own. This has largely happened with solar and wind and to a certain degree biomass boilers. In contrast, many agreed on my travels that AD was lagging behind in technology advance, largely due to the great biological complexity of the process as well as numerous engineering difficulties.

5.2 CO2

Biogas has a significant proportion of CO_2 (~40% CO_2) within the gas (along with other contaminants such as H_2S). The CO_2 proportion is the recalcitrant gas that reduces the density and calorific value of the biogas. However, it is neither toxic or corrosive and when adequately cleaned has many uses as a bi-product, for instance in the production of carbonated drinks, for slaughtering animals as well as producing beer to name a few.

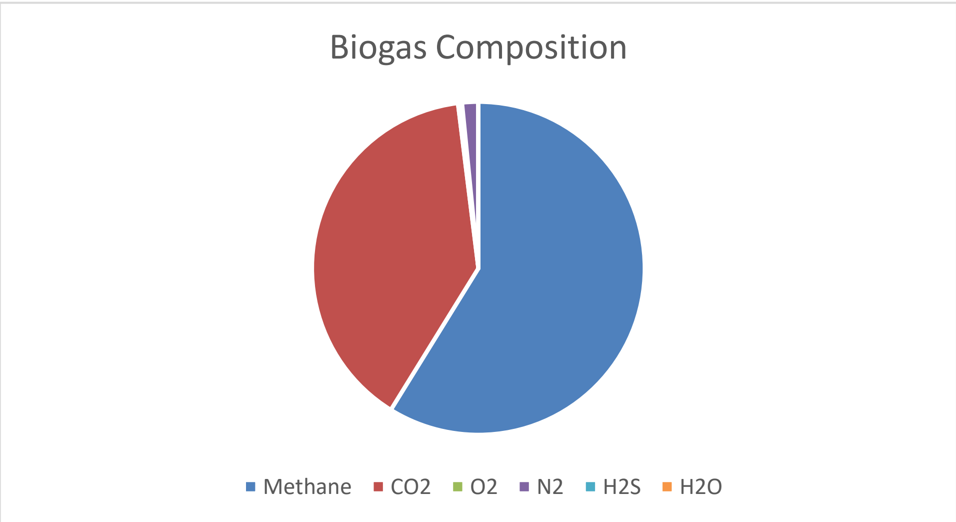

Figure 8. Biogas composition

During the start of my study, summer 2018, the UK experienced a severe CO2 shortage. The lack of supply, primarily due to a large proportion of producers all experiencing down time simultaneously (in addition to the reduction in the ammonia manufacturing process meaning producers were not starting up as quick), had large ramifications for food, drink and related processing industries across the UK. Within the UK there was a significant proportion of biogas plants that were separating the CO2 fraction from the methane but were not utilising the separated CO2 stream and selling it into an under supplied market. This seemed a shame and an opportunity missed for producers. However, digging deeper, it became apparent that one of the primary reasons for this under-utilisation of the CO2 fraction was due to the CO2 customer base (including large food brands) not being willing to use CO2 created from so called 'waste' products due to fears over their own brand protection.

Despite trying to seek out biogas operators who have been successfully cleaning up biogas, upgrading this gas and selling or utilising the CO2 it was unfortunately not common, although I visited many sites that, in theory, could utilise the CO2 that was being produced. For instance, in the Southern States of the USA I visited an AD plant on the site of a slaughterhouse, a clear producer and consumer of CO2 on the same site, yet it was not being separated and used. This was largely due to the substantial cost and complexity of introducing gas upgrading equipment to a biogas site. This view point was echoed on a gas injection site where the owner explained that the decision to expand and grow from just one CHP engine to a full gas upgrading equipment (using membrane separation) was not to be taken lightly as his increased running costs, expertise and initial investment trebled at the very least! Within the UK I also found similar examples of this combination of businesses yet few were realising the connection, largely due to inhibitive legislation, which meant no waste products (including animal manures) could be used in the biogas process if the CO2 was to be sold as food grade CO2. There is no doubt that if this legislation could be changed in the UK the potential for use of CO2 is high. As many academics point out, CO2 is CO2 and provided that its purity is ensured, there is no reason why the source (be it food waste, animal manure or energy crops) should have any bearing. However, as a farmer owner operator, in the north of Germany pointed out when considering the move, it is down to both the producer and consumer of the end users of the CO2. There is an obvious bad connotation between waste and food/drink. For an uninformed consumer, the thought of an ingredient/process that involves a 'waste' may be unpalatable and is a PR risk that many brand conscious producers are not willing to risk.

What I did commonly see, in the European sites that I went to, was the siting of biogas plants next to glasshouse systems for horticulture production – which by their very nature use both CO2 as well as heat. The use of CO2 on the same site as it is being produced on a biogas site is an obvious route to take. Although CO2 is often largely produced as a bi-product from industrial chemical processes, ammonia production or other means, having the ability to produce it on the same site as its final use has additional benefits of reducing road transportation which is a carbon intensive operation in itself.

5.3 Heat

Throughout my travels an AD plant that was not utilising the waste heat produced in some way was rare. However, it must be said that it was rare that this was carried out to its full potential, and largely done in order to claim additional subsidies available from respective governments. There are so many ways to utilise heat, some examples seen on my visits are illustrated in Figure 8 below.

