BIOMETHANE: THE PATHWAY TO 2030

The no regrets option for the hardest to decarbonise sectors

ADBA

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Time and time again, prominent organisations with the ear of our government have highlighted biomethane's vital role in the decade of decarbonisation: "There is no net zero without biogas" (EU), "It is a win-win-win-win-win industry" (UNFCCC), "A biogas plant is the hub in the future circular economy" (IEA). With the impacts of climate change becoming ever more apparent, immediate and extensive, urgent action is required to cut emissions. While the UK's net zero goal is suitably ambitious, it cannot be achieved without immediate and significant investment into sustainable technologies, such as anaerobic digestion (AD). It is, as the Committee on Climate Change says, a no-regrets option.

This all-encompassing report "**Biomethane: The Pathway to 2030**" provides the evidence to corroborate these strong statements. It envisions the UK with AD at the heart of its circular economy, whereby all organic wastes readily available in 2030 are collected and digested. The report guides policymakers through the barriers currently inhibiting the AD sector from reaching its full potential and recommends policies to help overcome them.

From manure to food waste, all organic material holds value. When left to rot, much of this value is lost to the atmosphere in the form of carbon dioxide and methane, a far more potent greenhouse gas (GHG). In ten years' time, we estimate that approximately 170 million tonnes of organic wastes will be generated by society, and therefore available each year, ready to be digested. Through AD, the harmful emissions these wastes would produce can be captured and recycled into valuable new green products, with AD widely recognised as the most efficient tool for recycling organic wastes.

The result of an industry digesting all available feedstocks will move the UK one (large) step closer to its net zero commitment, reducing its annual emissions by over 27 million tonnes of CO_2e every year, or 6% of today's emissions. Moreover, as a technology that is available today, AD has the potential to contribute 30% of the carbon savings required to meet the UK's legally binding targets for 2030 set in the 5th Carbon Budget, helping the UK to catch up and get back on track to meeting Net Zero by 2050.

Now is the time to make AD happen.

Charlotte Morton
Chief Executive, ADBA

Anaerobic Digestion (AD), which generates biomethane, is the ready to use technology to cut emissions in the hardest to decarbonise sectors of transport, heat, agriculture and waste management, and it must happen now.

Our environment, economy and society are facing an existential threat. It has been declared around the country and around the globe: **we are in a state of climate emergency**. Critically, we are collectively running out of time to avert this climate crisis. Sea levels are already rising, displacing many vulnerable people living in island states; fires are becoming commonplace all over the world; extreme weather events are happening with unexpected and increasing frequency, including at home in the UK with floods creating destruction on a regular basis; ocean temperatures are rising even faster than expected; and global food production is increasingly at risk due to adverse weather conditions, soil degradation and desertification. We now have just 10 years to cut global emissions by 40-60% from 2010 levels[i] to prevent a temperature rise above 1.5°C, above which the consequences of climate change are increasingly catastrophic. Arguably we need to act much faster given that we are already seeing the severe impacts of climate change on our planet, its biodiversity and humanity itself. To achieve this goal, we must rapidly deploy all available solutions, and immediately roll out solutions that are readily available to cut emissions now.

AT ITS FULL POTENTIAL ANAEROBIC DIGESTION DELIVERS:

- **30% of the saving needed to meet the 5th carbon budget for 2030**
- **6% reduction in total UK emissions and in the hardest to decarbonise sectors**
- **27m tonnes CO_2 equivalent saved**
- **6.4 million homes heated**
- **8 billion m3 of biomethane generated**
- **30,000 direct jobs across the country**
- **£20 billion investment into UK industry**
- **170 million tonnes of organic waste recycled through AD**

Some sectors such as power are already making significant in-roads into their emissions, for example by using wind and solar electricity, and the pathway to decarbonisation is clear. Others, including heat, transport, agriculture and waste management, are far harder to decarbonise and greater leadership and action are needed. If we don't have solutions for these key sectors, we will not meet our targets to limit the global temperature rise below 1.5°C, and the future will not be one we can live with. We must create a net zero economy as quickly as possible to minimise the environmental destruction that climate change is already so evidently causing, and this means cutting emissions in these hardest to decarbonise sectors as an urgent priority.

Biomethane is a key solution. It is the ready to use renewable energy that must be adopted now to cut these emissions. Critically, with a supportive policy environment it can deliver its full potential, decarbonising the UK economy by 6%, in the next 10 years. And it will help create a prosperous world that we all want to live in, creating over 30,000 direct jobs in the UK to support the just transition to a green circular economy and developing a thriving industry that can be exported globally. Furthermore, AD, the technology used to generate biomethane, has wide reaching benefits, contributing to at least nine of the UN's 17 Sustainable Development Goals[ii].

Biomethane is not an option. It is a necessity.

What could our future look like? A vision for 2030

We are just 10 years away from a milestone that will define the world as we know it. What 2030 will look like all depends on our actions today, and the actions of those in power. AD is a ready to use technology to cut emissions in the hardest to decarbonise sectors, but it needs support now to deliver its full potential in the next 10 years, a period dubbed the climate decade. With a supportive policy environment to grow the biomethane industry, our future is bright. Without it, the consequences are bleak.

[i] IPCC report 2019, Summary for Policymakers p 12:
www.ipcc.ch/2018/10/08/summary-for-policymakers-of-ipcc-special-report-on-global-warming-of-1-5c-approved-by-governments/
[ii] www.worldbiogasassociation.org/wp-content/uploads/2018/12/WBA_SDG_Biogas_Report.pdf

EXECUTIVE SUMMARY: BIOMETHANE'S PATHWAY TO 2030

Achieving the 2030 vision in which AD reaches its full potential will mean collecting as much organic waste feedstock as feasibly possible to generate biomethane. Based on existing technological efficiency and considering the impact of rising populations and projected reduction of food waste on feedstock availability, the UK could generate 5.7 billion m^3 per year of biomethane by 2030, enough to heat 4.5 million homes. Assuming a conservative improvement in plant efficiency of 25%, these figures could rise to 7.1 billion m^3 per year, enough to heat 5.5 million homes.

With emerging power-to-gas technology, the biomethane potential could increase to 8.0 billion m3 per year by adding hydrogen to the AD process to boost the methane content of the biogas generated, equivalent to heating 6.4 million homes. This would deliver a carbon saving of 27.2 million tonnes of CO_2 equivalent (CO_2(e)) per year – **6% of the UK's current annual emissions** – specifically within the hardest to decarbonise sectors. This would deliver **30% of the carbon saving necessary for the UK to cut emissions in line with the legally binding 5th Carbon Budget**. At its full potential, AD provides emissions savings equivalent to the emissions from all HGVs operating in Great Britain[iii]. However, **we are presently delivering just 19% of this potential**. As innovation continues to increase plant efficiency and total UK emissions decrease, AD's potential contribution to carbon savings will only increase.

Delivering this carbon saving will not just support the necessary transition to a healthier environment, but also a healthy green economy. **At its full potential, the AD industry will create over 30,000 green jobs in plants across the country, including in rural communities**. In addition, AD provides energy security, removing dependence on external nations for our energy needs as we generate local energy from local waste or locally grown produce. It also contributes to food security, recovering vital nutrients from organic waste and reducing dependence on mined nutrients from abroad, which have limited supply. By 2030, the AD industry could attract £20 billion of investment into building a greener Britain, both from domestic and international sources. With a thriving UK AD industry, the country can become a leading player in the export of innovation, technology and professional expertise.

PRIORITY POLICY ASKS TO DELIVER THIS BY 2030:

- **Immediate support for renewable heat, including biomethane, beyond 2021**
- **Commitment to the continuation of the RTFO beyond 2032, including a price guarantee**
- **Targeted innovation funding supporting key aspects of the industry**
- **Establishment of material hierarchies for all organic wastes with AD as the optimal recycling technology**
- **Development of a renewable biofertiliser obligation**
- **Support for local circular economy projects that use AD to transform local waste into local heat and power**

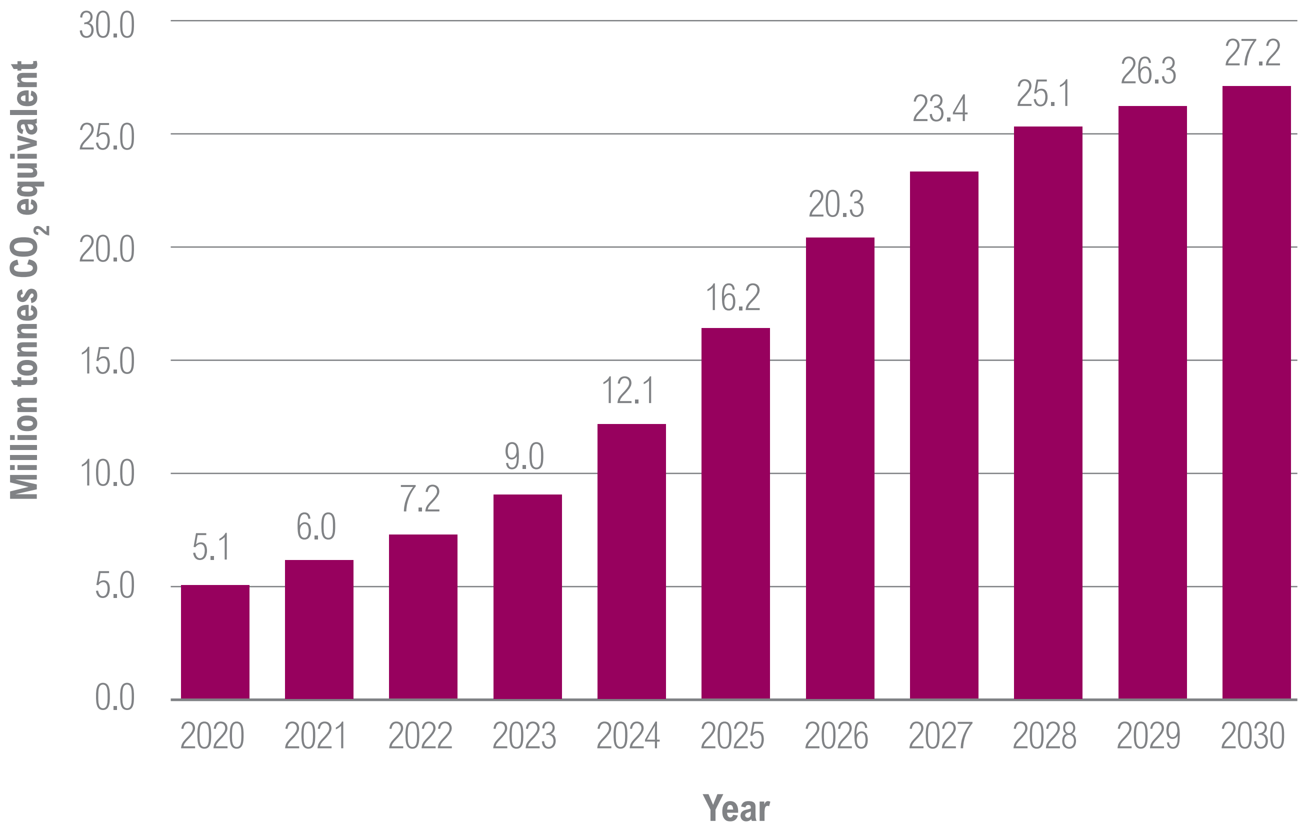
The pathway to 2030

Over 670 AD plants are currently operational in the UK, generating nearly 12 TWh. These plants are already preventing 5.1 million tonnes of CO_2(e) from being emitted each year, equivalent to the annual emissions from the entire bus and rail networks. This represents just one-fifth of the industry's full potential, with all available feedstocks processed through AD.

Between 2013 and 2015, strong government incentives resulted in the construction of over 100 new plants each year. However, to reach the industry's full potential by 2030, growth must be faster than this. While ambitious, this is not impossible. To achieve this the industry will require robust and immediate support from government to reflect and reward its wide-ranging environmental and social benefits and set it on a glide path to commercial viability. This will build a world class AD industry in the UK, with goods, services and expertise that can be exported around the world.

[iii] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/787488/tsgb-2018-report-summaries.pdf

POTENTIAL GHG SAVINGS FROM AD PER YEAR



The challenges and how to overcome them

Biomethane is a vital part of our urgent transition to a sustainable future. The benefits of AD, for the environment and for the economy are clear, but there are barriers that must be overcome to enable the technology to deliver these benefits. Technically the industry is more than capable of delivering the industry's full potential by 2030.

The main challenge to maximising the supply of biomethane and increasing the deployment of AD plants relates to the financial equation for projects. In particular, the multiple environmental services that AD delivers, for the climate, the environment and the circular economy, are not properly reflected in the revenues received by plants as the market price does not effectively incorporate the societal benefits delivered.

It is also clear that the general population is not aware of the huge potential AD represents for their country, as well as their local communities. Education and public awareness about the wide reaching benefits of AD will help overcome the barriers identified below, by empowering people to hold their political representatives to account when delivering energy, transport, agricultural and waste system that must meet the sustainability requirements necessary for the climate decade:

EXECUTIVE SUMMARY: BIOMETHANE'S PATHWAY TO 2030

BARRIERS	SOLUTIONS	
Stop-start policy support leading to uncertainty, limiting investor confidence and increasing price of finance	Immediate policy support needed beyond March 2021 in the form of a tarfiff	Long-term strategy for the AD industry that stimulates demand for all services delivered
The non-energy environment services that AD delivers are not effectively recognised/priced	Renewable biofertiliser obligation to stimulate the market for digestate	Effective shadow price for methane mitigation activities, or carbon price
A large amount of waste feedstocks is currently not being separately collected and diverted to AD for processing	AD set out as the optimal treatment for all organic wastes, not just food waste	Waste hierarchies actively implemented so organic wastes are diverted to AD, including manure
The complexity and cost of grid injection	Standardisation of gas grid connection requirements across the gas distribution networks	Centralisation of grid injection so connection cost can be shared by a number of plants
Adherence to industry best practice and environmental standards	Improved Ofgem and Environmental Agency resourcing to streamline regulatory processes	Policy tied to AD Certification Scheme to ensure all plants are adhering to best practice

Policy recommendations to deliver the 2030 vision

Realising the pathway to 2030 is entirely dependent on the objectives and policies the government enacts now and commits to. It is important that a strategy with specific targets is put forward to cover the next 10 years. The industry can deliver its full potential in this time, which would mean **30,000 direct jobs in the green economy** and more indirect jobs; an **investment of over £20 billion into UK industry** from both domestic and overseas investors; **30% of the carbon saving necessary for the UK to cut emissions in line with the legally binding 5th Carbon Budget**; and a **6% reduction of total UK GHG emissions**. To deliver this, investors must feel confident that they are operating in a stable environment. A supportive policy environment is key to deliver the long-term industry strategy and stimulate demand for the many co-products and environmental services of biomethane generation to create a more independently viable industry.

The policies needed to overcome the current barriers to industry growth need to be well coordinated across the different policy areas, to deliver the greatest impact from the public resources involved and to unlock AD's full potential. They should also be accompanied by the removal of tax breaks for the fossil fuel industry, with more targeted measures to address fuel poverty focused on low-income households rather than blanket support to reduce the price of fossil fuels; and the introduction of a robust and ambitious carbon pricing system in the UK.

Our policy recommendations are therefore organised in line with the different policy areas: heat, transport, agriculture and waste management.

HEAT:

- **Immediate interim support beyond March 2021** in the form of an energy tariff to urgently increase deployment, closer to the rates seen in 2013-2015 which delivered deployment of around 100 plants per year, while more tailored policy is developed. Lessons learnt from the RHI and FiT should inform the design of this interim policy, including length commissioning deadlines and tiering of the tariffs.
- **A green gas obligation on the gas grid**, with gradually increasing targets to stimulate demand and a minimum price for certificated gas to provide a level of certainty to investors.

TRANSPORT:

- **Commitment to extending RTFO beyond 2032.**
- **Infrastructure funding** for the development of alternative refuelling networks, delivering biomethane as a transport fuel.
- **Align classifications of waste between government departments** to simplify the participation across multiple incentive schemes, such as RHI and RTFO.
- **A price guarantee should be introduced within the Renewable Transport Fuel Obligation** to provide greater certainty to investors and to ensure a more stable supply of biomethane for transport.

AGRICULTURAL:

- **A renewable biofertiliser obligation** to stimulate the market for digestate and transition towards a more circular use of fertilisers based on nutrient recovery.
- In line with legislation requiring all digestate and manures stores to be covered by 2027, **appropriate support such as grants are required to effectively prevent emissions** and draw value from captured gas, without adversely impacting farmers and operators.
- **AD should be included in the Environmental Land Management Policy** in the Agricultural Bill to recognise the benefits it can deliver in terms of reduced on-farm emissions, alongside generating renewable energy and generating renewable biofertiliser.
- **Tighten the end-of-waste standards for digestate**, including restrictions on feedstock contamination, to give farmers greater confidence in the quality of digestate.

WASTE MANAGEMENT:

- **Support for small business and community projects** on circular economy, transforming local waste into local heat and power.
- Encourage the **treatment of all organic wastes through AD**, including manure and slurry, by developing hierarchies, like the food and drinks material hierarchy, for all organic material, and introduce mandatory measures to ensure these hierarchies are enforced.
- **Urgently implement separate collection of food and green waste** and diversion to AD as the optimal treatment method, with the possibility of co-mingled collection in localities with dry-AD infrastructure. Increase producer responsibility for waste collection, reuse and recycling.

OVERARCHING:

- **Targeted innovation funding** to unlock key aspects of the AD industry that reduce cost, including digestate upgrading; biomethane yield; and utilisation of bio-CO_2.
- **Increased administrative capacity in Ofgem** and streamlining of processes to ensure there is confidence that payment will be made on time and accreditation will be received in a timely manner, such as accreditation for innovative new feedstocks.
- **Lower business rates** for the AD industry and review of other tax allowances that could be offered to incentivise deployment.
- **Support best practice by tying policy to independent certification schemes**, such as the Anaerobic Digestion Certification Scheme, to ensure plants are adhering to environmental standards, plant optimisation and health and safety, thus minimising risks and costs.

Contents

ADBA POLICY TEAM ENQUIRIES

Rebecca Thompson, Senior Policy Manager
T +44 (0)203 960 0777
E rebecca.thompson@adbioresources.org
Viktoryia Nestserava, Policy Manager
T +44 (0)203 567 0751
E viktoryia.nestserava@adbioresources.org
Nick Primmer, Policy & Market Analyst
T +44 (0)203 960 0773
E nick.primmer@adbioresources.org

1.1. Introduction

Our environment, economy and society are facing an existential threat. It has been declared around the country and around the globe: we are in a state of climate emergency. Sea levels are already rising, displacing many vulnerable people living in island states; fires are becoming commonplace all over the world; extreme weather events are happening with unfathomable frequency; and floods are creating destruction on a regular basis, including at home in the UK. We now have just 10 years to cut global emissions by 40-60% from 2010 levels[1] to prevent a temperature rise above 1.5°C, above which the consequences of climate change are increasingly catastrophic. To achieve this goal, we must make use of all available solutions, and immediately role out technology that is readily available to cut emissions. We must create a net zero economy to prevent the environmental destruction that climate change is already bringing about today, and this means cutting emissions in the hardest to decarbonise sectors as an urgent priority. Biomethane can do this, capable of cutting the UK's emissions by 6% by 2030, and in the hardest to decarbonise sectors of heat, transport, agriculture and waste management. It is a ready to use renewable energy that must be expanded immediately.