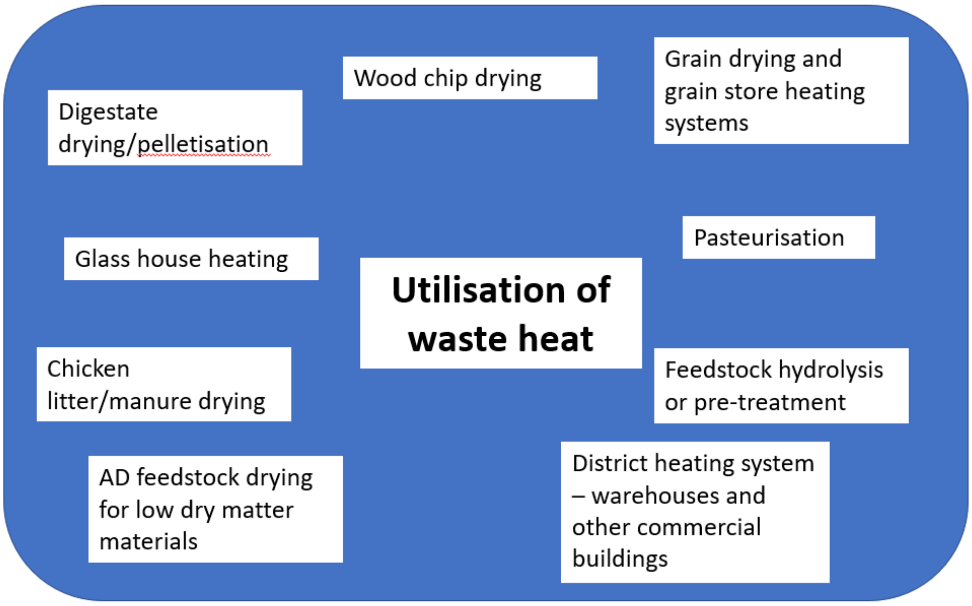

Figure 8. Some of the many different ways of positive use of waste heat

5.4 Nutrients

Broadly speaking agricultural digestate was utilised well at most AD plants where energy crops were being used. At most European sites there was some form of solid liquid separation, with liquors either pumped to storage lagoons or recirculated and the solid dewatered material (~40%DM) stored on the field before being spread. At agricultural fed AD plants on my visits there were no complaints of a lack of farmland in which to spread. However, where problems did seem to arise was in waste-fed plants. Sites both in Germany and the USA struggled to de-water the digestate, despite many trials using polymers with varying success. Many of these waste sites were having to heavily subsidise the digestate removal and spreading. However, it should be noted that the majority of waste AD sites visited were often not situated on a large farming operations, having to rely upon third party landowners to use the digestate on their land. In Sweden digestate from waste plants was a problematic point for waste AD operators because strict controls on phosphate had been introduced, limiting application in certain areas.

It is true and commonly cited that digestate is 'black gold': there are many stories around benefits to crop yields, reduction in fertiliser cost, increases in soil organic matter as well as the benefits of including maize within the rotation to wider crop yields. However, from my travels to AD plants across multiple different countries it became apparent that, generally speaking, the value of digestate is only fully valued when the agricultural farmland itself is linked to the owner of the AD plant. There are benefits to cropland but there are also drawbacks if the application of digestate is not managed correctly, it can cause significant damage and has routinely caused AD operators digestate residue to have a bad reputation. Reputational problems encountered included nutrient leaching issues to watercourses (France), phosphate pollution concerns near to biogas plants in Sweden, and concerns around compaction in Germany along with concerns of soil health management where maize has been grown routinely for many years.

Figure 9 .Field applications of digestate providing 100% of nutrient additions in this arable rotation in Switzerland. *Source: Author's own photo*:

5.5 Key Learnings

- There is a great opportunity for the sale or use of CO2, but this also involves large investment costs in gas upgrading equipment and large maintenance and operation costs.
- There are many uses for waste heat, the important thing is finding a co-located business to value the 'true' economic value of the heat, as this will replace the need for simply creating a nominal use for the heat in order to gain a subsidy payment (which has been done frequently to date in many highly subsidised countries including the UK).
- Digestate is a very valuable resource, however, sufficient investment in up-stream de-packaging is vital to ensure that plastic does not contaminate the land.
- Sufficient liquid digestate storage is vital, as is an engaged landowner willing to realise the digestate's maximum potential.

6. Biogas for road transport: compressed gas vs bioethanol

6.1 Introduction

Within the UK, government subsidies for 'biogas for road transport use' are arguably the most lucrative at this point in time, indicating this is an area that the UK government values in its future energy plans. Indeed, many argue that there is a real need in the UK and worldwide to de-carbonise road transport, and from my experiences, I very much agree. This chapter explores current trends around innovation in road transport fuel that I saw on my travels and explores what projects AD owners around the world are undertaking in response to this market need of gas for road transport.

6.2 Biogas versus bioethanol

The trade-off between bio-fuels and food production was a common thread of local debate amongst farmers and the wider community and a key learning from my trip to the USA. Bio-ethanol, produced from the common energy crop maize (locally known as corn), was a popular topic of conversation with the agricultural community. With the rise of cheap shale gas over recent years, government support for bioethanol production has reduced. It was a common sight driving along the highways and interstates to see banners adorning grain silos reading "Support Locally Grown BioFuels: Support local Farmers". This was particularly commonplace in Arkansas . However, in the neighbouring state of Texas, where oil is big business and nodding donkeys line many highways in West Texas there was no great support from either landowners or the public.

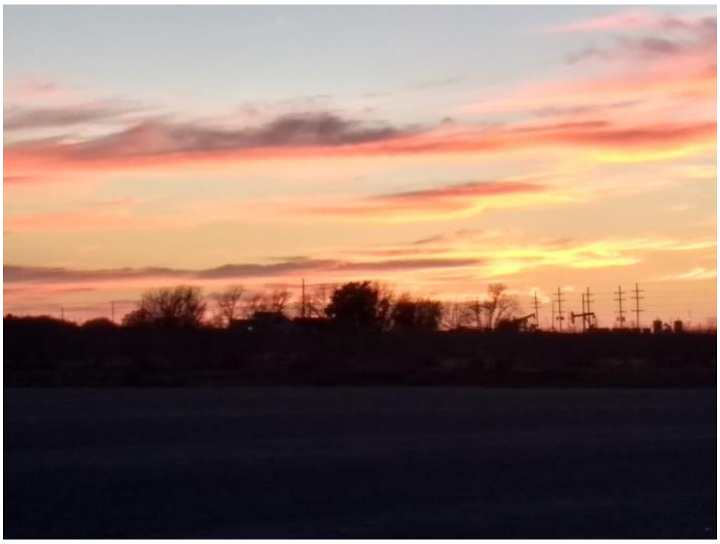

Figure 10. Nodding Donkeys dotting the landscape all over Texas. These pumpjacks have helped Texas remain as the number one oil producing state for numerous years with no great sign of slowing down. *Author's own photo*.

Indeed, public support and advertisements against the use of ethanol were ever present at many petrol stations, with many advertising on the promise of "no ethanol addition". This is largely down to a performance perspective from the customer but also illustrates the lack of public and governmental support for domestic bioethanol production. It was my pre-conception that government support for bioethanol was strong in the USA. However, on my trip within the southern states of the USA it was only within Louisiana that ethanol addition to fuel (5%) had become compulsory by state law. Other states such as Texas, Tennessee and Alabama all considered bringing in similar ethanol addition requirements, however, the proposals were dropped and no laws were put in place. In a country where consumer demand leads, this shows there was little public pressure for this to be put into place: to the contrary, there were clear advertising campaigns targeting customers perceptions of poorer performance from ethanol blended transport fuels, seen in the photo Figure 11 below. My visits in the country were of course biased towards the agricultural sector, but even here, the common train of thought was that eventually in some form or another the market would decide in the USA their own thoughts on bioethanol production. It indeed shows that biogas for use in transport cannot just rely on being a 'renewable fuel source' it has to not only beat the efficiency of bioethanol (which many argue it already does) but it also has to be more cost effective and as user friendly as conventional gasoline is - a very tall ask of biogas for fuel AD operators.

Figure 11. Gasoline advert advertising the virtues of 'ethanol free gasoline'. The inclusion of 10% ethanol in gasoline is not a state law in Texas. *Source: Author's own photo.*

6.3 Embracing biogas for road transport nationwide

On my visit to Sweden, all the biogas plants that I visited were being operated at a large scale – and were all exclusively being carried out at a municipal level by local authorities. There seemed to be very little evidence of small-scale farm level digesters. I was told this was primarily down to reduced incentives at smaller scale in the Swedish incentives system. However, the scale of these sites presented the Swedish operators with a benefit. They could capitalise on:-

a) large volumes of waste materials that were previously problematic (a consistent trend in Sweden was the large volume of fish processing waste) and

b) high rates of local government taxation which meant there were increased revenue streams for the collection and processing of kerbside collection of food waste from households.

The added benefit of operating at such large scales meant that the upgrading of the gas output (the cleaning of the gas and removal of the CO2 to produce pure methane gas) meant that the use of biogas in transport fuel was a realistic business proposition for the country. Talking to practitioners and policy makers at both Linkoping University and at industrial level with biogas developers/operator companies, such as Scandinavian Power, it was clear that this large scale production was a realistic proposition due to two factors:

firstly, it reduced both the high cost of biogas and the difficulty of finding a carbon substitute for transport fuel and

secondly, because of the higher price per unit of energy which is sold into the transport sector (80% of electricity production in Sweden comes from nuclear and hydroelectric power).

These considerations are underpinned by the thought process that renewable gas is an essential element for achieving Sweden's target of becoming 100% powered by renewable energy in 2040. (Sweden reached its 50% by renewable energy by 2020 target in 2012, so this is a country which knows how to reach its targets!) Although much of the publicity and hype in Sweden is around powering cars through biogas, it is evident that electric powered cars will most likely be more energy efficient. This train of thought to use biogas was profound throughout Sweden and I was told that over 25 cities in Sweden were now powering their municipal buses through biogas. However, from an energy balance perspective, academics I spoke to were dismissive about the energy efficiency of cars and buses using gas, pointing towards the more efficient electric batteries that will soon be available. Nevertheless, biogas offers real benefit to the heavy goods vehicle transport (HGV). In the HGV sector I was told that batteries are unlikely to suffice and this is where biogas will prevail: this is evident with the rise of Swedish company Scania's new Euro 6 gas powered engine which has had much attention across Europe.