This chapter sets out the vision for 2030, with anaerobic digestion (AD) central to delivering a better, more sustainable UK. It also establishes an alternate vision without AD, in which these hardest to decarbonise sectors are still heavily dependent on fossil-fuels and there is still poor management of organic wastes, generating high levels of GHG emissions that could be prevented with treatment through AD, and failing to capture the valuable energy, nutrients and organic matter contained within them. It explains how AD is vital to creating a circular economic system, based on recycling nutrients and generating green energy from waste, as well as how it delivers multiple carbon savings. It explores where the industry is today and what the remaining potential is for capturing waste feedstocks and turning them into clean, natural, renewable energy, biofertilisers and other bioproducts.

1.2. A vision for 2030: a zero-carbon circular economy with AD at its heart

The British public know that we must act now. Climate change is clearly an urgent priority for the people of this country. Not only are we seeing changes in consumer behaviour, but it is due to pressure from the public that our national governments declared climate emergencies. When we talk about a vision in which we have mitigated the worst effects of climate change, we are no longer talking about a distant future. This is an urgent crisis and AD is a ready to use technology that cuts greenhouse gas emissions in numerous ways, while sustainably treating organic wastes and recovering vital nutrients. In the next 10 years, dubbed the 'climate decade', AD can and must be extensively rolled-out to meet the challenge we face in cutting emissions in the hardest to decarbonise sectors of heat, transport, waste management and agriculture.

If we are to achieve Net Zero, we must build a future in which AD is used to treat all unavoidable organic wastes, so these harmful emissions are avoided. In 10 years, we must have a circular economy in which these materials are no longer considered wastes but resources, used to generate energy, replenish our soils, and act as a platform for biorefining. Our vision for the future is based on a world in which the biomethane generated will displace 22% of current fossil gas demand for domestic heat, 70% of the UK's bus and heavy goods vehicle (HGV) energy demand, or 21% of total electricity demand, supplying a baseload to meet demand in peak periods. Our organic wastes will be treated through AD such that the methane emissions created when they break down are captured. Methane is a greenhouse gas which is 28 times more harmful than carbon dioxide over a 100-year period.[2] Using this biomethane as an energy source will prevent these emissions from entering the atmosphere.

In this circular economy, businesses will be transformed so they recycle their inedible organic residues through AD to fuel transport fleets; supply heat and power for operations, replacing fossil energy needs; and recover nutrients to return to soil. Farms will use AD to treat manure and other farm wastes, preventing associated methane emissions; provide clean fuel for tractors and generate energy for their operations; diversify rural incomes; help replenish depleted soils; and provide community energy to rural areas. Circular cities will recycle all unavoidable, inedible food waste from their residents and businesses through AD, which will heat their homes, fuel their buses, and fertilise city farms and urban community gardens.

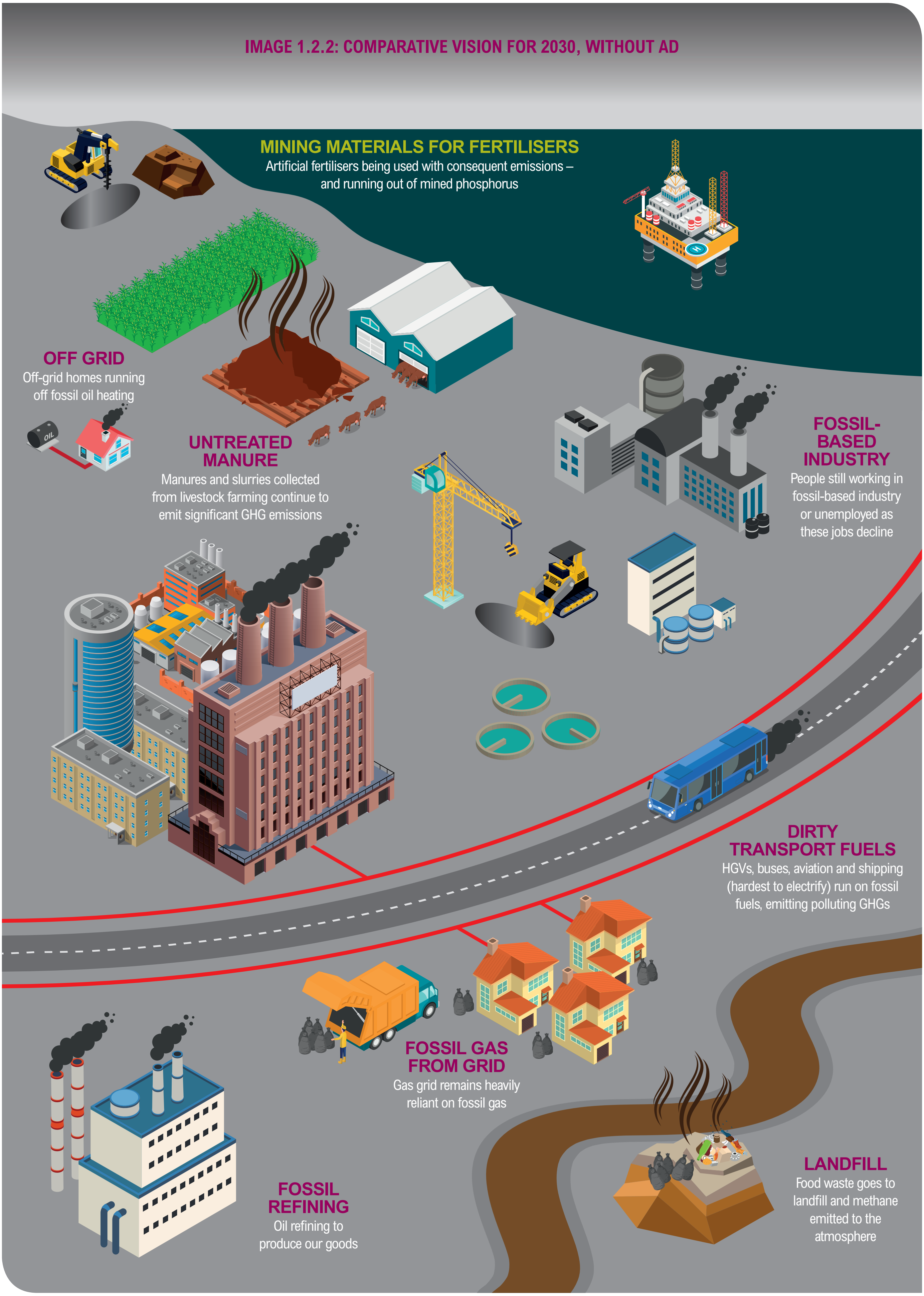
[1] IPCC report 2019, Summary for Policymakers p 12:
www.ipcc.ch/2018/10/08/summary-for-policymakers-of-ipcc-special-report-on-global-warming-of-1-5c-approved-by-governments/

[2] www.ipcc.ch/site/assets/uploads/2018/02/SYR_AR5_FINAL_full.pdf

1. AD at the heart of the carbon-neutral circular economy

1. AD at the heart of the carbon-neutral circular economy

IMAGE 1.2.2: COMPARATIVE VISION FOR 2030, WITHOUT AD



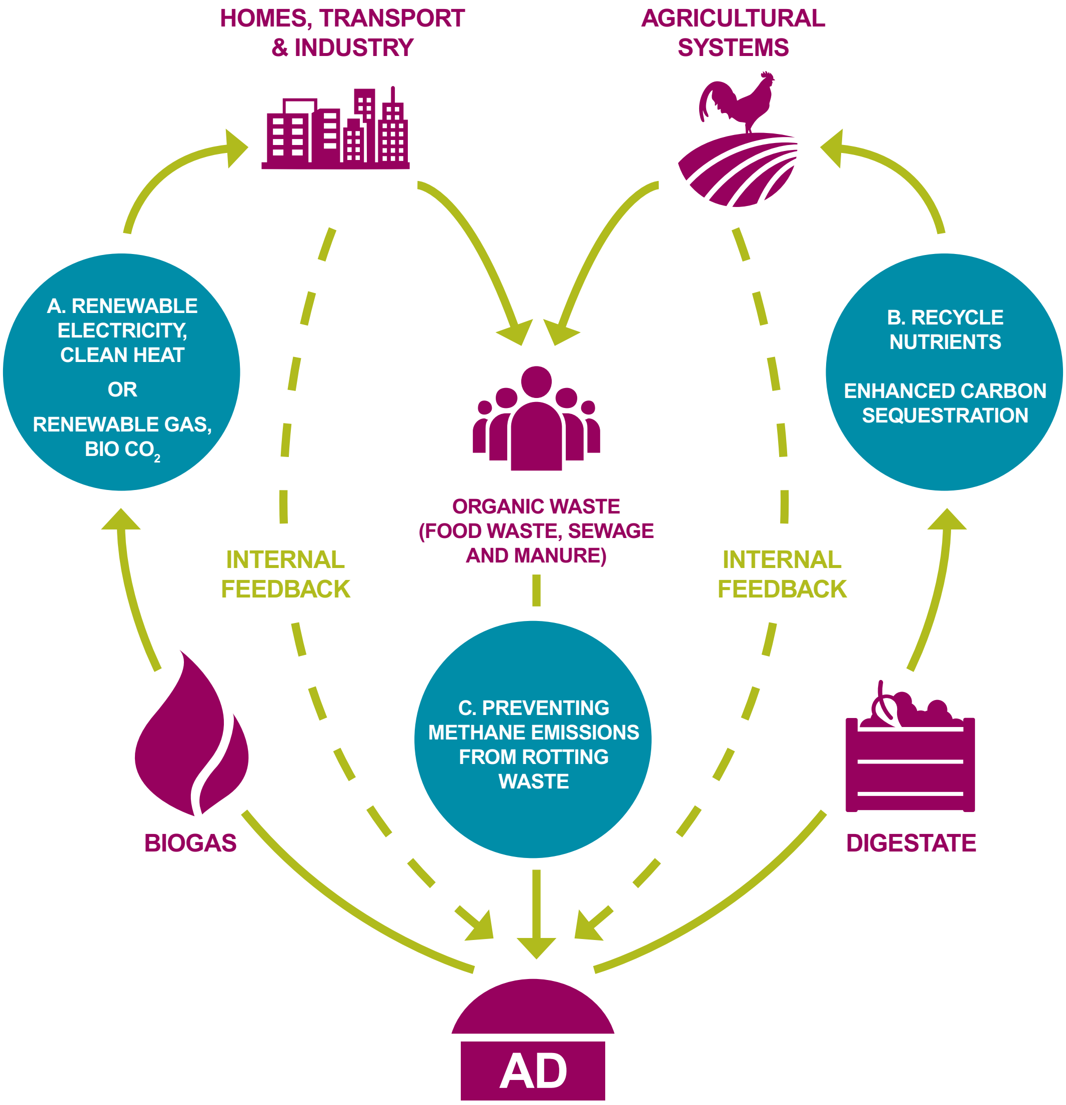
1. AD at the heart of the carbon-neutral circular economy

Without AD, heat, transport and agriculture will, in 2030, still be heavily dependent on fossil fuels, releasing GHG emissions into the atmosphere that would otherwise be safely stored deep underground. Organic wastes will continue to emit greenhouse gases directly into the atmosphere as they breakdown, rather than be captured and used as an energy source. It is unacceptable for organic wastes to still go to landfill when AD is a proven technology to prevent these emissions, and we cannot let this continue as we look to 2030. In addition, without AD, nutrient cycles will continue to be disrupted, with valuable nutrients and organic matter ending up in landfill and the continued mining and manufacture of artificial fertilisers generating emissions and depleting phosphorus reserves, among other key nutrients.

1.3. How it works: recycling organics

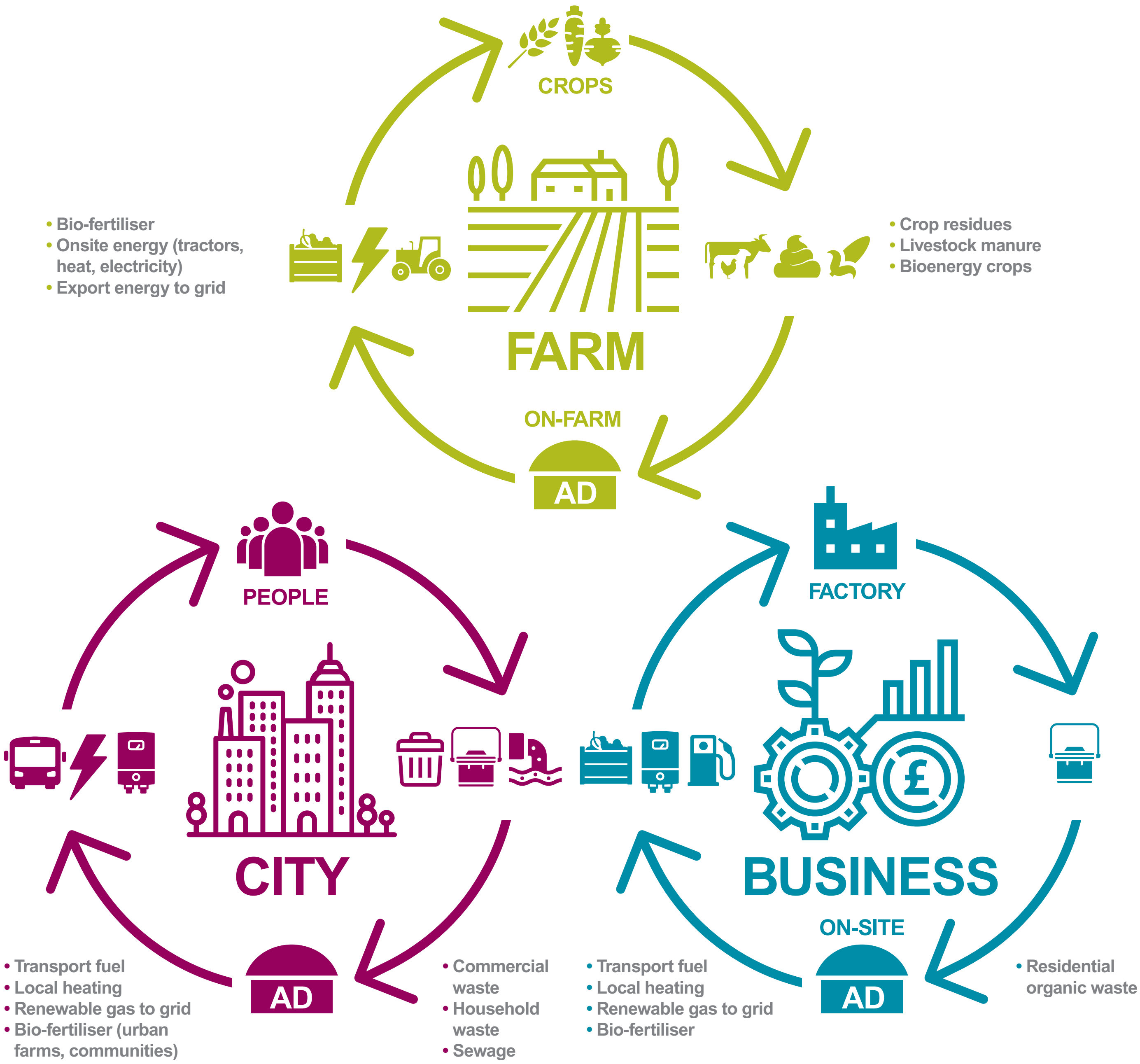
When organic materials break down, they emit GHGs. Anaerobic digestion (AD) is a natural process which occurs when organic material is broken down in a closed environment, for example in an animals stomach. When organic matter is processed at an AD plant, biogas is produced and captured, and a nutrient-rich organic matter, known as digestate, remains. The biogas produced is made up of a mixture of biomethane, bio-CO_2 and small amounts of other gases. The biogas can then be used to fuel a Combined Heat and Power (CHP) generator, or upgraded to biomethane, which is equivalent to fossil natural gas, by separating the methane from the bio-CO_2 and other gases. This is a circular process as the organic wastes that we produce, from food manufacturing and processing, farming and household waste among others, can be recycled through AD plants. Processing organic materials in this way means that the methane emissions, 28 times more harmful than CO_2 and classed as a short-lived climate pollutant, that would otherwise be released from the organic waste streams breaking down in landfill or elsewhere where the gases are not collected, are avoided.

IMAGE 1.3.1: AD CIRCULAR PROCESS



When cities, farms, or businesses recycle their waste through AD, their organic wastes become a resource to heat their homes, power their buildings, and fuel their transport fleets. The biogas they produce can be upgraded to biomethane, which can be injected into the gas grid or converted into compressed natural gas or liquefied natural gas to use as a transport fuel, displacing fossil gas and fossil-based transport fuels. Alternatively, the biogas can be used to generate electricity, which again displaces carbon-emitting electricity generation. This circular process also enables nutrients and organic matter to be recycled back to our soil, which are in poor health from years of intensive farming. Digestate is a nutrient rich liquid and can be used as a fertiliser, displacing carbon-heavy artificial fertilisers. Not only does this create circular systems in our cities, farms and businesses, but also helps to integrate our rural and urban economies, which are becoming increasingly disjointed.