Figure 12. A taxi powered by biogas created through the anaerobic digestion of waste in Stockholm, Sweden. *Source*: Scandinavian Power http://scandinavianbiogas.com/en/about-biogas/

6.4 Key learnings

- There has always been a food vs fuel debate in the USA around corn based ethanol production – there are many lessons we can learn from this to ensure that if biogas is adopted in the UK, it is there to stay
- There is a realistic business proposition for the country to decarbonise transport fuel which offer opportunities for biogas, and although this may be short lived in personal car use, the HGV market has the greatest potential for biogas as road transport.
- Biogas has been argued by numerous leading academics to be more efficient on a net carbon basis than ethanol production. Biogas for transport fuel should be the new 'packaging' to make biogas appeal to the electorate and government agencies.
- Biogas is not as clean as electricity production, but it is the next best alternative that solves many problem areas for government policy (waste, HGV transport networks).
- Solving biogas for road transport is hard done alone, a strong industry body promoting collaboration will likely win.

7. A marriage with big business and the need for a 'corporate' benefactor

7.1 Introduction

I constantly came across the multiple 'public good' element that the biogas industry has to offer. A common recognition throughout the different countries I visited was that AD plants were not just benefiting their own enterprise but providing multiple benefits to the wider community as well as the country as a whole. This has been recognised by government subsidies in many countries. However, where there is less appetite for government intervention, there were examples of larger companies as well as multinational corporations stepping in to monetise these aspects and reap the awards of investment in this sector. This chapter will explore how landowners and AD developers have worked with large corporations that have clear aims to reduce energy consumption including by reducing heating costs of industrial processes, making use of CO_2 production and waste and, if possible, creating a net-negative carbon sink to allow other parts of the company fall behind on CO_2 reduction targets where no other way of CO_2 reduction is possible.

Co-location of biogas plants with industrial process

7.2 Switzerland showed a great example of a working model of how 'big business' can benefit from the siting of a biogas plant on or next to a production site. A biogas plant was sited at Nestle Waters and at its time of opening was Switzerland's largest biogas plant. It capitalised on the waste produced from coffee processing as well as from other third party sites and enabled the subsequent electricity production and waste heat to be utilised in its bottling plant nearby. The benefits from such arrangements were highlighted as having many 'big picture' wins for the company – such as a reduction in the site's net GHG emissions as well as supply chain stability. It also became apparent that it was not only these 'big picture' goals that drove the site to be built but also the desire for relatively fixed costs for electricity and heat and security of supply. Although, government subsidies for electricity produced undoubtedly played their part in the story, a co-location arrangement (where a host site/business benefits from GHG emissions mitigation and supply chain stability) is bound to become more important for large global companies as Nestle is not alone in making pledges such as 'global zero waste by 2020'. For instance, on my visit to Holland it was also highlighted by an employee at the multi-national food-products company, Danone, that they had a commitment to become carbon neutral by 2050, to be achieved through not only reducing their own CO_2 footprint but also producing renewable energy to offset unavoidable carbon uses. Biogas has the potential to valorise once costly waste, meaning that instead of waste being sent to a landfill and emitting methane emissions to the atmosphere it can be given a new purpose and a value generated from it, solving two problems at once. Creating energy from waste can also be seen from a marketing point of view as being a way of offsetting carbon emissions from other unavoidable carbon dioxide emitting processes and being a net negative sink of carbon – i.e. producing more energy than is needed to help compensate for a more polluting practice.

Biogas will surely have a large part to play for waste avoidance as well as offsetting carbon dioxide emissions.

7.3 Co-utilisation of biogas with other industrial processes: feed for humans, animals or AD

One of the most interesting businesses that I visited on my travels, did not own a digester themselves. The company, *Nijsen Granico*, was principally an animal feed company specialising in pig and poultry feed. Where they differed was that they could produce a pig feed made up of 100% foodstuffs. Their slogan 'food for feed', was as sustainable as it gets and they partnered with companies such as *Kipster Eggs* who branded their products as environmentally sustainable products. This showed me a great example of the food/feed hierarchy – the waste products (not fit for human consumption) were re-purposed and a valuable product created for animal feed. Creating such a product, however, took a lot of expertise to make sure the right feed balance and that no feed ingredients had begun to rot or grow harmful toxins that could be harmful to animals. Of course, no animal by-products could be included in the feed created, and these were currently diverted to pet food production.

Figure 12. A selection of feed ingredients used by *Nijsen Granicco* in the production of their compound feed for pigs *Source: Author's own photo.*

Future plans were in place for an AD plant on-site to help deal with the animal by-product streams that they had the opportunity to acquire. The other big driver for an AD plant was the need for heat for their energy intensive drying process. The plan was to harness the power of products that they cannot utilise for animal feed by producing energy to help power the dryers for drying out moist materials, such as waste dough ,so this would be a substantial benefit and would help create a truly carbon neutral feed for the market. This comprehensive approach presented a fantastic business model. A model such as this really would reduce the CO_2 footprint of farmed animals and would present global multi-nationals supplying meat products with a fantastic saving in carbon emissions in their supply chain.

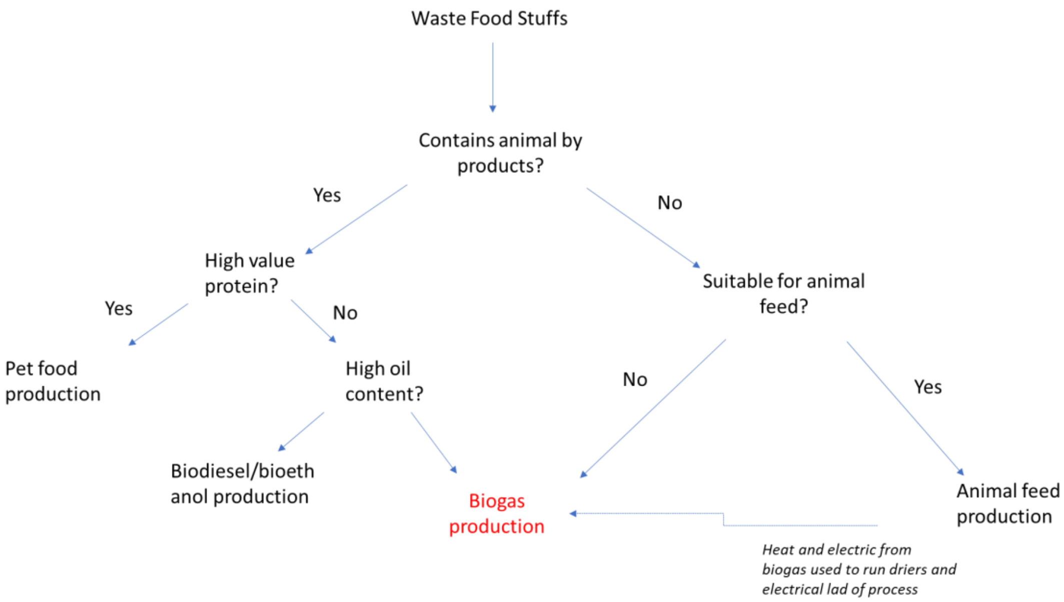

Figure 13. Flow diagram of combined food for feed concept with AD. *Source: Author's own*.

7.4 Key Learnings

- Co-location alongside a larger business that has ambitious carbon reduction, waste or sustainability targets presents both the AD developer as well as the larger business multiple benefits
- Co-location and achieving a carbon emission reduction, sustainability and waste avoidance gains will undoubtedly provide a new revenue stream as the targets set by ambitious companies will be a challenge to meet.
- Location on a site that needs to have a carbon neutral heat, CO_2 or gas supply will help bring greater support and investment by third party companies.

8. Government support to the private sector in waste valorisation

8.1 Introduction

The UK is now at a point where is it under pressure to drastically reduce its CO2 emissions but also, and more immediately, the agricultural sector is often frequently highlighted as a major contributor to UK CO2 emissions, with agriculture producing over 10% of the UK's greenhouse gas emissions in 2017. In addition, the government also has a clear waste strategy to move away from landfill sites and there is also the need to reduce the CO2 emissions from the waste industry (waste management accounts for around 4% of the UK's greenhouse gas emissions). This chapter will explore the role of the government in supporting the AD industry but in ways other than subsidies.

8.2 Growing demand to reduce waste

There was an ever present demand in most countries visited to avoid 'waste'. Overall, this was most paramount in Sweden, where local councils had the opportunity to take this to great lengths to ensure maximum recycling and avoidance of waste. In the USA, despite there not being massive popular support for renewable energy, there was clearly growing consumer demand for a reduction in waste. Recycling is of course key to reducing waste to landfill but reducing food waste is also a major player in reducing tonnages of waste going to landfill. A food waste recycling enthusiast told me that as food waste is a heavy fraction of the municipal solid waste fraction, any impact on reducing this fraction going to landfill has huge positive consequential results because food waste is a) so energy dense and b) emits methane which is one of the most damaging greenhouse gasses for global warming. I saw several campaigns against waste, illustrated in the figures below.

Figure 14. Public Works advertisement against food waste on bus in Nashville, Tennessee.

Source Author's own photo

Campaigns for instance in Austin, Texas helped to get a law introduced that banned restaurants from throwing away anything organic that could be composted. There, the preferred route was through food charities, followed by animal feed before the final option of composting. This highlights the food hierarchy that should be in place worldwide, although in this particular case the final option of composting means that while the nutrients may be recycled, the carbon dioxide will be lost to the atmosphere without any recovery of energy. The feed hierarchy was also of great importance in countries such as France where often large water treatment companies, such as Veolia, were in charge of not only wastewater treatment but also municipal food waste anaerobic digestion as well as composting.