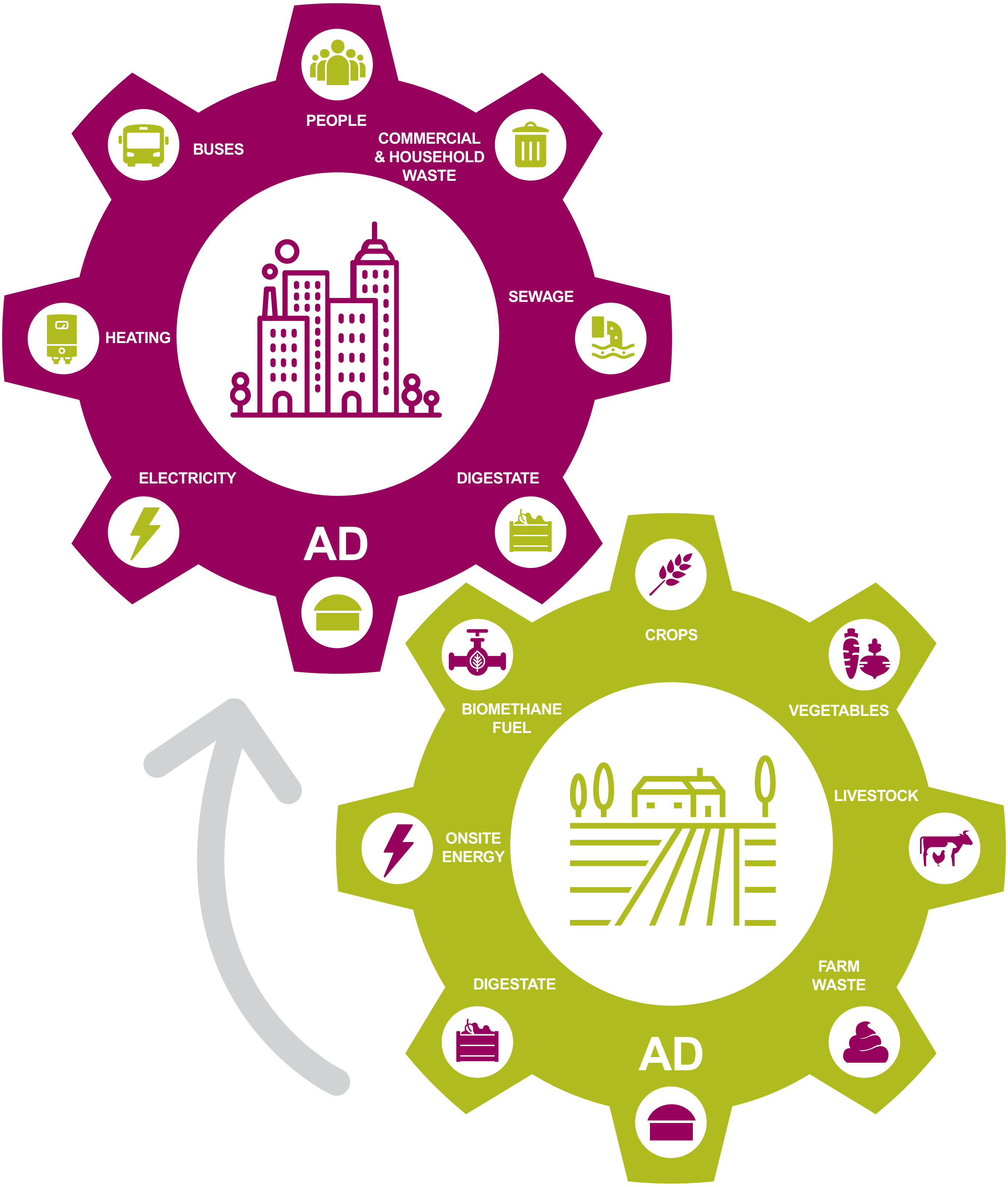
IMAGE 1.3.2: AD CIRCULAR CITY, CIRCULAR FARM, CIRCULAR BUSINESS



1. AD at the heart of the carbon-neutral circular economy

In addition, AD can form the building blocks for biorefining. Both digestate and biogas are rich in nutrients and chemicals that can be processed and refined for use in manufacturing and to develop new bio-based products to replace petrochemicals. Compared to utilising the products for energy and fertiliser, this is currently not commercially viable. However, with long-term government commitment to the bioeconomy and finite resources such as phosphorus becoming increasingly rare as they approach their peak, the technology will become more cost competitive making this a significant growth area for the industry.

IMAGE 1.3.3: INTEGRATING URBAN AND RURAL SYSTEMS



1.4. Current carbon abatement: what AD is already delivering

Not only does AD displace fossil-based products, it also prevents GHG emissions, primarily methane, that would have been emitted by organic wastes rotting in open environments. AD offers a controlled environment to capture these emissions and utilise this valuable natural gas. In the case of methane emissions, these are converted into CO_2 when burnt in place of fossil natural gas as a heating fuel, which is over 95% less harmful than methane over a 100-year period[3].

There are currently 672 AD plants in the UK, with an installed capacity of 992 MWe-e. This is enough to heat close to a million homes. Of these plants, 108 are biomethane plants, in which the biogas is upgraded to biomethane, which has the same chemical structure as natural gas, so it can be injected into the gas grid or used as transport fuel, with a total installed capacity of over 85,000m^3/hr, equivalent to the gas demand of Edinburgh[4], with a population of over 500,000 people[5]. The sector is currently injecting 2.1 TWh of biomethane into the grid each year, which is enough to heat more than 170,000 homes.

This production means that the equivalent amount of fossil gas and non-renewable electricity is displaced. In addition, artificial fertiliser is also displaced when PAS110 certified food waste digestate is spread to soil. Along with the prevention of methane emissions from organic waste streams breaking down in the open air, this equates to a total carbon abatement of 5.1 million tonnes of CO_2-eqivalent. This already reduces the UK's greenhouse gas emissions by 1% each year and is equivalent to taking over 2 million cars off the road[6], or planting over 83 million trees[7]. This is a hugely significant carbon saving. Broken down into its component parts, table 1.3.1 shows the carbon saving achieved by different aspects of the AD process.

TABLE 1.4.1: CARBON SAVING BROKEN DOWN BY COMPONENT BENEFIT OF AD

	CARBON SAVING, $MtCO_2$-eq	EQUIVALENT TREES PLANTED[7]
Displaced fossil gas (heat & transport)	0.42	6,944,000
Displaced fossil-based electricity	1.70	28,109,000
Displaced artificial fertiliser	0.46	7,606,000
Prevented methane emissions from…		
…farm waste	0.22	3,637,000
…food waste	0.69	11,409,000
…sewage	1.58	26,125,000
Total	**5.07**	**83,767,000**

NB: total equivalent trees planted do not sum due to rounding.

1.5. The best treatment: using AD to prevent emissions from organic wastes

If left untreated, organic wastes emit greenhouse gases (GHGs) into the atmosphere as they break down. This is the natural process of decay, but these emissions are still a direct consequence of human consumption and waste, that is they would not occur otherwise. When these GHGs are released, they directly contribute to global warming and climate change. Methane is one of the primary GHGs released when organic matter breaks down and is 28 times more damaging than carbon dioxide over a 100-year period. Using AD, these organic waste streams can be broken down in a contained environment and the methane emissions captured. Once captured and separated, the biomethane can be used as energy, replacing fossil-based energy, and in the combustion process this methane is converted to a less harmful GHG, CO_2. AD is, therefore, a ready to use technology for methane capture, use and conversion that could be used to treat all forms of organic waste and prevent these harmful emissions entering our atmosphere. In addition, the treatment of these organic materials, which have directly extracted CO_2 from the atmosphere during their lifecycles, is a form of carbon capture that isolates this CO_2 in a concentration 1,000 times greater than present in the air. This is far more efficient than Direct Air Capture, and the utilisation of the bio-CO_2 transforms AD from a carbon neutral to a carbon negative technology.

[3] www.epa.gov/ghgemissions/overview-greenhouse-gases#methane

[4] www.gov.uk/government/statistical-data-sets/gas-sales-and-numbers-of-customers-by-region-and-local-authority

[5] www.nrscotland.gov.uk/files/statistics/council-area-data-sheets/city-of-edinburgh-council-profile.html

[6] www.smmt.co.uk/wp-content/uploads/sites/2/DEF571-SMMT-Co2-report-2017.pdf

[7] www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

1. AD at the heart of the carbon-neutral circular economy

In all nations of the UK, AD is already classed as the optimal form of treatment for food waste that cannot be prevented or redirected for consumption by humans or animals. AD has been used to treat sewage in the UK for over 32 years, capturing the methane and carbon dioxide emissions from this waste and using it to power the treatment facility. However, there is still a huge amount of organic waste that is currently not treated through AD. For example, 29 million tonnes of sewage are still not recycled through AD, with few projects planned to increase this, and of the 13.6 million tonnes of food wasted each year in the UK, only a fraction is anaerobically digested, with the rest either left to emit methane directly into the atmosphere or treated through less efficient processes such as incineration and landfill. New legislation in England will now see mandatory separate collection of food waste across the country, which should increase the proportion directed to AD. Possibly most significantly of all, over 90 million tonnes of animal manures and slurries are currently collected and spread directly to land, untreated, as fertiliser[8]. By weight, this constitutes approximately 60% of untreated organic waste in the UK, but there is no framework which suggests that such organic waste should be treated. If this farm waste were treated through AD, 445,000 tonnes of CO_2(e) would be prevented just from the capture of GHG emissions, and the digestate could still be spread to land as natural fertiliser.

TABLE 1.5.1: COMPARISON OF THE ORGANIC WASTE IN THE UK TREATED THROUGH AD AND THAT LEFT UNTREATED

	TREATED THROUGH AD (MILLION TONNES)	**CURRENTLY IN 2019** (MILLION TONNES)	**ESTIMATES OF 2030 FEEDSTOCK, CURRENTLY UNTREATED** (MILLION TONNES)
Food waste	3.8	5.9	3.8
Sewage	23.9	28.7	30.3
Farm waste	4.2	91.4	96.5
Industrial waste	8.4	4.0	4.0
Green waste	<0.1	1.2	6.7
Other residues	1.6		
Total	**41.9**	**131.2**	**143.7**

Over the next 10 years, certain feedstock streams are predicted to increase with innovation and population change, estimated to increase by an average 0.5% each year by the ONS[9]. Projected food waste available in 2030 is estimated with the assumption that per capita food waste will be halved from today's levels, and 69% will be collected and directed to AD. In terms of waste emissions and energy recovery, AD represents the optimal means of processing this organic waste. In addition to methane capture, use and conversion, the biogas generated by treating these wastes through AD displaces fossil-based energy sources, preventing their emissions; and digestate, which displaces artificial fertiliser and the emissions generated from producing them.

1.6. Untapped potential: the value in organic wastes

We currently produce over 170 million tonnes of organic wastes as a society, only a quarter of which is currently treated through AD to capture the biogas and produce digestate. Without even considering the potential of energy crops, this means that there are an additional 120-140 million tonnes of potential feedstock that could be treated through AD. This is a valuable resource that is currently being wasted rather than utilised to generate energy and recover nutrients back to our struggling soils.

As shown in table 1.6.1, this can be broken down by feedstock type. The different types of feedstock have different efficiencies for generating energy, which can go some way to explain why farm waste hasn't been widely utilised.

[8] http://sciencesearch.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=14500
[9] https://bit.ly/31VFhDe

TABLE 1.6.1: POTENTIAL OF UNTREATED ORGANIC WASTE STREAMS AS A FEEDSTOCK FOR AD (EXCLUDING THE POTENTIAL FROM ENERGY CROPS)

	UNTREATED FEEDSTOCK ADJUSTED FOR 2030 (MILLION TONNES)	BIOGAS POTENTIAL (TWh)	HOMES HEATED
Food waste	3.8	4.3	358,000
Sewage	30.3	3.3	275,000
Farm waste	96.5	18.3	1,525,000
Industrial waste	4.0	4.2	350,000
Green waste	6.7	5.7	475,000
Total	**141.3**	**35.8**	**2,983,000**

However, the carbon abatement benefits of treating all organic wastes through AD make this worthwhile even if the energy efficiency of some feedstocks is lower. If all these waste feedstocks are diverted to AD, the industry has the potential to produce an additional 35.8 TWh of biogas, heating another 3 million homes. This potential is based on current yields and so provides a very conservative estimate of the industry's potential. Innovation and improvements in technological efficiencies will significantly increase these figures.

2.1. Introduction

As we look ahead to how we best tackle the climate crisis before it's too late, it is essential that we make the most efficient use of resources to have the greatest climate mitigation effect. This is not only true of the wastes we generate, and the need to ensure they are treated and utilised in the best way, but also of the end products from the anaerobic digestion (AD) process. The majority of the UK's biogas is used to generate electricity and residual heat, in a combined heat and power (CHP) generator. This electricity helps to provide a baseload of domestic electricity that can be utilised in periods of peak demand and when wind and solar supply is lower due to weather conditions; and can provide local waste management and local energy solutions to off-grid communities, in line with circular economy principles. However, improvements in renewable electricity generation in recent years, in the offshore wind and solar sector, due to long-term stable government support, have meant that these are now very competitive technologies for electricity generation and the path to decarbonisation is well on its way.

The role of biogas in our 2030 energy mix, therefore, looks to address the harder-to-decarbonise areas in which it is one of few technologies that are at technological maturity and can make significant inroads. The Committee on Climate Change (CCC) has identified biomethane as a low-regrets option[10] as it clearly has a significant role to play in decarbonising heat and transport, with the accompanying benefit that AD has on decarbonising agriculture and recycling nutrients. AD is already saving nearly 5.1 million tonnes of CO_2(e) from being emitted every year – around 1% of the UK's annual emissions – and this represents just one-sixth of its full potential. At its full potential, the AD industry could be delivering nearly 5.7 billion m3 of biomethane, equivalent to heating 4.5 million homes. This would deliver a carbon saving of 27.2 million tonnes of CO_2(e) and cut UK emissions by 6% each year. To unlock the full potential of AD to decarbonise the UK economy, we must first overcome existing barriers to industry growth, including stop-start policy support; complexities around grid connection; low collection rates for separate food waste; AD not being priorities as the best form of treatment for organic wastes, with some feedstocks not treated at all; and the environmental benefits of AD currently not being valued effectively within traditional pricing mechanisms.

This chapter explores the role of biomethane in our future energy mix in more detail. Biomethane is a flexible resource that can be used adaptively depending on need, to cut emissions in transport and heat in varying proportions depending on need and the technological maturity of alternative solutions. The chapter sets out the full potential of biomethane to cut emissions in these sectors, as well as the wider benefits for clean air, sustainable agriculture and soil health, among others.

2.2. Biomethane generation potential

Biomethane is generated from the upgrading of biogas, a process which separates the methane in the biogas from the carbon dioxide and any contaminants in the biogas, increasing the methane content to over 95%. Various technologies can be applied to upgrade biogas to biomethane. The four major technologies for separating the bio-CO_2 are adsorption (pressure swing adsorption), absorption (water scrubber / physical absorption using organic solvents / chemical absorption), permeation (high pressure membrane separation / low pressure membrane separation) and cryogenic upgrading.

Biomethane can be used as a direct alternative to fossil gas, as it has the same chemical structure, meaning it is already compatible with the UK's existing gas infrastructure. Unlike biogas electricity, biomethane cuts emissions in the hard to decarbonise sectors of heat and transport, where there are very few alternative technologies and few that are at technological maturity. Biomethane is, therefore, the key solution to decarbonise heating and heavy goods vehicles in transport, with a great deal of potential for shipping and planes, over the critical 10 years ahead of us. At its full potential, the AD industry would be able to save over 27 million tonnes of CO_2(e) from being emitted into the atmosphere every year – greater than the current emissions of all HGVs operating within Great Britain[11].

[10] www.theccc.org.uk/publication/next-steps-for-uk-heat-policy/

[11] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/787488/tsgb-2018-report-summaries.pdf

BY 2030, AD COULD SAVE 27.2 MILLION TONNES CO_2 EQUIVALENT EVERY YEAR

The equivalent to:

12.3 million cars or **63 million barrels of oil** or **450 million trees**

Biomethane is therefore forecast to be the primary growth area for the industry as we look to the future. If the currently untapped waste feedstocks are diverted to biomethane generation, based on existing technological efficiency, the UK could generate 5.7 billion m^3 per year of biomethane by 2030, enough to heat 4.5 million homes. If we consider the impact of rising populations and projected reduction of food waste on feedstock availability; improved energy efficiency and energy saving measures in homes; and assume a fairly conservative improvement in plant efficiency of 25%, this rises to 7.1 billion m^3 per year, enough to heat 5.6 million homes. We are currently delivering just 19% of this full potential.

This potential can be broken down by feedstock type, as shown in table 2.2.1, and can be supplemented by biomethane generation using bioenergy crops, sustainably integrated into our agricultural system. The Committee on Climate Change's 2020 Land Use report estimates that 690,000 ha of land will be required to grow bioenergy crops to meet net zero by 2050[12]. To model AD's full potential, we assume that 41% of this land will be used specifically for AD, applying the average proportion of bioenergy land use that has been dedicated to AD over the past 5 years[13]. On this land, the CCC also estimate that 15 tonnes of dry organic matter can be produced per hectare[12]. Consequently, 4.2 million tonnes of energy crops are modelled within our estimate for AD's full 2030 potential, providing that these bioenergy crops may be grown sustainably[14]. New approaches to agricultural practices are helping to ensure that all farms are sustainable, without adversely effecting productivity. This can be achieved by integrating bioenergy crops into crop rotations, increasing the number of crop cycles (three in a two-year period) or as cover crops to help manage certain pests and diseases.

Dry AD represents a highly underdeveloped sector of the industry, with only two operational plants in the UK. Compared to wet AD, a dry digester contains a higher concentration of dry solids (>15%). Feedstock is mechanically fed into the digester in batches and typically requires far less heat in the process. Dry AD is particularly well suited to treating garden waste – currently a vastly underutilised bioresource – and produces both renewable biomethane and compost-grade digestate (PAS100) with significantly fewer regulations restricting its commercial and agricultural use. Drawing these environmental benefits from the 6-7 million tonnes of green waste produced each year is vital for AD to reach its full 2030 potential.

The biomethane potential can be boosted further if we consider the potential of new technologies, namely power-to-gas. Excess wind and solar power can be used to generate hydrogen through the electrolysis of water, which, especially as our infrastructure is not ready for large volumes of hydrogen, can be added to the digestion process. This significantly increases the proportion of methane in the biogas as the hydrogen reacts with the carbon dioxide to form methane (CH_4). Including power-to-gas, the full potential of biomethane is nearly 8 billion m^3, enough to heat 6.4 million homes.

[12] www.theccc.org.uk/publication/land-use-policies-for-a-net-zero-uk/

[13] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/856695/nonfoodstatsnotice2018-08jan20.pdf

[14] http://www.biogas.org.uk/images/upload/news_114_ADBACLANFUREACaseforcropsinADNov2011.pdf

TABLE 2.2.1: THE UK'S BIOMETHANE GENERATION POTENTIAL IF ALL FEEDSTOCKS ARE UTILISED

FEEDSTOCK	BIOMETHANE CAPACITY OF TODAY'S AD INDUSTRY MILLION m^3	EQUIVALENT HOMES HEATED	BIOMETHANE POTENTIAL FROM 2030 FEEDSTOCK MILLION m^3	EQUIVALENT HOMES HEATED	GHG EMISSION ABATEMENT FROM 2030 FEEDSTOCK $MtCO_2(e)$
Food waste	456	380,000	443	369,000	1.81
Sewage	272	227,000	616	514,000	5.55
Farm waste	83	69,000	1,992	1,660,000	10.46
Industrial waste	924	770,000	1,364	1,137,000	2.62
Green waste	3	2,000	748	623,000	1.44
Bioenergy crops	463	386,000	514	428,000	0.99
Subtotal	**2,201**	**1,834,000**	**5,677**	**4,731,000**	**22.86**
Power-to-Gas			2,271	1,892,000	4.36
Total			**7,947**	**6,623,000**	**27.22**

While the figures above are based on current average yields, we know that there are a number of innovations in the pipeline, both biological and technical, that are expected to significantly improve this. These are therefore conservative estimates of the full potential for biomethane generation.