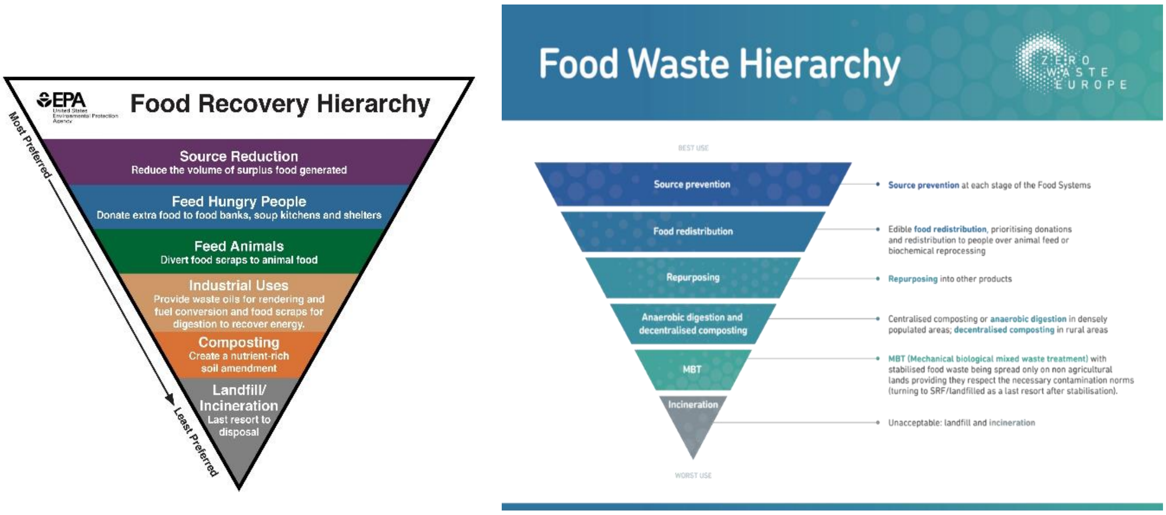

Figure 15. The food waste hierarchy showing the most preferable to least preferable options for dealing with food waste. It should be noted that AD is not explicitly mentioned in the US EPA hierarchy but it is presumed that this is implied under the 'composting' section, although in Europe AD is generally seen as preferable to composting due to the energy generation and prevention of CO2 emissions to the atmosphere.

Source: USA EPA and zero waste Europe food waste hierarchy.

It is clear that even in countries such as the USA where there is a large land mass and space for landfill sites to be situated with minimal disturbance to the local population and environment, there is still an appetite to reduce waste. The opposition to landfilling food waste is a trend seen across the world. For instance, on my visit to a waste processing facility in Mid- Western France it became apparent that France were in fact the world leaders in food waste avoidance after passing a law in February 2016 which prohibited supermarkets from throwing away unused food. I was told by AD plant operators how this had helped to make the shift from sending organic material to landfill that could easily be biogas feedstock.

Figure 16. French biogas plant visited fed on food waste collected from numerous commercial establishments. Waste that was not readily fermentable was treated by windrow composting

Source: Author's own photo.

8.3 Co-digestion with sewage sludge

AD has been used widely in the sewage treatment sector for decades as a means of processing sewage sludge. Sewage sludge is created from a wide number of smaller treatment works and then often transported as a sludge material to a more centralised site where it is treated by anaerobic digestion. The co-treatment of sewage sludge alongside other organic material streams, such as food waste, was a possibility I was especially interested in exploring. The co-digestion of sewage sludge and food waste is a well-researched and hypothesised concept, with most industry trade bodies, water treatment utility companies and practitioners in the UK advocating it as having a net beneficial effect to all. However, due to regulatory issues, it has not yet come into being. Therefore, finding sites which already co-digest food waste and sewage sludge was an aim of my travels. Yet despite references to co-digestion taking place in Sweden, I only heard first hand of trials work and no sites actively co treating material. A visit to Hornsby Bend, Texas, highlighted the opportunity for co-digestion, with a composting operation set up on the same site as the AD plant dealing with sewage sludge. Digestate from the sewage AD plant was then blended with composted digestate before being sold to the open market. However, the subsequent difficulty in selling the mixed co-product to the open market was highlighted

Figure 17. Hornsby Bend treatment works, Austin, TX, USA. *Source: Author's own photo*

AD plant to the left of the photo treating biosolids which was then combined with composted green waste before being sold as a balanced fertiliser to local farmers. *Source: Author's own photo.*

8.4 Key Learnings

- AD provides numerous public benefits: avoidance of landfill, CO2 and methane emissions
- There is growing public support worldwide for waste reduction, electorates demand it from their governments and collaboration with private AD owners/operators can be done successfully
- Combining waste treatment with sewage treatment provides multiple efficiencies and should be encouraged.
- Sewage waste is a valuable resource that is readily available and could help reduce the reliance on energy crops when subsidies inevitable reduce and a 'free of charge' or feedstock that gives operators a positive cash flowing gate fee will be required.

9. Discussion

9.1 The future direction of the UK AD industry

European Parliament has backed net zero emissions target for 2050. This has implications for European member states not only to reduce their emissions from waste, energy production and transport but to also produce a net positive benefit to help make up for losses elsewhere in sectors not able to adapt to the changes as readily. The UK has committed to meeting this target and AD can and should play a big part in this, however, AD should be seen holistically along with the government's waste strategy. There is also a critical role for the agricultural industry serious about reducing from its substantial emissions levels. In an industry that is always going to find it hard to become carbon neutral (i.e. making or resulting in no net release of carbon dioxide into the atmosphere), encouraging an agricultural sector that has the potential to be a net carbon negative industry (reduction of carbon footprint to less than neutral, so that the entity has a net effect of removing carbon dioxide from the atmosphere rather than adding to it) - through the avoidance of methane emissions of manures, wastes, and residues is surely something to promote and nurture.

9.2 Embracing where biogas can add value

Biogas production is different from many other forms of renewable energy, it can:

- Provide a natural gas alternative (not just electricity that renewable energy forms such as hydropower, wind and solar create).
- Provide electric output on demand – gas can be stored relatively easily – large scale electricity storage is proving problematic
- It can de-carbonise our current home heating system with little disruption (conversion from gas to electric would be disruptive to consumers and would not use our current gas network infrastructure).
- De-carbonise road transport – providing renewable methane gas for HGV road transport will help solve the problem of how to power HGVs on our roads, where batteries have struggled with to date
- Reduce damaging methane gas emissions to the atmosphere through the avoidance of food waste going to landfill or composting
- Provide flexible gas production – there is no reliance on natural conditions such as wind or sun – if the demand for production is not there, feeding can be reduced or ramped up according to meet gas demands
- Provide valuable by-products such as heat, CO_2 and nutrients and organic matter that can be returned to soils

Embracing these differences and key USPs of AD can and should help shape future investments and government policy.

9.3 Key opportunities for the AD industry

An ever present theme I found throughout my visits to multiple plants is that if AD is to be viable in the absence of subsidies there is a definite need to shift away from the thought process and business model of using one or two energy crops, such as the maize: rye (70:30) model that has proved so popular in the Europe and the UK. In the absence of subsidies there will be the need to adapt and move quickly to new feedstocks and manage the switch over between feedstocks which would be easier with a more robust microbial population within the digesters. Taking advantage of market opportunities, both local and global, is key here.

The most successful and profitable AD plants have developed a specific niche that works well for their AD's location. Those that have done this also never sit still and are constantly looking to take advantage of waste/residual products from other markets. This was largely done at sites to maximise the profitability of the site and increase profitability. However, in a future AD world without subsidies this will become a day to day necessity. For AD developers looking for potential sites there is a real need to look at the feed hierarchy, that is- does it make sense for the waste or residue stream to go to AD, if not, then it is highly likely that at some point this feedstock will be lost to other applications (such as animal feed, or for biomass burning). If a waste or residue looks like it fits well with the feed hierarchy, then there is likely longevity and greater long term success, as well as conforming to how governments generally see fit and desire waste/residues be treated.

In the UK 85% of domestic heat is currently provided by gas, furthermore it provides ~50% of the cooking needs for households and commercial premises*. For the UK to decarbonise heating from its current position, the use of methane either in renewable forms or from wastes or residues is one of the easiest and achievable ways of achieving this aim. Further, there is the added benefit of achieving improved domestic energy security.

Biomethane production is also key for decarbonising road transport, which, in the UK, accounts for approximately 25% of carbon dioxide emissions. Although electric cars are likely in the future, the problems faced by HGVs around range and power have not been solved. This problem is further exacerbated by the fact that 21% of the carbon dioxide emissions stated come from HGV transport. It is clear that HGV transportation needs decarbonising and the demand for renewable gas will be strong. Governments may get involved in attempts to decarbonise the haulage sector but it is likely this will fall to large corporations and their environmental goals. There is a clear opportunity to engage with companies in the UK that want to commit to renewable gas for the road transport needs. These companies will likely be willing to invest in infrastructure in order to secure a long term, decarbonised fuel as in the future cost of buying green gas certified certificates on the open market will surely be much higher.

*(source: http://www.energynetworks.org/assets/files/news/publications/GAS%20FAST%20FACT%20CARDS%20-%20ALL.pdf).

10. Conclusions

1. AD plants should aim to be based primarily on wastes/residues instead of purpose grown energy crops.

2. New biogas plants would benefit from a partner or sister business to utilise either the gas/electricity or heat that is produced. In an ideal world this business should be co-located on site or at least close.

3. The future biogas plant could benefit large corporations needs and desires to become carbon neutral – this is a great opportunity to work with large corporations and help them meet both their zero waste and energy neutral corporate goals.

4. A demand orientated approach for flexible biogas production would fit into the current renewable energy production framework.

5. Co-digestion of food waste and sewage makes perfect sense and will benefit both the water sector and waste treatment sector – overall more energy will be produced more locally. Government policy has to catch up to reflect this factor in the UK.

11. Recommendations

To current and future AD operators and developers and to Government

11.1 To current and future AD operators and developers

In order for a biogas project to be a likely profitable venture there has to multiple elements involved. The following recommendations give a good starting point for a profitable AD process and one for which, if such a model could be achieved , minimal subsidies would be required.