On top of this, biomethane generation, like biogas CHP, also delivers wider non-energy benefits through the AD process. It produces nutrient rich digestate, replacing carbon-intensive artificial fertilisers and helping to restore our depleted soils. This targets another hard to decarbonise sector of the economy, agriculture. This is in addition to capturing and treating the organic farm wastes that generate a significant portion of on-farm emissions, while providing on-site energy to decarbonise the farm's heat and power needs.

At this full potential, the biomethane industry would be delivering an estimate of over 30,000 direct jobs throughout the UK, comprising over 20,000 permanent jobs and over 10,000 temporary jobs in construction and design. There would also be more indirect employment as a result of these new enterprises.

2.3. Heat: decarbonising the gas grid and replacing off-grid fossil fuel heating

The UK economy is still heavily dependent on fossil gas for heating homes, businesses and industrial processes. The gas grid currently supplies 88.1 billion m^3 of gas to homes and businesses across the UK each year. By 2050, energy efficiency measures have the potential to reduce this demand to 22-42 billion m^3 [15], which translates to roughly 66-73 billion m^3 by 2030. The biomethane potential of the UK, as set out above in table 2.2.1, can provide up to 36% of projected 2050 gas grid requirements if all biomethane were diverted to gas-to-grid, or 8-10% of the 2030 estimate. This goes a significant way to reducing the carbon intensity of the gas grid. Biomethane is a ready to use technology to decarbonise the grid now and can make significant inroads in the next 10 years to meet our emission reduction targets.

Because biomethane is a direct replacement for fossil gas, it can be injected into the gas grid without any need to adapt the existing infrastructure and used in existing cookers and boilers. There are, however, considerations that need to be made to facilitate a greater transition towards biomethane.

[15] www.energynetworks.org/assets/files/gas/Navigant%20Pathways%20to%20Net-Zero.pdf

At the moment, because biomethane has a slightly lower calorific value than fossil gas, it has to be injected with 1-10 m^3 of propane per 100 m^3 of biomethane, depending on the location of the grid injection point. This is so that the customer still gets the same energy regardless of the composition of the gas they are getting in their homes. This propane currently has a carbon footprint of 21,500 tonnes of CO_2, which would require over 350,000 trees to offset these emissions[16], and is essentially unnecessary but costs the developer a significant amount. The need to have consistent calorific value across the network is largely because the existing charging regime is based on volume rather than calorific value. If the charging system could be adapted to charge for the calorific value of the gas consumed, as explored in the Real-Time Network project[17] and the Future Billing Methodology project[18], biomethane could be injected into the grid without adding propane as the calorific value is fairly similar: 36 MJ/m^3 and 39.5 MJ/m^3 respectively for biomethane and the overall gas grid[19].

The existing regulatory framework also applies to the injection of hydrogen into the grid, which has a far lower calorific value, and so the regulations will need to be reformed in any event to adapt to other green gases in development. Once hydrogen is introduced into the grid, and mixed with methane, there are further considerations necessary around consistency for industry who would find a variable calorific value, which could be created by the blending of hydrogen, disruptive to their processes.

Another challenge currently facing biomethane injection relates to grid capacity. Biomethane plants can be backed off the grid due to low summer demand, particularly in rural areas where the grid pressure is already low but which are otherwise areas very well suited to AD projects. If a plant is backed off the grid it cannot inject its biomethane, preventing it from supplying its green gas to the grid and consequently losing potential carbon savings and revenue. Gas distribution networks (GDNs) rely on gas flowing through the network and tend to buy all their capacity off the National Transmission System (NTS). Biomethane sites don't operate with a commitment to inject gas, and networks strictly don't have any liabilities if biomethane plants are unable to inject. This is due to the risk to the networks of potential periods of down time interrupting a constant gas flow and making it difficult for plants to guarantee supply.

However, as more biomethane sites are commissioned and as reliability improves due to greater focus on industry best practice, we would expect the GDNs to assume a proportion would flow such that they could start reducing the NTS bookings accordingly. In addition, the OptiNet Network Innovation Assistance project is investigating how smart pressure controls, compression and storage might be used in parallel to alleviate network constraints. This could help reduce the need for a biomethane plant to have to reduce their output or flare. These barriers need to be overcome so that there is space, or demand, on the grid for biomethane with more contractual agreements between GDNs and biomethane plants or portfolios of plants to reduce the risk of downtime; increased use of gas fuelled vehicles that would put a year-round demand on the grid; or in grid compression. This would also be stimulated by consumers increasing demand for renewable energy sources and Government policy that put a green gas obligation on the gas grid.

As other technologies reach maturity, for example hydrogen, these can be added to the energy mix alongside biomethane, with the necessary adjustments to infrastructure, including the grid network, cookers and boilers. It is also possible that if heating were to fully transition to hydrogen, biomethane from AD could be used to generate green hydrogen, using biomethane rather than the fossil methane used for blue hydrogen. However, research conducted by the Energy Network's Association in partnership with Navigant has set out that the most sensible energy composition for 2050, if we are to achieve net zero emissions, is 22% derived from hydrogen, 18% from biomethane, 46% from electricity and 14% from other sources, with the majority of heat supply coming from biomethane and hydrogen[20]. The CCC also sets out that biomethane has a clear ongoing role in our future energy scenario[21], as does National Grid[22].

[16] www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

[17] www.smarternetworks.org/project/nia_sgn0066

[18] https://futurebillingmethodology.com/

[19] www.flogas.co.uk/uploads/asset_file/2_21_biomethane-1.pdf

[20] www.energynetworks.org/assets/files/gas/Navigant%20Pathways%20to%20Net-Zero.pdf

[21] www.theccc.org.uk/wp-content/uploads/2018/06/Imperial-College-2018-Analysis-of-Alternative-UK-Heat-Decarbonisation-Pathways.pdf

[22] fes.nationalgrid.com/media/1409/fes-2019.pdf

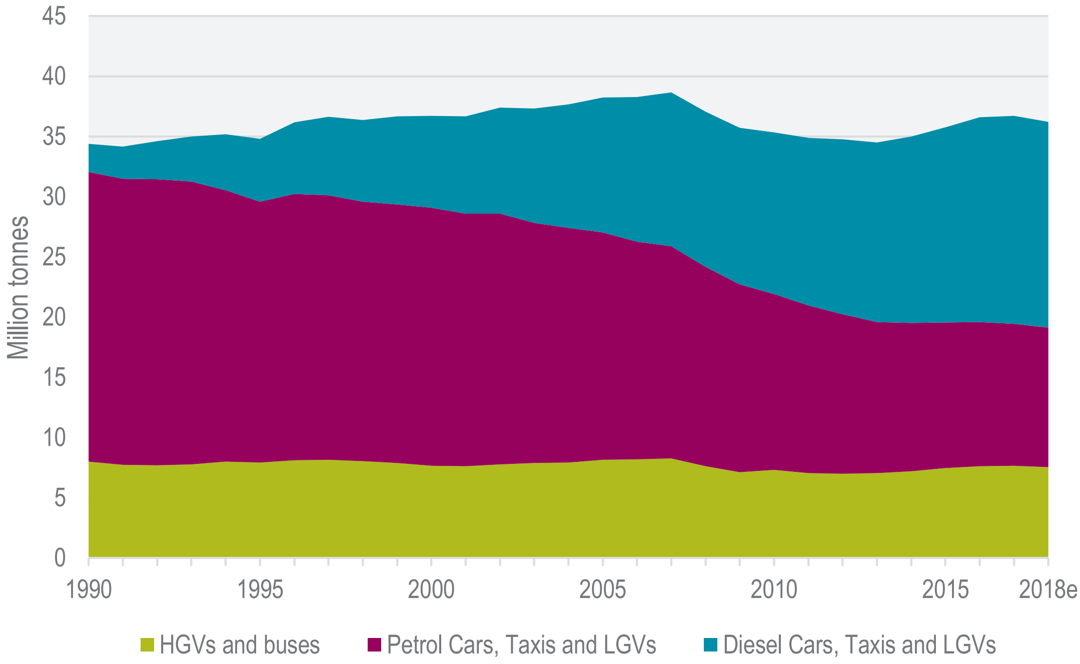
2.4. Transport: fuel for better air quality

According to UNECE[23], air pollution is now the largest environmental health threat in the world, accounting for approximately 7 million deaths globally each year. It also exacerbates pre-existing diseases, ranging from asthma to cancer, heart disease and mental health issues, especially in children and young adults.

The main pollutants affecting health are nitrogen oxides, ammonia, sulphur oxides, ozone and particulate matter. The latter – especially particulate matter below 2.5 microns, which is mostly present in transport pollution – has the greatest impact on human health as it contains microparticles that can penetrate deep into the lungs, affecting both the respiratory and vascular systems. The higher the level of exposure to these pollutants, the more dangerous they are for health[23]. According to the report published by BEIS during the summer of 2019[24], the transport sector was the largest single source of GHG emissions in 2017, accounting for 27.4% of total emissions. Between 1990 and 2017, emissions from this sector only decreased by 1.7%[25].

This low decrease in emissions is attributed to the fact that the majority of biofuels in the UK are used as weak blends with conventional fossil fuel-based petrol and diesel that have different mixture variations. Since the early 1990s demand for diesel almost doubled, which led to reduced demand for petrol. This was caused by the increased use of diesel-fuelled cars and Light Goods Vehicles (LGVs). In 2018, however, petrol was once again in demand followed by the additional tax rates charged for diesel vehicles after it was identified that diesel engines emit nitrous dioxide and particulate matter more heavily than their petrol equivalents.

DEMAND FOR ROAD FUELS, 1990 TO 2018



Source: BEIS - UK energy in brief 2019

[23] www.unece.org/environmental-policy/conventions/envlrtapwelcome/cross-sectoral-linkages/air-pollution-and-health.html

[24] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/819511/UK_Energy_in_Brief_2019.pdf

[25] The UK government has set a free, detailed platform that measures air pollution levels across different regions in the UK. The information is supplied through 120 monitoring systems taking hourly readings. In addition to these, there are over 150 non-automatic monitors which sample air pollution levels on a daily, weekly or monthly basis. Available here: https://uk-air.defra.gov.uk/

The recommendations by the World Health Organisation's Air Quality Guidelines state that the average levels of fine particulate matter concentrations in the value of 35 µg/m^3 should be reduced to 10 µg/m^3 in order to reduce air pollution deaths by 15%[26]. These are sought through investment in cleaner road transport, as well as reform of the current policy environment. Biomethane is a ready to use transport fuel that cuts emissions in this clearly hard-to-reach sector. It has the potential to reduce emissions by 60-80% when compared to gasoline, diesel or liquefied petroleum gas.

Today, biomethane is already upgraded from biogas to the same quality as fossil natural gas so can be used in Liquified Natural Gas (LNG) or Compressed Natural Gas (CNG) fuelled vehicles. The upgrading process generates a high methane (CH_4) content (at least 90%, commonly 96-99%) and low share of impurities. Biomethane is often compared to biodiesel and bioethanol as alternative biofuels that are already available for commercial use. The distinction, however, is made due to the origin of feedstock. While bioethanol and biodiesel are considered to be first generation biofuels, obtained from food crops such as corn, sugar cane, soybeans and other vegetable oil crops, biomethane is often considered to be a second generation biofuel as it is mainly derived from feedstock that is not appropriate for human or animal consumption such as food waste, manures, and sewage sludge[27]. This makes biomethane a more attractive biofuel as it prevents methane emissions from these organic waste streams, increasing its overall GHG emissions abatement, and it is generated according to circular economy principles, converting wastes into valuable resources.

Using biomethane to fuel HGVs can reduce well-to-wheel emissions by up to 81%, compared to diesel[28] – even low blends of biomethane into the fuel gas mix can offer significant reductions to GHG emissions. The same trial also demonstrated that HGVs fitted with LNG systems offered similar miles per gallon-equivalent to diesel, and up to 45% further range on a full tank (spark-ignition engines only). Benefits of biomethane and gaseous fuels are not limited to GHG savings: drivers reported increased comfort while driving, quieter engines, and increased engine braking, without compromising overall vehicle reliability. While these systems may be more expensive to install, significant savings from gas prices mean costs can be recovered after just 2 years of operation (160,000 miles per year).

However, drivers also expressed concern over the low number of refuelling stations currently installed. For biomethane to be a viable fuel for HGVs, drivers need confidence that they can always reach a refuelling station. Consequently, new infrastructure is urgently required across the UK to facilitate the switch to gaseous fuel systems. Additionally, HGVs with 3 axles, utilised in the UK due to regulations regarding haulage weight, have less space to fit fuel tanks, compared to 2 axle vehicles. Smaller tanks means lower range31. While innovation seeks to maximise tank size, the need for well-distributed refuelling stations becomes even more important.

In addition to the multiple GHG emission savings that biomethane delivers, there are now also cost savings for vehicles entering urban areas where high levels of pollution may require the use of cleaner fuels, for example in Ultra-Low Emissions Zones, Clean Air Zones and Low Emission Zones.

The UK now has 108 AD plants already producing biomethane and injecting it into the grid, which acts as a distribution network for the use of biomethane as a transport fuel.

Retrofitting of existing vehicles enables fleets to cut emissions as soon as possible, without having to replace fleets. According to the Department for Transport's Freight Carbon Review report (2017)[29]:

"Retrofit equipment such as aerodynamic devices and fairings and low rolling resistance tyres can offer fleets a cost-effective GHG emission reduction solution."

However, retrofitting is fairly uncommon due to lack of specialised government support and limited expertise on the market. As an alternative, Original Equipment Manufacturers (OEMs) are already producing a range of dedicated gas vehicles that are available for purchase with no modifications needed, so Heavy Goods Vehicles (HGVs) can refuel with CNG or LNG, and therefore also bio-CNG and bio-LNG.

Biomethane fuels are increasingly seen as an important supplement to the fuel market for the transition period between the first generation of liquid and

[26] www.who.int/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health

[27] https://uk-air.defra.gov.uk/assets/documents/110322_AQEG_Biofuels_advice_note.pdf

[28] www.cenex.co.uk/app/uploads/2019/11/324-003-004-Dedicated-to-Gas-Assessing-the-Viability-of-Gas-Vehicles.pdf

[29] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/590922/freight-carbon-review-2017.pdf

compressed gaseous biofuels and the commercial implementation of more advanced biofuels[30]. It is a critical step in the pathway to decarbonising transport while other technologies are not yet at maturity. However, when looking at the different generations of biofuels, it is possible to conclude that the structure of the biofuel itself does not necessarily change between generations, but rather the source from which the fuel is derived changes, i.e. with Second Generation biofuels using more efficient feedstocks that are often derived from wastes.

Many second generation biofuels, such bioethanol from lignocellulosic biomass feedstocks such as wood and straw, biobutanol, Fischer-Tropsch diesel and hydrogen, are technologies still in development. Biomethane as a transport fuel is ready to use to cut emissions now. There is also a significant role for biomethane in our transport future, both in its own right and as a feedstock for new fuels, such as the creation of hydrogen by steam reformation.
In January 2019, the UK government published its Clean Air Strategy, having had different departments work in collaboration to identify a plan of action that tackles common values and sets common objectives. It was agreed that, in the past, the priority was tackling the individual sources of pollution, whereas today the focus has been put on the smaller and more diffuse sources of air pollution, like smaller industrial sites, product use, open fires and incineration, spreading manure on farms and open landfills. Additionally, one cannot disassociate air pollution from land use, soil health, effects on food crops, biodiversity management, water use and water pollution.

Therefore, collaboration amongst the different sectors of the economy is fundamental to achieving cleaner air, because one sector of business activity fundamentally influences or depends on another. In order to restructure the transport sector and guarantee more efficient fuel use, the challenge will be to identify the related sectors and attempt to work with them in order to allow the realisation of their biggest potential, while still accounting for the cost, policy and practical limitations. Biomethane has an important role to play in phasing out fossil-fuels in transport and shifting to cleaner energy sources, but this can only be realised through structural processes and collaboration amongst the various stakeholders.

2.5. Agriculture and the food system: soil, manure and food waste

There are currently over 90 million tonnes of untreated manures and slurries spread to land in the UK and more crop residues left to breakdown in an open environment to create compost. While this recycles key nutrients back to soil and fits within a circular economic system, these organic wastes emit over 211,000 tonnes of methane, equivalent to 5.9 million tonnes of carbon dioxide, directly into the atmosphere. In addition, there is a significant amount of food waste throughout the food supply chain, which equates to a great deal of resources being wasted to grow something that is discarded. These are societal issues which need to be addressed. Whatever the solution, anaerobic digestion must be involved. Not only can AD treat all these organic wastes, generating storable, domestic, renewable energy, it also recycles the nutrients and organic matter back to soil, ready for the next season of crops, and improves the ability of soil to sequester carbon from the atmosphere.

The global ambition, Sustainable Development Goal 12.3, is to halve per capita food waste by 2030[31]. At the same time the UN's IPCC has set out the important role of land use for animal husbandry[32]. There is an important interplay between these two factors as milk is the third most wasted food in the UK at household level, with 3.1 million glasses thrown away each day[33]. In addition to the treatment of farm and food waste, AD can be fed from bioenergy crops that can be sustainably integrated into our agricultural system. As we move to a more efficient agricultural system that has more respect for the resources used to grow our food and its environmental impact, it looks increasingly likely that less land in the UK will be needed to grow food that is thrown away or fed to livestock, reducing the pressure on agricultural land and increasing its capacity to integrate bioenergy crops into rotations. A diversification of farmers' crop portfolios encourages crop rotations, which has significant benefits compared to monocropping[34]. In 2018, there were just 94,000 hectares of land used to grow bioenergy crops accounting for just 1.6% of arable land use (compared to the 7% maximum recommended by the EU), and just 0.01% used to grow crops for AD[35]. This is compared to over 1.7 million hectares used to grow food that is thrown away, accounting for nearly 30% of land use, and a further 2.9 million hectares used to raise and grow feed for livestock.

[30] www.intechopen.com/books/biofuels-state-of-development/biomethane-as-transport-fuel

[31] https://champions123.org/target-12-3/

[32] https://www.ipcc.ch/report/srccl/

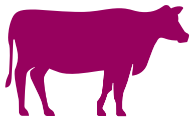
[33] https://feedbackglobal.org/wp-content/uploads/2019/02/Milk-waste-in-the-UK_feedback-report-1.pdf

[34] www.biogas.org.uk/images/upload/news_114_ADBACLANFUREACaseforcropsinADNov2011.pdf

[35] https://bit.ly/38oc9Hd

The areas of our food system that AD can contribute important solutions to can be loosely divided into three sections: livestock, food waste and soil health. These are addressed below.

Livestock



Methane accounts for 53% of the UK's agricultural GHG emissions, which mostly originate from the raising of livestock for human consumption[36]. We are now seeing a growing trend observed in many western nations to reduce the consumption of animal products, with meat consumption per capita falling over the past 10 years[37]. The National Farmers Union (NFU) has committed to achieving net zero emissions in agriculture by 2040, and the integration of AD into our food system is a pivotal part of their plan to deliver this.

Within our current food system, AD can be used to treat the manures and slurries that are collected during periods of the day and year when livestock are housed, or from intensive livestock buildings, and capture the methane. There are currently 91 million tonnes of manures and slurries collected and spread to land, all of which is available for treatment through AD, but instead is left to emit greenhouse gases into our atmosphere. An enlarged network of small on-farm AD plants to replace manure and slurry stores would enable farmers to cut these emissions and generate on-site power and heat to displace fossil-based energy, or the biogas generated could be upgraded to biomethane using a hub and spoke model for transport fuel or grid injection (see chapter 3.5). This would help to cut the carbon footprint of our society's animal-based diets, and still generate a natural fertiliser for farmers to use in place of manure.

Food waste

There are currently 10 million tonnes of food waste thrown away every year[38]. This requires a minimum of 2 trillion litres of water[39], 2.8 TWh energy[40], and 1.7 million hectares[41] of land to grow and throw away, as well as the resources used to transport these good through the supply chain. Not only is this an appalling waste of scarce resources, but it also pushes up the cost of the food as these wasted resources must still be factored in throughout the food supply chain. Instead of throwing all this resource away, far more could be diverted to AD, which currently treats just 37% of the food wasted.

The end goal is to eliminate all avoidable food waste. This is estimated to be 7 million tonnes, still leaving 3 million tonnes of unavoidable food waste to be treated through AD[42]. If the 7 million tonnes of avoidable food waste are prevented, that frees up at least 1.4 trillion litres of water, 1.9 TWh of energy and 1.2 million hectares of land. This would reduce pressures felt within the agricultural system and free this land up to increase the sustainable integration of bioenergy crops into our agricultural system, enabling us to create more energy from nature, rather than grow food to throw away.

Soil health

Soil degradation is putting the UK's agricultural capacity under threat. The current rate of soil erosion is 10-100 times higher than it has been in the past, with 2.2 million tonnes of soil eroded each year in the UK[43]. This has implications in terms of GHG emissions, agricultural costs, loss of productivity and reduced flood resistance. This soil degradation is only going to be exacerbated by climate change, as warmer and drier weather increases the decomposition of organic matter in soils and extreme rainfall increases erosion. However, soil can be a major ally as we seek solutions to the climate crisis, because healthy soils also are a major carbon sink.

Anaerobic digestion can do a great deal to address these issues. Digestate, the residue of organic matter left once the biogas is extracted, is rich in key nutrients that are routinely removed from our soil. This is because the technology, by its nature, recovers these nutrients from the plant and organic matter that extracted it from the soil in the first place. It is therefore imperative that digestate is treated equally as a co-product of the anaerobic digestion process, not just as a biproduct in the generation of biogas. Using digestate as a natural fertiliser both displaces artificial fertiliser and increases the ability of soil to sequester carbon[44].

[36] www.ons.gov.uk/economy/environmentalaccounts/bulletins/greenhousegasintensityprovisionalestimatesuk/2018provisionalestimates

[37] www.gov.uk/government/publications/family-food-201718/family-food-201718

[38] http://wrap.org.uk/sites/files/wrap/Food%20Surplus%20and%20Waste%20in%20the%20UK%20Key%20Facts%20(22%207%2019)_0.pdf

[39] https://waterfootprint.org/en/water-footprint/product-water-footprint/water-footprint-crop-and-animal-products/

[40] www.ncbi.nlm.nih.gov/pmc/articles/PMC2935130/

[41] https://bit.ly/38pctFp

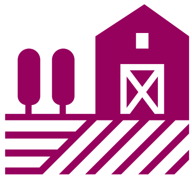
[42] https://bit.ly/2vyCbsr

[43] https://publications.parliament.uk/pa/cm201617/cmselect/cmenvaud/180/180.pdf

[44] Béghin-Tanneau, R., et al (2019), www.sciencedirect.com/science/article/pii/S0167198719301709

AD plant operators currently need to process the food waste they receive in a number of ways to ensure that digestate produced is a high quality, marketable product, turning this waste into something of great value. It is critical that the upstream supply chain for AD feedstock has a greater responsibility for the quality of the waste they are creating. In our linear society, products are created with limited regard for the impact this has once it becomes a waste. Moving to a circular economy model, producers must have a greater responsibility for creating products that can be effectively recycled. This includes ensuring that organic waste streams are not contaminated with plastics or other pollutants. Higher standards for organic material being separately collected will increase the volume of feedstock that can be treated through AD. This will improve the quality of the digestate generated, as well as its ability to regenerate our depleted soil.

Biodiversity and sustainable agriculture



Although there are large volumes of untapped waste feedstock, there are still concerns that biomethane cannot be produced in limitless quantities. There is a finite quantity of agriculture-appropriate land currently available for farming of crops for all human needs, including both food and energy, and this could be negatively impacted by climate change. This means that there is a perceived trade-off between energy and food farming, with implications for the price of both, but also scope for reductions in price pressures as yields and productivity are improved.

Growing a single type of crop, monocropping, can have short-term benefits, for example it is possible to select the one crop that is easiest to grow, and which requires the least amount of water and other resources. However, the biodiversity is fundamentally impacted, along with soil quality, soil erosion, water supplies and even landscape which further exacerbate the issue. If only one crop is consistently grown, pests that feed on this one particular crop will begin to proliferate and create a biodiversity imbalance. The pesticides used to combat this may also become inappropriate due to pests' resistance over time, and can be high cost.

It is incorrectly believed that this type of farming is required to produce large quantities of bioenergy, and therefore that bioenergy crops are inherently opposed to promoting biodiversity and may affect food crops, as well as other crops grown for production of fibre and pharmaceuticals. However, bioenergy crops can be grown sustainably within our agricultural system in a number of ways, to both prevent the negative impacts of monocropping, diversify farm incomes and ensure that our agricultural system is able to provide the multiple requirements placed on our land. And with climate change the biggest threat to our food system, there is an urgent need to ensure we our using our resources in the best way now to address this crisis. This might be achieved by more tightly integrating bioenergy crops into diversified crop rotations and increasing the number of sequential crops (e.g. three in a two-year period). Similarly, herbal leys, comprised of a diverse mix of grasses with varying root lengths, can also be planted to first restore soils, before providing a "super feedstock" to an AD plant. Their high mineral element concentrations are known to increase biomethane productivity.

3.1. Introduction

Innovation is key to ensuring the industry can deliver its full potential and keep the cost of transitioning to a greener economy to a minimum. Best practice is also critical to ensuring that the industry delivers the maximum potential, both in terms of its energy output and environmental impact. Developing and operating projects according to best practice helps to minimise risk and maximise returns, both in terms of cost-effectiveness and decarbonisation. This chapter explores these two areas in detail, looking at new technologies on the horizon and how best practice helps to deliver the desired outcomes.

3.2. Technological maturity: biomethane and other green gases

It is becoming increasingly apparent to those in positions of power that biomethane and AD, the technology that creates it, have a significant role to play in cutting emissions in the hardest to decarbonise sectors of our economy, namely heat, transport, waste management and agriculture. And it is already in use today and ready to scale up. While cutting emissions in these sectors, anaerobic digestion (AD) is also an effective, environmentally responsible technology to treat organic wastes. As we consider our energy system over the next decade to 2030, biomethane from AD will need to play a significant role as other renewable gas technologies are still in development.

Biogas is a flexible resource that can be used adaptively depending on need, to cut emissions in electricity, heat and transport in varying proportions depending on need and the maturity of alternative solutions in the different sectors. These are addressed below, looking at the expected timelines for alternative technologies, and both how biomethane can deliver as a transitional energy source as well as its integral role in the long-term system beyond.

Electricity

At present, around 80% of AD plants in the UK generate electricity using a combined heat and power (CHP) unit. Many small rural on-farm AD units are more suited to electricity generation than to biomethane upgrading. This is because they may not be well located for injection into the gas grid or the size of the unit does not make it economically viable to invest in an upgrading facility for the volume of gas generated. In addition, electricity generated from a biogas CHP plant can provide consistent base-load electricity throughout the year, ensuring that in low supply periods of wind and solar (i.e. winter) the electricity demand can still be met, as this generally coincides with peak demand. Biogas, or biomethane, can act as a form of energy storage for the generation of electricity to meet peak demand.

Given that there are comparatively more sources of green electricity than green gas, the demands on biomethane to cut emissions in the hardest to decarbonise sectors of heat and transport will increase as pressures mount to make in-roads in these sectors too. This will most likely mean a move away from electricity to utilise the biogas as upgraded biomethane. Even with a distributed network of smaller CHP plants, this may be possible with new models for grid injection that look to connect more rural plants to the grid. This 'hub and spoke' model is explored in more detail in chapter 3.4.

Heat

There are already over 100 biomethane plants injecting gas into the grid. The fact that biomethane is a direct substitute for natural gas, and so already compatible with existing gas infrastructure, significantly reduces the transition cost as we move to a low-carbon heat system. It would, therefore, require far lower investment than alternative green gases to deliver an equivalent level of carbon abatement. Recent work by the ENA has proposed that the gas network could be delivered in clusters[45], to reduce the need to replace gas grid infrastructure in areas that could be wholly supplied by biomethane.

The next decade must see significant carbon savings in our heat system. The cost and disruption required to transition to hydrogen will make it more challenging to use this technology to decarbonise our gas in this period. Another barrier which makes biomethane the necessary first step, is that blue hydrogen is produced using fossil fuels and so is not renewable, and only cuts emissions if it can be combined with carbon capture, use and storage (CCUS). Green hydrogen generated from the electrolysis of water using renewable electricity is a renewable gas, but currently requires more energy to create it than the end product provides. It is, therefore, well suited as a method for storing energy from excess electrical capacity in periods of low demand and high supply but otherwise is not an efficient use of resources.

[45] www.energynetworks.org/assets/files/gas/Navigant%20Pathways%20to%20Net-Zero.pdf

These factors can all be overcome so that hydrogen can become an important part of decarbonising our heat system, but we do not have time to wait for it to reach maturity. The next 10 years are critical for mitigating the worst effects of climate change, so it is vital that biomethane receives the support it needs to meet its full potential to decarbonise heat today.

Transport

Biomethane is a very clean and carbon-efficient transport fuel. The primary technologies likely to decarbonise our transport system are biomethane, bioethanol, biodiesel, green hydrogen and electrification. Table 3.2.1 below shows comparative emissions. While there is a very strong case for using biomethane for transport, it will only form part of the energy mix. Net zero can only be achieved if all available technologies are used, and so it is important to look at where biomethane delivers the most value added. The hardest to electrify parts of the transport system are presenting themselves as the largest vehicles, carrying heavy cargo, that may need to travel longer distances, such as buses and heavy goods vehicles (HGVs).

TABLE 3.2.1: COMPARATIVE WELL-TO-WHEEL GHG EMISSIONS OF DIFFERENT ALTERNATIVE FUELS COMPARED TO FOSSIL-BASED TRANSPORT FUELS.

	kg CO_2 (e) per kWh		kg CO_2 (e) per kWh
Biomethane	0.0004	Electricity (grid average)	0.2556
Bioethanol	0.0014	Electricity (coal)	0.3056
Biodiesel	0.0035		
		Natural gas	0.1844
Hydrogen (electrolysis)	<0.1000	LPG	0.2145
Hydrogen (bio-gasification, no CCS)	0.1100	Petrol	0.2410
Hydrogen (stream reformation, no CCS)	0.3000	Diesel	0.2527

Data taken primarily from BEIS (2019) greenhouse gas conversion factors[46]; figures relating to hydrogen taken from Houses of Parliament (2017)[47].

In addition to road transport, biomethane is becoming increasingly important in the development of solutions for decarbonising aviation and shipping.

3.3. Biomethane best practice

Best practice is crucial in any anaerobic digestion project and especially for biomethane plants due to the increased infrastructure on site. This is essential throughout the project, from its initial design and construction down to its operational analysis and daily maintenance requirements. Best practice plays a role in all aspects of a biomethane plant to ensure high standards are set alongside creating awareness and capability to deal with the inherent risks associated with the technology. As the sector has matured, consolidation has led to a greater focus on industry best practice with many plants now in operating groups, allowing for standardisation. However, there is still more that can be done to encourage the adoption of common standards across the board.

The sections below outline how best practice not only protects the plant, its employees and the nearby environment but the wider environment and those who live and work within a close proximity to the plant. This level of protection is provided by diligent procurement, risk management and operational best practice, which in turn can positively impact the quantity and quality of AD outputs.

[46] www.gov.uk/government/collections/government-conversion-factors-for-company-reporting

[47] https://researchbriefings.parliament.uk/ResearchBriefing/Summary/POST-PN-0565

Procurement

To design, build and run an AD plant, plant owners, operators and developers must purchase multiple individual items, which must then work together. Critical components are required throughout the process from pre-processing the site's feedstock, upgrading biogas to improving environmental and human safety such as personal gas monitors. The cheapest option is not always the best option, so it is important to source items and services that offer cost-effectiveness, that are good quality, effective and suitable for the specific plant and intended use. During the procurement or build phase technical due diligence is essential in ensuring a plant will operate to best practice. Purchasing a cheap, poor quality or unsuitable item may not be cost-effective in the long term as it may have a shorter lifetime or could cause wider operational issues, which increase the plant's risk.

Following good procurement practice can contribute to effective risk management, improved safety standards, environmental protection and operational performance that in turn rewards the operator, and funder, because their plant is likely to perform better and experience less downtime. Therefore a few of the questions that must be asked in the procurement stage for biomethane plants can be:

- What does the plant need to achieve;
- Has a clear specification of this been provided to suppliers, to ensure equipment is correctly sized and capable of the functions required of it;
- Does the plant, and its associated equipment, meet UK legal requirements and standards; and,
- Does the technology supplier have a good reputation, maintenance plans, and is its equipment insurable and able to deliver what it is required to do?

Procurement best practice is not only essential for the initial parties involved in an AD plant. The careful selection of equipment and suppliers mitigates risk of health and safety, operational and potential financial issues, or replacement later in a project's life. For instance, choosing a more expensive biogas upgrading unit may have initial financial implications but if maintenance time is reduced, biomethane quality improved and replacement of parts reduced then this cost will be offset over the unit's lifetime and employees can work in a safer and insurable environment.

Risk Management

Best practice risk management should identify all potential risks and put in place suitable measures (such as design features or operational procedures) that will reduce these risks to acceptable levels. Ensuring the health and safety of employees and the public, and the protection of the environment, should be a priority when undertaking any activity that could result in their harm. Biomethane plants due to the nature of their pressure, electrical and biological systems should aim for continuous improvement in this regard; although many risk management techniques are obvious and common sense it is important to review the systems in place to ensure they remain effective and fit for purpose.

Factors to consider when looking to manage risk on biomethane plants should not solely include the outputs but include; feedstock, site setting and layout, ensure competence, legal and contractual management, health and safety management systems and regulations, planning permission and environmental permitting. If all the risk is effectively managed on a biomethane plant it should be commercially beneficial, which is highlighted in the case study as effectively it results in:

- Better overall financial performance.
- Prevention and/or management of catastrophic events.
    - Pollution incidents and therefore avoidance or reduction of remediation costs.
    - Prevention of accidents that could result in harm to employees, prosecution and business disruption.
    - Improved reputation of individual companies and the wider industry.
- Better staff retention, by demonstrating commitment to their safety and wellbeing.
- Reduced cost of insurance premiums and better insurance policies.
- Improved operational performance, delivering higher quality outputs.

3. Innovation and best practice

Operational Best Practice

As mentioned in the Case Study below, Wardley Biogas, plant monitoring is a key part of best practice. However, monitoring a plant should go beyond the biological process and include equipment, staff requirements and permit and regulatory compliance, to ensure all paperwork and management systems are up to date. Monitoring, recording and analysing the biological process is an easy way to ensure a biomethane plant is being optimised. Process monitoring is best practice as it can provide early indications of instability and highlights periods of optimised outputs. This monitoring and acknowledgment of biological instability not only increases output performance but reduces the environmental risk of the plant by preventing rather than reacting to incidents such as foaming, venting and crust formations. The biological monitoring should also include gas analysis that can prevent damage to a biomethane plant's equipment and ensure the process is being fully optimised and reduce lost grid availability time frames.

Maintenance is an obvious aspect of any process with living and moving parts. Best practice in maintenance is not achieved simply by ensuring it is carried out through daily, weekly, monthly and annual checks. The checks should be supported by adequately trained personnel and the procurement of experts where required. Maintenance will not only reduce the plant's downtime but can increase the longevity of equipment, which in the case of anaerobic digestion can be expensive.

Case Study: Wardley Biogas funded by Privilege Finance

Wardley Biogas, the only food waste processing plant in Tyne and Wear, has been delivered as part of a joint venture between Privilege, renewable energy developer EOS DevCo and waste management business, GAP Organics. As a specialist energy from waste funder, Privilege Finance understands well that following best practice and compliance is key to a successful, safe and profitable biogas project. Privilege are, therefore, uniquely placed to provide oversight throughout the lifetime of a project and can work with trusted partners to ensure plants run at optimal levels and follow best practice to ensure AD plants are safe places for people to work and for the communities around them; are less risky investments; and provide beneficial outcomes for the environment and the local economy.

Below are a few examples of how the plant, and Privilege, support and exemplify industry best practice.

Procurement

While considering investing in a new renewable energy project, Privilege actively look for opportunities to reduce risk wherever possible and ensure cost effectiveness. Each Privilege project, including Wardley Biogas, undergoes an extensive review, including detailed analysis of plans, technical due diligence, scrutiny of budgets and evaluating the technology provider's ability to deliver.

The Privilege team has now invested over £500m into the UK AD and biogas sector to date. They, therefore, have an extensive knowledge and understanding of the sector, including how projects should be put together and the ability to highlight and mitigate risk, which subsequently helps reduce any additional costs once the plant is in build. Importantly lessons have been learnt plant-by-plant and this has allowed serious procurement decisions to be made drawing on first-hand experience that helps to reduce operational, maintenance and environmental costs later in the project's life.

Risk Management

Privilege views health and safety as paramount, and the company policy is continuously reviewed to make sure it is up to date, safe and follows applicable laws and regulations. This is supported by their high skilled teams on the ground, who regularly check the condition of the site and ensure compliance with policies.

Operations

There are innovative ways to reduce risk and cost through monitoring of operational plants. Sophisticated, real time, on-site data feeds that monitor sites performance remotely and securely will be in place at Wardley Biogas. This technology is highly effective as it provides clear, accurate financial forecasting for each plant and highlights if a plant is operationally underachieving. In situations when a plant is generating less biogas than expected, the operating team can help plant owners to resolve any issues before they become a serious problem and pose environmental, health and safety or process instability issues.

continued>

The benefits of best practice from a funders' perspective is assurance that the plant is being operated correctly, giving greater confidence that the plant will meet regulatory, operational and environmental targets such as the PAS 110 standards for digestate, which Wardley will have processes in place to achieve when operational. Alongside this, the plant will have positive externalities such as providing a circular route for over 50 businesses to channel their food waste to whilst producing green gas, reducing their waste management costs, and the plant itself will create 12 new permanent jobs in the area. This will all contribute towards promoting sustainable economic growth across the region.