- Feedstock Supply: the days of 100% energy crops are likely behind us. The future will likely lie in the by-products, residues and wastes.
- Co-location with a secondary business which will profit from the heat, electricity, gas or CO2 production, such as large corporations looking to offset CO2 emissions, or wanting to secure a carbon free or even carbon negative supply. Large corporations' green credentials will act like the once-government subsidies were. They will help monetise the public good aspect
- Solve a waste problem. Identify existing waste streams that are not cost efficiently dealt with. This market will be more competitive, however, as long as there is organic matter there will likely be a pre-treatment method in order to access its full biogas potential. Identifying the market that will give a long term source of cost reliant and secure feed will be the key. Any subsidies that are available will likely only be around waste or residue material.
- Digestate: Quality is key. A poor quality digestate may save money in the short term through reduced investment. However, any investment in digestate treatment and nutrient recovery will be a worthwhile investment that will reduce the risk of pollution incidents and competition with others in a saturated market place.
- Work to the strengths of biogas and fill the gap that other renewables cannot. This includes peak load demand feeding schemes and gas storage and renewable gas for HGV transport.
- Engineering design, right first time. Rather than look to what has been done already in the commercial biogas sector , look to lessons learnt by AD plants in other sectors, in particular the water treatment sector. Decades of experience here provide multiple design lessons.
- Biology robustness: AD is a biological process, if the bacteria are not happy the biogas will not be created. Biological management protocols and KPIs have a key part to play.
- Modify, adapt, evolve with engineering challenges. The best AD plants visited have in house operations and maintenance teams that take responsibility, can react quick and do not rely on third parties. Not the cheapest but will likely pay dividends.
- AD plants must be designed in order to maximise the full energy flows. All heat flows need to be valorised to the maximum. Third party heat supply arrangements in an ideal world but in feedstock pre-treatment at the very least.
- Co-digestion with sewage sludge. Sewage sludge is a feedstock that will only increase with increasing population. It is one of the few readily accessible 'wastes' that can be secured at a competitive price due to the diverse geographical distribution of treatment works.

11.2 To Government

- The need for realism – current rates of subsidies do not provide adequate levels of incentives to make the conversion of low value wastes alone viable. Difficult to digest or low strength wastes will need government incentives to be treated on a commercial level – otherwise it is more economically viable for wastes to be spread on land without AD – further adding to CH_4 losses to the atmosphere and posing an increased pollution risk .
- Certainty of direction
- Willingness to quickly change legislation to meet commercial demands which have a net positive outcome for the country: the regulatory authorities must be flexible and approach issues with a willingness to solve attitude rather than putting up barriers.
- Co-digestion of sewage sludge and food waste has an obvious benefit to water utilities, commercial AD operators as well as helping to promote greater efficiency with reduced carbon emissions.

12. After My Study Tour

Through becoming a Nuffield Scholar both my personal and professional outlook have changed substantially. Through both being part of my peer group of fellow Nuffield Scholars and visiting some remarkable individuals and businesses; my thought processes, beliefs and values have been challenged and I have learnt to be more reflective, holistic and ambitious in my endeavours.

Starting my Nuffield study, I had a strong technical base of knowledge, however, building on this through my travels I have learnt to love the world of business, finance and economics on both a micro and macroeconomic level. All key factors that impact the successful implementation everywhere around the world of AD. This aspect of owning and operating an asset I have been inspired by many to 'grab the low hanging fruit', 'start now, get perfect later' and learn by doing.

I have learnt a valuable lesson that I will take forwards throughout my life – an investment mindset. The desire to build up an asset base delivering stable cashflow is no doubt the dream for many others also. However, my travels reinforced this factor clearly and made it clear that this is achievable for the everyday person. AD plants – as well as other forms of renewable energy - is no doubt a great asset class in which to invest in. It has the ability to be developed from nothing (or often bought as a distressed asset at below market value), using creatively structured finance and can be owned and operated at a relatively small scale. Energy production is no longer exclusively for the large multi-billion dollar energy multi nationals and can be done at a much smaller scale and provide a great asset class in which to invest in. As with all investments, the skill comes from due diligence and risk management, something that will stay with me in my future investment career.

The last decade has provided a fantastic environment in which to invest in renewable energy – AD included. However, the current political and public will does not currently seem to be supportive of the biogas industry in general. The once generous subsidies are going or gone, technological advance within the industry has not kept pace enough to be non-reliant on these subsidies. No doubt, the best operators, running the most efficient sites, with the best feedstock contracts will prosper – but it will be tough and further consolidation is likely with larger groups taking advantage of economies of scale in relation to contract negotiation and leveraging specialist expertise. The fruit is no longer low hanging at this period in time, it will undoubtedly return as pressure around global warming increases and governments are held to account on the carbon emissions. The right scenario will come again and when it does I will be waiting in the wings to ride that wave and invest early in the curve. Indeed, AD was not new in 2012, when the bulk of UK biogas plants were built, it will not be new in the next several years when things change once again. You cannot change the winds but you can adjust the sails.

Following my Nuffield travels I have decided to leave my job as a paid employee working in the agriculture and AD sector and devote all of my working time to building up an asset base of my own. In the immediate future this will largely be through increasing my commercial and residential property investments. However, the findings in this report will stand me in good stead that when the time comes around again for investing in AD then I will be there ready and poised to take advantage of a technology that has so many benefits on a local, national and global level.

I am sure AD will be ever present in the UK and it should play a pivotal role in waste reduction and carbon emissions reduction. AD should not be seen in isolation, it should work in conjunction with key industries such as natural gas, electricity production, landfill avoidance, animal feed and in decarbonising road transport and home heating. AD is a relatively new industry there is so much to establish and build upon and a massive opportunity to support and drive change in a positive direction in so many areas. I look forward to help and support drive change in the right direction.

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