Wardley Biogas will also provide a range of wider benefits to the environment including: producing carbon neutral energy from waste and saving over 10,000 HGV 'waste miles' per year, by enabling food waste to be recycled locally. The impact of this reduced HGV mileage will equate to 6,500kg of CO_2 each year, which if converted to a liquid is equivalent to one and a half Olympic swimming pools.

The ADCS (Anaerobic Digestion Certification Scheme)

Ensuring compliance with policy and regulation and certifying that those operating the plant have the relevant skills and competence are paramount to achieving best practice in the AD industry. The nine sections covered in the ADCS, mentioned below, are all directly or indirectly related to training and competency. An operator with an understanding of the process and industry should be able to operate a plant with best practice and reduce risk, improve outputs and provide reassurance to neighbours of the plant that it is not a health and safety or environmental risk. This reassurance should come through having robust management systems in place to address plant odour, noise, fire protection, traffic and environmental management systems where applicable.

ADCS

The ADCS (Anaerobic Digestion Certification Scheme) provides the industry with an opportunity to demonstrate its commitment to operational, environmental and health and safety best practice via an industry-led initiative. So, as operators, engineers, technology suppliers, and developers are constantly seeking ways to optimise their performance, the scheme provides a focused approach to facilitate the application of safe engineering and design principles, safe operating practices and optimisation of processes, which in turn will improve industry performance and ensure regulatory compliance.

The ADCS's criteria are neatly split into the nine clear sections:

- Site information and understanding
- Managing health and safety risks
- Staff training and competence
- Process monitoring
- Maintenance of plant, kit and infrastructure
- Procuring services
- Managing environmental risks
- Animal By-Product Regulations (ABPR) compliance, and
- Digestate management

3. Innovation and best practice

The nine sections show how the certification scheme encompasses construction, compliance, optimisation and reducing health and safety and environmental risks. By assessing all these sections the scheme can promote best practice across varying sites due to the individual audit process.

This section highlights how all parts of the plant should be operated, built and procured with best practice in mind to protect; employees, the public and the wider environment from any negative externalities. Best practice becomes an easy process once fully integrated into an AD plant's management systems, like at Wardley Biogas, as all the sections addressed above, procurement, risk management and operations, are interlinked.

3.4. Latest innovations: efficiency, digestate, and new applications

Research and innovation continue to improve all aspects of AD, enhancing the energy- and cost-efficiency of its many processes. Nevertheless, there remains plenty of room for further development – the following outlines some of the most exciting areas of development in the pipeline, each widening the potential of AD in the UK (and beyond):

- **The development of micro-scale AD plants.** Capable of fitting inside shipping containers, these versatile plants can increase AD's accessibility. At this size (<50kW), the specialist equipment can be factory produced at-scale and driven to location on the back of a lorry, significantly reducing the cost of set-up and repair. As a result, new markets and feedstocks could be tapped, where remote sites may have been previously considered unfeasible and high capital investment requirements might have deterred smaller communities. To achieve net zero, all organic waste needs to be processed, and these standardised, ready-to-go plants can help make digesting all feedstocks more viable.

  Similarly, EU-funded research at BioVale is developing a portable AD plant. This can be driven from site-to-site enabling prospective AD operators to test their feedstocks and provide on-site training on plant management. Used as an education tool, this portable plant can help persuade people to deploy more digesters, growing the industry, and develop public support through education about AD and its many environmental benefits.

- **Increasing energy efficiency.** Multiple research laboratories are now suggesting that breakthroughs to the biota used inside a digester can increase biogas yields by up to +50%, i.e. for the same feedstock input, a plant will provide 1.5 times the amount of biomethane. If successfully rolled-out and scaled-up to larger plants, this would have a profound effect on AD's energy potential in the UK, offering significant increases to renewable energy production and, consequently, GHG emissions savings. Of course, AD plants would also see a concurrent rise in revenue, moving the industry closer to being financially viable without subsidies.

- **New digestate products.** Rich in both key nitrogen, phosphorus and potassium (NPK) nutrients and trace elements, digestate is a sustainable natural fertiliser, capable of replenishing soil health and displacing artificial fertilisers. However, several market and policy barriers are inhibiting digestate's value from being realised. Consequently, innovation is required to transform it from a by-product to a highly-valued commodity, thus developing the circular economy.

  By weight, digestate offers one of the cheapest sources of NPK and trace elements available. Unfortunately, wet AD predominately creates liquid digestate – one such barrier to its market value. As a liquid, it is inconvenient to transport and harder to store, and its spreading is strictly regulated to minimise ammonia emissions. Dehydrating wet digestate, and converting the ammonia gas into ammonia sulphate, overcomes all these issues yet requires a lot of energy to produce. Several AD plants use the excess heat from a CHP unit to dry digestate, where dried digestate can be used as a fertiliser and substrate for seedlings within both agricultural and domestic markets.

  Similarly, dry-AD is a novel industry in the UK yet can resolve many of these challenges. The technology produces compost-grade digestate and with a far lower water content. This reduces the cost of spreading as there are not the same concerns around ammonia, and it is far easier to store and transport.

  ALG-AD is a research project led by Swansea University, and funded through the Interreg NWE scheme, to cultivate algae using digestate. Liquid digestate provides an abundant supply of nitrogen and phosphorus, required for algae to grow, where the biomass produced could be used as a low carbon intensity animal/fish feed. If successfully scaled-up, this would help decarbonise meat production, and expand the market for digestate, such that AD plants may be able to add another source of revenue to their operations.

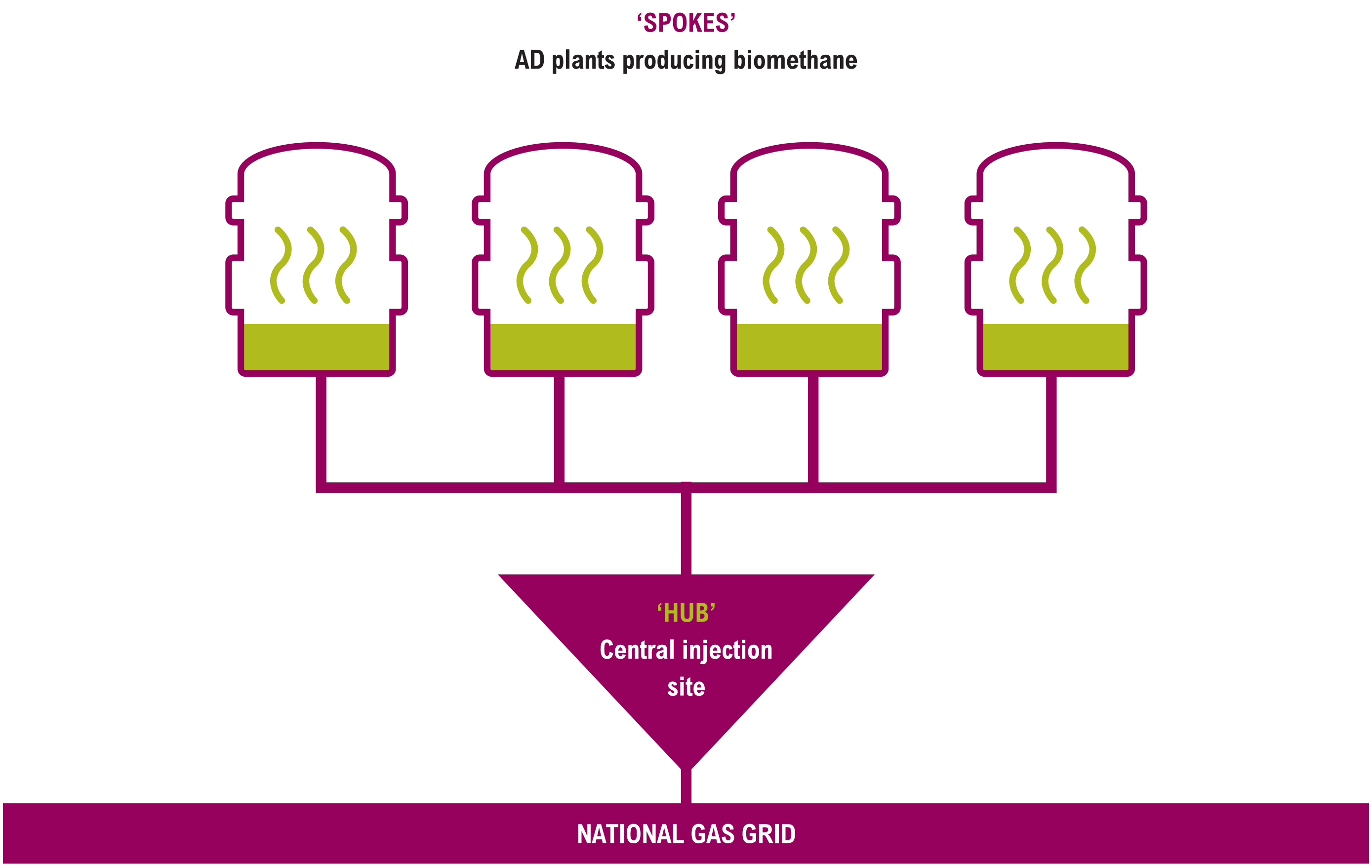
- **ICT and the use of artificial intelligence:** There is huge potential for algorithms and machine learning to regulate the many processes in an AD plant, including temperature, biology and acidity, among others. ICT monitoring software can also advance life cycle analysis of plants. Such technology can lead to significant improvements in biogas yield and may also help to customise the nutrient content of the digestate generated.

- **Centralisation of infrastructure.** Discussed in more detail below, innovation is helping to minimise plant costs by centralising infrastructure, such as biogas upgrading and biomethane injection. Removing this expenditure will help CHP plants to convert to biomethane production, and new plants to be more cost-effective.

3.5. Cooperative upgrading: the hub and spokes model

As previously discussed, biomethane for transport and heating is emerging as the optimal use of biogas, over electricity generation. While there are still strong arguments in favour of biogas electricity remaining part of the mix, biomethane stands out as the future direction for AD. However, around 80% of AD plants currently operating in the UK are CHP plants, many of which will not have feasible access to the national gas grid.

There are significant costs associated with converting these plants to biomethane upgrading sites, both in terms of investing in biogas upgrading equipment, and then delivering the infrastructure required to inject biomethane into the high-pressure national grid (if you are close enough to the gas grid to do so on site). As such, the innovative hub-and-spoke model for gas injection presents a new approach to reduce this cost by centralising injection.



Portsdown Hill is the pioneer in the UK operating this hub-and-spoke model, marking a significant step forward in this challenge. With the success of this first project, the model could be rolled out across the UK to connect dispersed plants to the grid. It also has the potential to centralise biogas upgrading too. Again, the expensive equipment and infrastructure required to upgrade could also be shared, accepting biogas from several far smaller plants rather than upgrading to biomethane on-site.

Case Study: Portsdown Hill

About

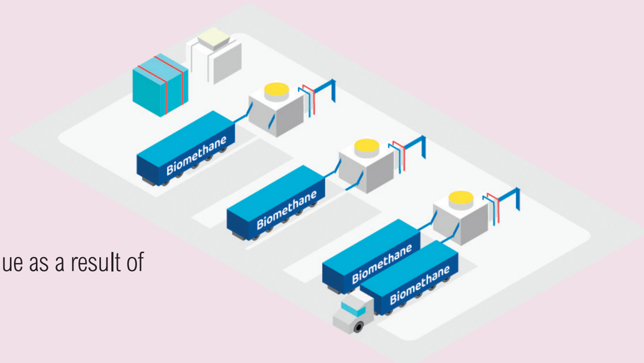
SGN's Portsdown Hill Gas Injection Facility was commissioned in 2014 and is designed to inject compressed biomethane into a gas transportation and distribution network, blending the biomethane with natural gas without the further need to add propane for Calorific Value (CV) enrichment.

Once operating at full capacity, the site will supply low carbon energy to meet the annual heat demand for up to approx. 27,000 customers in the local Havant and Portsmouth areas. The Biomethane entry facility at Portsdown Hill is the largest connection or 'green gas' source entering a Gas Distribution Network (GDN) within the country – and the only entry point into a GDN not requiring the addition of fossil derived propane to enrich the Biomethane.

Virtual Pipeline Concept

The concept of the 'Virtual Pipeline' was first considered by SGN in 2012. This proposed the building of a centralised injection facility where low carbon 'compressed' biomethane could be transported by road from remote AD sites and downloaded into the network. This approach unlocked the pathway to optimising energy export from both existing and new AD infrastructure overcoming barriers and providing benefits, such as:

- distance from the site to a suitable network connection;
- cost of connection;
- suitability of network infrastructure to maintain export;
- provision of storage, resulting in less on-site flaring of green gas when networks are unable to accommodate biomethane import in low demand conditions; and,
- reduction in net carbon footprint of project, less haulage of feedstock due as a result of the AD not requiring to be located close to suitable gas network.



Unlocking Potential

There are approximately 100 sites across the UK producing methane in this way and most have the benefit of being close to a gas pipeline where the injection takes place adjacent to the point of manufacture. However, it has been identified that a further 500 UK gas producing sites have the potential to contribute to the gas network but are constrained by their location.

Technical Challenges

The transport of gas is by trailers and this technology was already well established and tested pre-2012 with methane trailers operating at pressures of around 250 bar. It was the injection facility that presented the technical challenge as this was a new concept to the gas industry. Traditionally, gas networks within the UK operate up to pressures of 100 bar so innovative safety systems and downloading equipment were developed and added to the gas network at this entry point to ensure the extension of the gas network could operate safely up to 250 bar.

Benefits

There are several benefits associated with a virtual pipeline model compared with direct injection via a conventional 'gas-to-grid' model:

- **No enrichment** – no propane to meet the target CV – cost saving (typically 4% of volume injected to grid is propane)
- **Reduction in flaring**, due to:
  - Storage availability;
  - More stable gas quality (propane addition / control is the single largest gas quality excursion event);
  - Low gas demand within network (Portsdown Hill is a high-volume site); and
  - Increased resilience – multiple streams provide greater system availability for continued injection.
- **Open Access** – supporting multiple customers
- **Connection ready**
- **Reduced costs** – sharing of expensive equipment and maintenance cost, redundancy included
- **Technical risk reduced** – site maintained by network operators

3.6. Connecting academics and industry: establishing a 'virtual' research centre

It is important for the AD industry to share its knowledge across platforms and sectors. By working together, issues can be resolved and efficiency improved, in ways that are appropriate, practical and achievable. Communication between academics and industry is crucial for this to occur, ensuring that laboratory-based experiments may be reasonably scaled-up and research is focused on the following key areas:

- Building on UK academic expertise;
- Supporting on farm and agricultural AD;
- Solving the global food waste problem;
- Exporting waste management technologies; and,
- Developing anaerobic biorefineries.

The creation of a 'virtual' Centre for Anaerobic Biotechnology and Bioresources Research (CABB) has been proposed to support this cooperation, with the common goal of propelling AD to its full UK potential. The UK already has world-class knowledge in the field and could be a global leader, exporting to the world. creating over 30,000 jobs. CABB would consolidate this expertise in a 'virtual' centre, with a core administrative function of distributing funds to the UK's existing world-leading research bases.

Thus far, the Universities of Oxford, Southampton, Reading, Newcastle, Cranfield, Imperial College, and the Royal Botanic Gardens at Kew have offered their support, and the Anaerobic Digestion & Bioresources Association (ADBA) would play an integral role in facilitating industry participation and successful research translation. A total budget of £50m over 5-7 years is sought, and it is believed this will provide better value and outcomes compared to the piecemeal, competitive grant environment that is currently in place, which does not lend itself well to the interdisciplinary research requirements illustrated above.

4. The cost of decarbonising with AD

4.1. Introduction

The financial equation that underpins the business case for plant deployment is integral to how quickly AD can be scaled up to decarbonise heat, transport and agriculture. The more cost-effective the technology is the more plants can be built with a set amount of government funding to support roll-out. Therefore, in order to achieve our full potential and contribute as much as possible to the decarbonisation effort, the cost of building plants needs to be minimised and all areas for generating revenue maximised.

This chapter explores the costs of decarbonising through AD in detail. It begins by setting out our model for the industry's costs today, including the cost of alternative infrastructure options for biomethane for transport. It goes on to explore how innovation, best practice and incorporating the cost of finance can bring down the cost of plant development and operations, bringing the industry closer to being independently viable.

4.2. The current economic model: cost of an AD plant today

Note: throughout net operational costs are calculated over a 20-year period to correspond with the length of time government incentive tariff rates (FiT and RHI) pay AD plants for their energy production.

Costs

Generally, the cost of an AD plant has not changed significantly over the last 10 years. Raw materials (concrete, steel etc.), planning permits and labour have not got any cheaper. The cost of a plant is principally determined by its capacity – simply put, larger plants cost more – where 500 kW and 2,500 kW plants constructed in the UK have cost £1.8 and £8.0 million respectively. However, the cost per kW installed capacity can vary substantially from site to site. While all plants generally comprise the same fundamental components, every project is unique, requiring bespoke planning and development to suit its location, feedstock and surrounding environment.

The average plant size in the UK (excluding those that process sewage sludge) is approximately 1.45 MWe-equivalent. The composition of the UK industry is very diverse with many smaller on-farm AD plants, and with the larger plants generally processing food waste, crops or sewage.

So far, government incentives (such as FiT and RHI) have been based entirely on energy generation, with restrictions according to sustainability criteria. While construction costs increase with plant capacity, the relative cost of construction and operation per kW installed capacity decreases with plant size (see table below). Therefore, larger plants have far lower cost per operational hour and, providing investors can overcome the initial capital costs, return on investments can be more safely assured, reducing the associated financial risk.

TABLE 4.2.1. MODELLED EXPENDITURE OF PLANT CONSTRUCTION AND OPERATION OVER 20 YEARS, BY PLANT SIZE

SCALE	CAPACITY (kW)	CONSTRUCTION AVERAGE COST PER kW CAPACITY (£)	OPERATIONAL AVERAGE ANNUAL COST PER kW CAPACITY (£)	TOTAL EXPENDITURE AFTER 20 YEARS (£ MILLION) APPROX. COST
Micro	10-50	9,800	1,000	0.3 – 1.5
Small	50-500	6,300	400	0.7 – 7.2
Medium	500-1,000	4,300	300	5.2 – 10.3
Large	1,000-2,000	3,000	200	7.0 – 14.0
V Large	>2,000	3,800	400	23.6 +

*average calculated from a sample of 41 AD plants across the UK

As you can see, the total expenditure of an AD plant over 20 years can be sizeable, even for the smallest AD units. While the price per kW capacity appears to increase slightly for the very large plants (>2,000 kW), at this scale prices vary greatly from site to site. Within the data used to model these costings, construction costs range between £6.5-24.0 million, and operational costs between £1.0-2.5 million pa. This high variability is associated with the complexity of operations at these larger sites, each requiring very specific requirements to run efficiently.

To break the costs down further, we can explore the approximate expenditure of a **1.0 MW plant's development** – the following outlines the main stages:

Project development (£0.4 – 0.6 million)

This initial stage encompasses all planning, management and due diligence. Architectural and engineering designs can be particularly expensive to produce, requiring the consideration of multiple different operations: from waste transportation and storage, to energy exportation. The cost of due diligence can also vary substantially according to any issues identified. Due diligence may include, but is not limited to:

Ecological surveys

- Landscape and visual impact assessments
- Noise and odour assessments
- Air quality analysis
- Flood risk assessment

Construction (£4.0 – 10.0 million)

This stage includes the cost of raw materials, groundworks, building, and specialist equipment. Plants of this scale typically require a lot of concrete and steel, built over several hectares. However, it is AD's specialist components that generate the bulk of the cost. CHP units (1 MW), and related software and equipment can cost over £400,000; whereas, the cost of biomethane upgrading equipment starts at £150,000 for a small 10-60 m^3/h unit. A plant's feedstock also influences the infrastructure requirements, whereby different types require different storage conditions (e.g. covered, lined). If an AD plant processes food waste, additional equipment is required to segregate and pasteurise wastes, which can increase the cost base by £1 million.

Installation and commissioning (£0.1 – 1.2 million)

This includes all work required to utilise and/or export AD's products. Connecting to the national electric or gas grid largely depends on the plant's location. For electricity connections, prices are typically in the region of £100,000. Whereas, for gas, connections are more expensive and the proximity to the network is far more important, as distance can exponentially increase the connection cost. As a rule, to remain cost effective, plants must be less than 5 miles from the network over 10 miles it is essentially impossible; anecdotal evidence indicates a cost of £500,000 per km of pipeline required to connect to the grid. Regardless of the quantity of biomethane injected, grid entry units may also cost £500,000 (excluding the cost of propanisation; see below). Moreover, the injection requirements can vary between gas distribution networks, due to differing gas pressures, standards and fail-safe systems, which can consequently mean that the price to connect to grid can vary substantially, from £40,000 to £250,000.

As previously discussed (see section 3.5), the centralisation of biomethane injection into the grid can help minimise the importance of a plant's proximity to the gas grid and share the cost of grid injection.

Operation and maintenance (£0.6 – 1.0 million per year)

Once the plant has been built, this stage includes the cost of obtaining and managing feedstocks, equipment maintenance and repairs, and staffing. If an AD plant injects biomethane into the grid at 250 m^3/h (~1 MW capacity), propane must be added to raise its caloric value to match that of the gas grid – by weight, injected gas typically comprises 4%. At this scale, the cost of propane is around £150,000 per year, yet current innovations are looking to remove the need to propanise biomethane altogether (see Section 4.5). Depending on the feedstock type, over 25,000 tonnes are typically required to power a 1MW plant. The cost of collecting and transporting this varies greatly from site-to-site but can total over £250,000 per year. However, if the plant manages municipal waste, gate-fees can instead be a source of revenue, where councils pay plants to process their community's organic waste. With an average capacity of 2.0 MW, municipal plants are larger than most, and can earn over £500,000 per year in gate-fees. In regard to staffing, 1 MW plants need full-time, trained operators, thus costing upwards of £100,000 per year. The cost of repairs is less predictable by their nature, however, estimates of 5-8% of annual operational costs (£0.6-1m pa) are often used.

4. The cost of decarbonising with AD

Income

To cover the costs of developing and running an AD plant, there are multiple potential streams of revenue: wholesale electricity/gas, government incentive schemes, biomethane certificates, and where possible gate-fees and digestate. However, AD can offer additional financial benefits to their local industry and community – from creating new jobs and reducing energy bills for businesses with on-site AD, to negating the need to export organic wastes to other processing plants and supplying a low-cost, natural, nutrient-rich fertiliser.

The following section estimates annual income from these various revenue streams, depending on installed capacity (kW) and operational capacity (%). The latter refers to the proportion of the year in which the plant is generating energy at its full capacity. While the average operational capacity is currently 70-75% in the UK, newer plants performing in line with industry best practice often target, and may attain, levels over 90%. While plants typically aim for this level of operational capacity, it will not always be realised due to periods of downtime for maintenance or feedstock limitations. This will, of course, have ramifications for the amount of energy generated, reducing the annual revenue received compared to their forecasts.

The following outlines all key income and savings opportunities:

Wholesale energy

Simply, any gas/electricity produced has value. It can be bought and sold per kWh, the same as energy from any other sources, including non-renewables. Graph 4.2.1 below shows how the wholesale price of gas and electricity have varied over the last six years, where the three price points within this period are used to estimate an AD plant's potential annual earnings in table 4.2.2. The calculations in table 4.2.2. assume the energy price remains the same for the entire year, and plants are achieving 92% operational capacity, the best case scenario.

GRAPH 4.2.1: WHOLESALE ELECTRICITY AND GAS PRICES SINCE JANUARY 2014

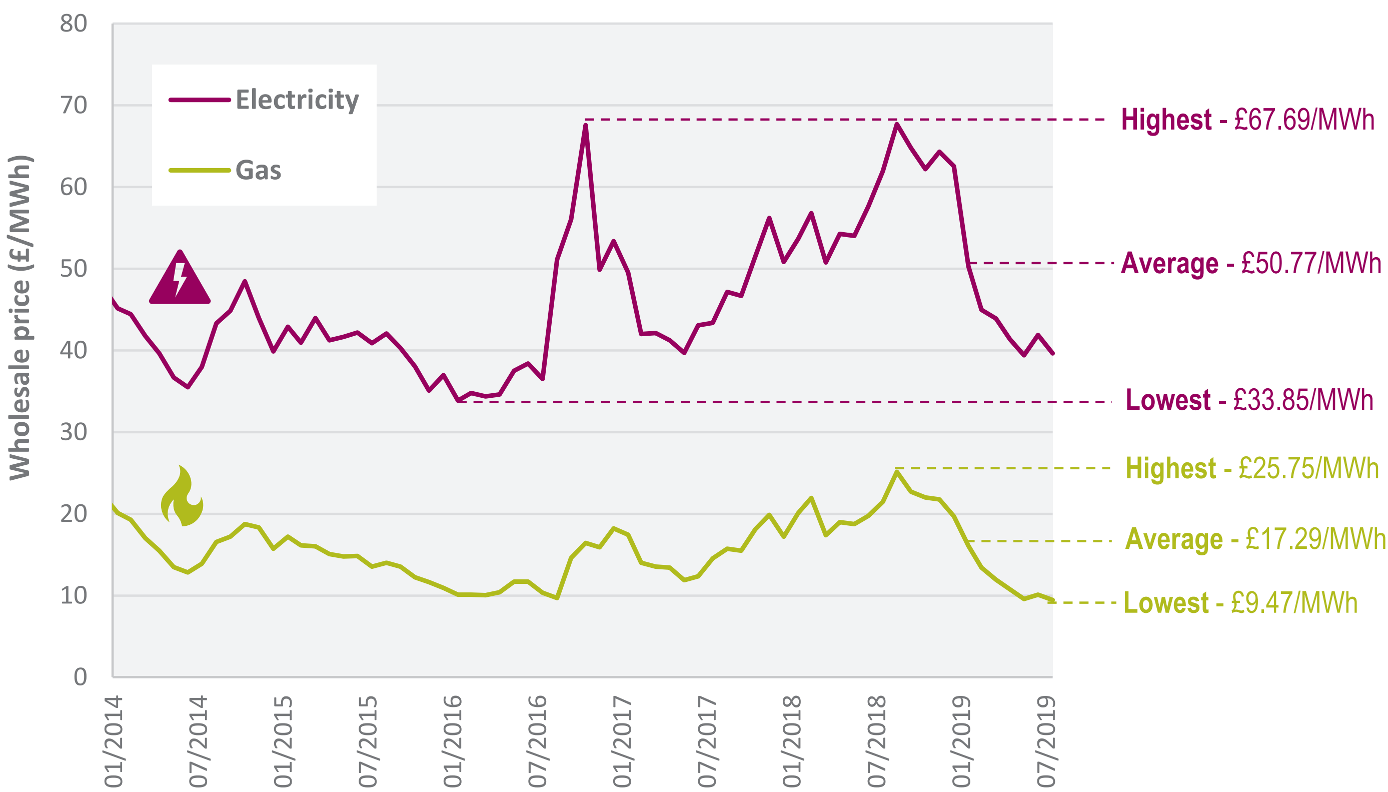


TABLE 4.2.2: POTENTIAL REVENUE FROM WHOLESALE ENERGY PRICE OF ELECTRICITY AND GAS PER YEAR

SCALE	CAPACITY (kW)	WHOLESALE ELECTRICITY (£ pa)			WHOLESALE GAS (£ pa)		
		LOWEST	AVERAGE	HIGHEST	LOWEST	AVERAGE	HIGHEST
Micro	50	14,000	20,000	27,000	4,000	7,000	10,000
Small	250	68,000	102,000	136,000	19,000	35,000	51,000
Medium	500	136,000	205,000	273,000	38,000	70,000	101,000
Large	1,000	273,000	409,000	546,000	74,000	136,000	198,000
Very large	4,000	1,091,000	1,637,000	2,182,000	305,000	558,000	811,000

Estimates assume that the lowest, average and highest prices remain constant for the entire year.

Solely considering the average annual revenue from wholesale prices, this income is not enough to cover the costs of construction and 20 years of operation, even at the lower end of cost estimates – particularly for biomethane production. For example, building and running a 1 MW biomethane plant for 20 years would only bring in around £2.7 million from selling biomethane, significantly below the £7.0-10.3 million cost estimates. Even if the wholesale gas price maintained its highest value of the last 6 years at £25.75/MWh for 20 years straight, it still would not cover the plants costs.

These calculations would suggest that only low cost micro- or small-scale electricity production are financially viable without other revenue streams. Based only on wholesale electricity, a 50kW plant might be able to earn around £400,000 over 20 years, which corresponds roughly to its construction and operational costs over the same period. However, even with the most optimistic expenditure and sustained operation over the entire period, assuming minimal down-time for repairs or maintenance, these small plants still wouldn't turn a profit.

These annual incomes from wholesale electricity and gas prices emphasise the importance of other revenue streams, such as government incentives, and cost savings, such as reduced energy bills for businesses with onsite AD, to make AD financially viable at this point in time. **Within the current energy market, plants (any size) cannot be run profitably solely through these wholesale prices**, but there are many other potential revenue streams that ought to come from the wider benefits and services that AD delivers.

Cost reductions of onsite AD

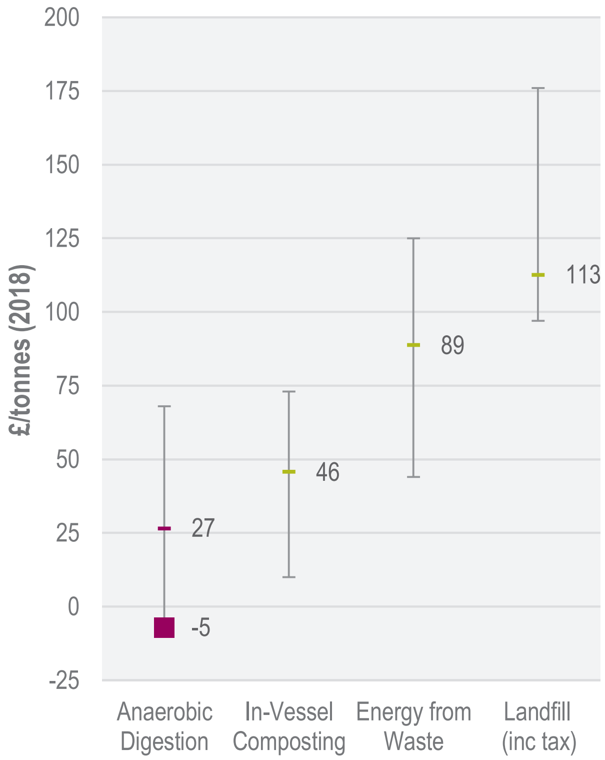
By producing energy on-site, an AD plant can replace the need to import gas and/or electricity from the grid. Energy is expensive, and prices have risen over the last several years. Therefore, AD can significantly cut the energy costs required to operate industrial/agricultural processes, particularly for larger industries with high energy demands (e.g. breweries, dairy processing). In addition, the development of on-site industrial and agricultural AD can also save money previously spent on external waste treatment and disposal. Exporting waste from a factory or farm can be costly, where companies would have to pay for the logistics and gate fees to external waste management companies. In these cases, the value of AD is more than the wholesale value of energy produced, and its true cost-effectiveness should consider the savings made by cutting its energy and waste disposal bills, which can be significant.

Gate fees

An AD plant may also receive revenue from gate fees, whereby a council or commercial entity will pay a plant to process the organic waste they have collected (most often food waste). Gate fees are generally paid per tonne of waste processed and vary in value between different technologies and the supply and demand of feedstock.

The graph shows the median gate fee (per tonne) for the four main technologies which manage organic waste in the UK[48], suggesting an average of £27/tonne. However, it is important to understand the full story behind these figures. The maximum gate fees presented here for AD, £68/tonne, are from long-term legacy contracts made with councils when there was far less plant demand for feedstock. While some plants may still be receiving these fees, as the contracts still stand, any new plants built will see fees much closer to the minimum, around zero or negative. This is because there is significant demand for food waste feedstock from existing AD plants. It is, however, clear from the graph that AD currently presents the cheapest means of processing organic waste available to councils, thus allowing them to save their often-limited budgets. Not only is AD widely recognised as the optimal means of processing organic wastes due to its multiple environmental benefits, it can also save the government and local authorities money.

GRAPH 4.2.2: THE MEDIAN AND RANGE OF GATE FEES (£/TONNE) BY TECHNOLOGY, PAID BY COUNCILS IN 2018; DATA FROM WRAP (2019)



If food waste supply can be increased, for example with the new policy to separately collect food waste across England, gate fees could become a source of revenue for new plants once again. Due to the non-hazardous nature of food waste, there would be scope for most AD plants to supplement their feedstock with municipal or commercial organic wastes, and therefore boost their annual income with the gate fees. However, there is a significantly limited supply of food waste until the policy is implemented to separately collect in all cases, and it often goes to less preferential treatment facilities in contravention to the food and drink material hierarchy[49].

Incentives

The Renewable Obligation (RO), Feed-in-Tariff (FiT) and Renewable Heat Incentive (RHI) have driven AD growth over the last two decades, through the incentivisation of electricity and heat/gas production respectively. These schemes rewarded plants according to the energy generated, providing a £/kWh in a similar way to the wholesale energy market. The Renewable Fuel Transport Obligation (RTFO) also offers an alternative means of selling biomethane's green credentials, on top of the wholesale energy market.

Electricity:

AD's electricity generation was first incentivised through RO and the trade of Certificates (ROCs), introduced to England, Scotland and Wales in 2002, and Northern Ireland in 2005. The scheme incentivised large-scale generators with installed capacities over 1MW and which complied with specific sustainability criteria. ROCs provided the financial incentive to stimulate AD growth across the UK, particularly in the sewage sector, which saw plant numbers nearly triple over the subsequent 10 years. While the scheme closed to new applicants in 2017, the scheme continues to pay many AD plants generating electricity. ROC buy-out prices were set at £48.78 per certificate during this current obligation period (2019-2020) and a plant will receive 0.484 certificates per MWh generated in England, Scotland and Wales (0.190 in Northern Ireland).

[48] www.wrap.org.uk/sites/files/wrap/WRAP%20gate%20fees%20report%202019.pdf
[49] https://bit.ly/2HngTkc

Running from April 2010 to March 2019, the FiT scheme helped drive industry growth over the last decade, with the number of AD plants generating electricity growing three-fold over this period. Electricity is generated through Combined Heat and Power (CHP) units, where the residual heat produced can be used locally, permitting RHI to also be claimed. However, many plants with CHP units cannot use or claim for the heat they produce, especially for the smallest plants.

Plants claiming FiT secured a fixed tariff, for both electricity generation and export, over their entire 20-year lifecycle. While the export tariff remained relative stable at ~5.24p/kWh throughout the scheme, the generation tariff varied greatly – early rates of 11.82-17.54p/kWh were reduced to 1.54-4.50p/kWh by the FiT's closure. Depending on the rate secured, the profitability of a plant can vary substantially.

Operational capacity has, and continues, to play a vital role in the economics of a CHP plant. Over the last ten years, the AD industry has matured and collectively gained the experience required to improve efficiency within the system. As previously mentioned, it is estimated that AD plants currently run at an average operational capacity of 70-75% nationwide, yet improvements in the industry now make it possible for >90% to be realistically targeted. Despite the initially favourable rates, operational capacity achieved in the industry's early years impacted the profitability of CHP plants.

As of the 1st January 2020, the Smart Export Guarantee (SEG) has replaced FiT's export tariff. SEG places an obligation on electricity suppliers to source a proportion of their energy from renewable sources, including AD. These suppliers offer a tariff rate to an AD plant for the electricity they produce and export to the grid – i.e. there is no longer an incentive for energy generated, only exported. As the scheme is in its infancy, data on the rates offered are not yet readily available. While energy suppliers must offer a rate above zero, companies agreed rates between 0.5p/kWh and 5.5p/kWh for all eligible technologies in January 2020[50].

TABLE 4.2.5: THE EFFECT OF SEG AND OPERATIONAL CAPACITY ON PROFIT RATES AND REPAYMENT PERIOD; MODELLING CONSERVATIVELY ASSUMES LOW WHOLESALE ENERGY (£33.85/MWH)

CAPACITY (KW)	OPERATIONAL CAPACITY (%)	SEG TARIFF (P/KWH)	PROFIT RATE AFTER 20 YEARS (%)	REPAYMENT PERIOD (YEARS)
500	73	0.5	-69	N/A
	73	5.5	-28	57
	92	0.5	-61	N/A
	92	8.0	**15**	15
1,000	73	0.5	-57	N/A
	73	5.5	-1	20
	92	0.5	-45	N/A
	92	4.8	**15**	15
2,000	73	0.5	-62	N/A
	73	5.5	-13	34
	92	0.5	-52	N/A
	92	6.0	**15**	14

Note that plants with capacity below 500 kW are never profitable after 20 years within these scenarios. The SEG tariff rates modelled reflect the lowest rate offered in Jan 2020 (0.5p/kWh), the highest rate offered in Jan 2020 (5.50p/kWh); and for plants operating at 92% capacity, the tariff that would deliver a 15% profit rate over the project lifetime. The modelling also assumes a parasitic load of 10% - where energy generated is used on-site to power the AD plant, and is therefore not exported.

[50] www.which.co.uk/reviews/solar-panels/article/smart-export-guarantee-explained

4. The cost of decarbonising with AD

There is a lot of uncertainty with the tariff rates offered and modelled in the table above. Contractual agreements between an AD plant and energy supplier, and the tariff rate offered therein, will depend on a number of factors: the duration of the rate agreed, the wholesale energy price, plant capacity and export potential, and the reliability of energy produced. AD plants may be able to negotiate more favourable rates due to their ability to provide base load, unlike wind and solar whose power output varies daily, as this offers greater operational certainty to electrical providers.

While the modelling above suggests that SEG can prove highly profitable, the rates available to AD plants specifically are not yet clear. Even at 92% operational capacity, plants will not run profitably without an appropriate tariff. A larger plant consistently operating optimally over its full 20-year period would need an SEG tariff rate of 4.8-8.0p/kWh, depending on plant size, to deliver a profit rate of 15% over the 20-year period, the kind of profit level necessary to attract investors to put their money into the AD industry rather than an alternative investment. While at some scales this is achievable with the highest tariff rate on offer, the variability and market-driven nature of the SEG system is likely to limit AD growth for electrical production as it does not provide the financial certainty necessary for major investment into the industry.

Biomethane

Since opening in November 2011, the RHI has been a key driving force, supporting the growth of biomethane-to-grid (BtG) plants and resulting in the development of 108 plants so far. All but two of these plants have a capacity over 600kW, which means they would claim RHI under the category 'Large biogas and biomethane for injection (600kW and above)'. Over the last eight years, plants within this category have been awarded over £375 million.

The following looks at the RHI and RTFCs for biomethane and potential earning when combined with wholesale gas prices. Note that biomethane producers can claim both the Renewable Heat Incentive (RHI) and the Renewable Transport Fuel Obligation (RTFO) within a single year; however, for each quarter within a year, a producer

TABLE 4.2.3A: TOTAL POTENTIAL REVENUE GAINED AFTER 20 YEARS FROM WHOLESALE GAS, AND RHI OR RTFC SCHEMES FOR A WASTE-BASED PLANT, VS THE ESTIMATED EXPENDITURE REQUIRED TO CONSTRUCT AND OPERATE THE PLANT OVER THE SAME PERIOD.

					REVENUE	EXPENDITURE
SCALE	CAPACITY (kW)	RHI TARIFF (JAN 19*) (£ pa)	AVERAGE wRTFC MARKET** (£ pa)	AVERAGE WHOLESALE GAS (£ pa)	POTENTIAL EARNINGS OVER 20 YEARS (£)	ESTIMATED PLANT COST OVER 20 YEARS (£)
Micro	50	20,000	20,000	7,000	**540,000**	1,490,000
Small	250	98,000	99,000	35,000	**2,670,000**	3,575,000
Medium	500	196,000	197,000	70,000	**5,330,000**	5,150,000
Large	1,000	382,000	385,000	136,000	**10,390,000**	7,000,000
Very large	4,000	1,567,000	1,579,000	558,000	**42,620,000**	47,200,000

* Current RHI tariff used (set January 2019) at 4.86p/kWh

** Average wRTFC price (for waste-based plants) in 2019 of 17.9p/RTFC; to obtain this rate, 100% of the feedstock must be derived from wastes and residues. If the feedstock includes a significant portion of bioenergy crops, the annual revenue potential from RTFCs is halved.

Note these estimates optimistically assume an operational capacity of 92%, in line with best practice and typical financial modelling.

Our modelling shows that the current RHI policy and the average RTFC market yield deliver very similar revenue potential. While RHI provides a steady, predictable income, a plant may switch to the RTFO scheme for a quarter when the price of the certificates increases significantly. Between November 2019 and February 2020, the price has remained over 25p/RTFC, a two-year high. At this price, plants could receive up to 25% more income over a 20-year period. As obligations increase over time, and therefore the demand for RTFCs, the certificates' average price will likely increase towards the ceiling price of 30p/RTFC. However, the scheme also saw its lowest price in two years at the start of 2019, with a price of just 11p/RTFC in March. This illustrates the variability of the price, which, combined with the fact that there is no floor price, makes the scheme less bankable. RHI currently provides this protection, giving a guaranteed tariff to plants when the RTFC price is low. Considering how these two schemes and sectors interact is, therefore, vital for understanding the business case for new plant deployment and for designing future policy.

RHI and RTFC schemes favour larger plants, with the combined revenue from wholesale gas and incentives only exceeding construction and operational costs at plants with a capacity >500kW. While table 4.2.3 suggests profit margins may be narrow within a 20-year period, it is important to note that the total expenditure can vary substantially (as shown above), particularly for larger plants. These larger plants may also be able to supplement their revenue through gate fees; 25% of biomethane-to-grid plants currently process waste from the municipal sector.

Profit rates and repayment periods are two key financial aspects investors assess when considering new AD developments. As shown above, plants cannot run profitably from wholesale energy alone and investors must be confident that incentives are sufficiently high and for a long enough term. Equally, financial planning must account for variations in operational capacity in case of unforeseen downtime needed for repairs. The following highlights the uncertainty, risks, and potential gains when investing in a new medium-large plant:

TABLE 4.2.3B: THE EFFECT OF THE RHI RATE AND OPERATIONAL CAPACITY ON PROFIT RATES AND THE REPAYMENT PERIOD; MODELLING CONSERVATIVELY ASSUMES LOW WHOLESALE ENERGY (27.75P/THERM)

CAPACITY (KW)	OPERATIONAL CAPACITY (%)	RHI TARIFF (P/KWH)	PROFIT RATE AFTER 20 YEARS (%)	REPAYMENT PERIOD (YEARS)
500	73	4.86	-48	N/A
	73	7.90	-21	38
	92	4.86	-35	93
	92	9.30	**15**	15
1,000	73	4.86	-28	60
	73	7.90	10	16
	92	4.86	-9	26
	92	6.40	**15**	15
2,000	73	4.86	-37	N/A
	73	7.90	-4	23
	92	4.86	-21	56
	92	7.50	**15**	14

Note that plants with capacity below 500 kW are never profitable after 20 years within these scenarios. The RHI tariff rates modelled reflect the final tariff rate offered in Jan 2019 (4.86p/kWh), the peak rate in the RHI's history (7.90p/kWh), which led to significant growth in biomethane plants; and for plants operating at 92% capacity, the tariff that would deliver a 15% profit rate over the project lifetime.

This modelling conservatively assumes the lower bound of wholesale gas price and highlights the impact of key variables on profitability and repayment period. A larger plant consistently operating optimally over its full 20-year period would need an RHI tariff rate closer to those seen in 2011-15 to deliver a profit rate of 15% over the 20-year period, the kind of profit level necessary to attract investors to put their money into the AD industry rather than an alternative investment. While a developer may target an operational capacity of 92%, prolonged downtime cuts into profit rates and can potentially result in financial loss over the plant's life, depending on the tariff rate secured. Moreover, due to the sizable investment required (£ millions), it can still take at least 14 years for a plant to turn a profit in the scenario modelled above. This long period of time creates uncertainty as the UK's economic and environmental landscapes can change drastically through the decades. Long-term debt may not be sustainable and can result in the buying and selling of plants for far less than their value. This uncertainty further adds to investment risk, which can be alleviated by long-term, favourable incentives to promote AD growth.

With the RHI due to close in 2021, the new Government needs to urgently replace the scheme with a new policy designed to significantly increase deployment (specifically biomethane production) to achieve the industry's full potential and cut emissions in the hardest to decarbonise sectors of heat, transport, waste management and agriculture. The current RHI rate is not generating enough turnover to encourage serious investment in new plants. Therefore, either a higher tariff rate is required or a new policy that effectively stimulates demand for AD's outputs to increase other revenue streams. Moreover, plants at all scales are necessary to process all available feedstocks, regardless of their biogas yield. If biomethane production is the preferred energy-type, future incentives must enable all-sized plants to be profitable. While innovation within the AD industry is poised to increase biomethane production (see Chapter 3 and Section 4.3), the government needs to provide adequate support to make AD worthwhile; this may be increasing revenue (e.g. tariff rates) or minimising expenditure (e.g. grants, tax breaks, reduced regulatory burden etc).

Biomethane Certificates:

Biomethane's 'green' credentials can also be sold on the private market via biomethane or green gas certificates. These operate in a very similar way to the RTFC's system:

- an AD plant is certified to verify the methane it produces is renewable;
- the certified plant receives a set number of certificates according to the quantity of biomethane produced; and
- the certificates are bought and sold to energy providers to demonstrate their renewable credentials and/or fulfil sustainable quotas.

Overall, a plant may sell wholesale biomethane, claim financial incentives through the government's RHI or RTFC schemes, and sell biomethane certificates to reward its green origin.

In the UK, there are two prominent certification schemes: Biomethane Certification Scheme (BMCS) and the Green Gas Certificate Scheme (GGCS). Both of these schemes assign certificates per MWh or kWh of biomethane respectively. The certificates' prices are solely market driven, affected by the demand for renewable gas in the UK and Europe. Over the last 5 years, the cost per certificate has remained relatively low at around £2/certificate, however, their value has increased four-fold this year to £9/certificate. This upwards trend is expected to continue, as the need for renewable gas for transport and heating continues to increase. In the past, government incentives have proved comparatively more profitable than these certificates, but much like the RTFCs, increasing demand for renewable gas as the public momentum for climate action translates to changing consumer preferences, and as industry commits to its own net zero targets with biomethane forming a key part of many delivery plans for heat, these schemes will become more lucrative, and attractive to future investment. However, prices are variable, as with RTFCs, and so investors cannot rely on these revenue streams when making funding decisions.

TABLE 4.2.4: TOTAL POTENTIAL REVENUE GAINED AFTER 20 YEARS FROM BIOMETHANE CERTIFICATES AS ESTIMATED FROM THEIR AVERAGE PRICE PRE-2019 (£2/CERTIFICATE) VS 2019'S (£9/CERTIFICATE)

SCALE	CAPACITY (kW)	LOW £2/CERTIFICATE (£ pa)	HIGH £9/CERTIFICATE (£ pa)	POTENTIAL EARNINGS OVER 20 YEARS (£)
Micro	50	1,000	4,000	16,000 – 73,000
Small	250	4,000	18,000	81,000 – 363,000
Medium	500	8,000	36,000	161,000 – 725,000
Large	1,000	16,000	73,000	322,000 – 1,451,000
Very large	4,000	64,000	290,000	1,289,000 – 5,803,000

Digestate:

Digestate delivers a vital service within a circular economy model as it recovers nutrients from biogas feedstocks. This should be a significant revenue stream for AD plants but is not yet valued as it should be. When integrated into farming practices, digestate returns nutrients back to the soil, therefore, using digestate as a fertiliser means farmers do not need to buy expensive artificial fertilisers. Certain farmers have already demonstrated that digestate can provide 100% of their fertiliser needs, thus saving up to £250 per hectare on artificial fertilisers each year. With an average UK farm size of approximately 50-55 hectares, spreading digestate could save over £13,000 pa.

Moreover, digestate's substrate can help to recover soil structure, support water retention and carbon sequestration, both beneficial to crop yields. Its use can help, in part, to ensure agriculture remains sustainable, and ultimately reduce any long-term costs incurred recovering soil from degradation.

Unfortunately, the production of digestate does not often offer economic benefits to AD plants. Those which do not have convenient land to spread digestate to, typically plants fed by municipal waste and sewage, can have trouble selling it and the cost of transporting it may outweigh any revenue received. In these cases, this valuable resource may be given away to nearby farms for free (or even at a loss) in order to keep their AD plant operational. While this can be challenging, research and innovation are expected to improve the marketability of digestate, and digestate-derived products, and develop its income potential (see Section 4.4). A carbon price would also incentivise demand for renewable biofertilisers such as digestate, as would an obligation placed on consumers to use renewably sourced fertilisers.

4.3. Refuelling: the cost of alternative infrastructure

Transport has grown to be the largest emitting sector of our economy. The development of alternative refuelling infrastructure is essential to facilitate the transition to a lower-carbon transport system. This can be achieved either by supplying biomethane through refuelling hubs, from transport that will return to a central site, or a network of fuelling stations across the country, to supply vehicles without a central hub site. When considering the overall cost of implementing alternative infrastructure for biomethane refuelling stations in transport, demand and distribution are the two major factors to consider.

Demand

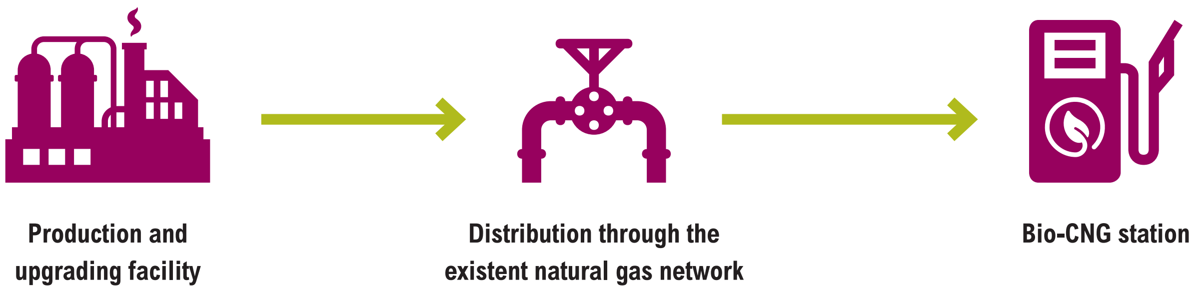
Demand for biomethane refuelling infrastructure is driven by the number of vehicles committed to using biomethane. Due to the relative maturity of alternative technologies in other transport sectors, biomethane is better used in heavy goods vehicles, public transportation and to a lesser extent aviation and shipping. Most HGV manufacturers are already making biomethane models; but transitioning from existing transport infrastructure presents a significant challenge to using biomethane as a transport fuel in these sectors. It is one that needs to be overcome.

To avoid high costs and to employ the technology that is readily available, public transport and HGVs need to run on biomethane in the coming decades. It is the most efficient fuel to deliver long distance haulage, fast refuelling and low carbon emissions at source. Cost effectiveness is expected to be greater for vehicles with higher annual mileage as there is increased potential to make fuel savings. In addition, implementation of the Clean Air Zones and the Ultra-Low Emissions Zones will make biomethane buses and HGVs highly cost competitive.

Distribution

Biogas, when upgraded and purified to biomethane can be transported from the location of production to a filling station by means of the national gas grid, a local gas pipeline or by trucks in either gaseous or liquified form. The main assumption is that the farther the refuelling station is located from the production site the more costs are added to the distribution. Compression and liquefaction, necessary for the distribution of biomethane for transport, are a cost intensive stage of distribution.

SUPPLY THROUGH THE NATIONAL GAS GRID



In order to supply biomethane using the gas grid it needs to be compressed to match the grid's pressure levels. Currently, the biomethane may need to be injected with a small amount of propane to raise its calorific value to match that of the grid. Today this option is considered the most cost effective as it does not require any additional operations to be undertaken, despite requiring the addition of another fossil-derived gas. The regulatory framework will need to be adapted to enable the injection of alternative green gases, such as hydrogen, that have a far lower calorific value than fossil gas.

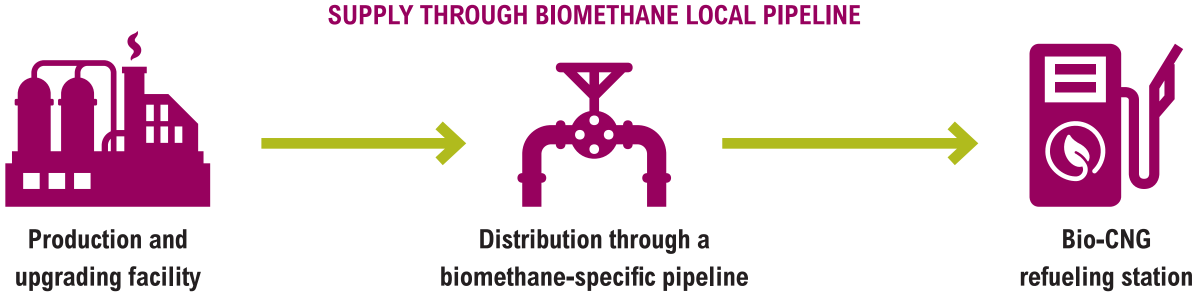
It is important to note, however, that the practical supply of biomethane is, today, very much linked to the financial system surrounding the purchase of renewable energy certificates. When biomethane is supplied through the distribution networks it is mixed with the fossil-based natural gas for which, historically, these distribution networks were built in the first place.[51]

The Renewable Transport Fuel Obligation (RTFO) is the primary policy that promotes the supply of renewable fuels, allowing suppliers of sustainable biofuel to apply for Renewable Transport Fuel Certificates (RTFCs); 1.9 RTFCs are issued per kg of liquid biomethane derived from crop-based feedstocks. However, for biomethane derived from wastes and residues, twice the number of RTFCs are issued per kg (3.8 RTFCs/kg) to reflect the preference of waste-derived fuels.

[51] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/752990/notes-and-definitions.pdf

In practical terms, biomethane displaces natural gas and not diesel or biodiesel. The end user of the biomethane for transport will take natural gas from the grid and pay for green gas certificates to indicate that they own the green element of the biomethane generated, even if the specific gas they have removed may not be the biomethane injected due to how the grid distributes gas.

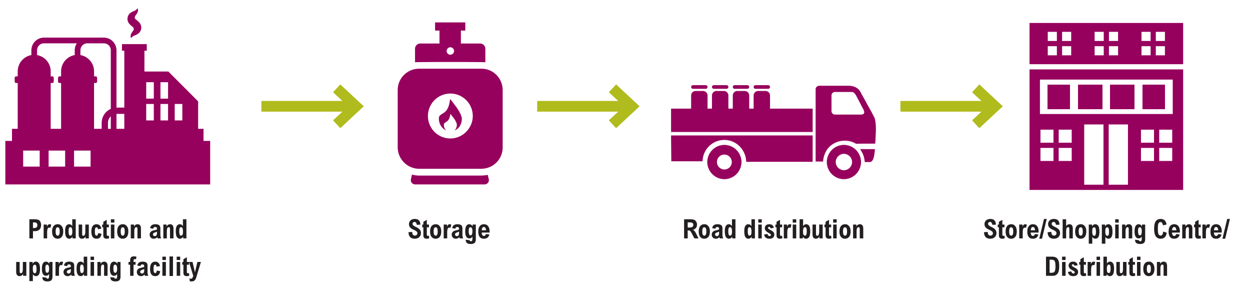
SUPPLY THROUGH BIOMETHANE LOCAL PIPELINE



It is also possible to build or acquire a local pipeline directly linked to the production site for the exclusive supply of biomethane. This option allows for the vehicles refuelled to have a guarantee of origin that the energy consumed has been produced by anaerobic digestion. This option requires additional investment in distribution infrastructure. The larger the distance between the production site and refuelling station the larger the overall costs of the infrastructure will be, which invites biomethane providers for transport to consider investment in industrial hubs that supply fuel to nearby fleet operators and/or staff.

Biomethane assures an estimated range value of 300 miles and above, meaning that a local supply, for example based on a hub and spoke model, is preferred to longer range, unless the refuelling stations are located at strategic points that will facilitate route planning, such as along arterial motorways. Route optimisation and traceability of fuelling stations in our digital era may be solved through mobile apps that signal the location of a given refuelling station. Nonetheless, given the current limits in the number of the existent fuel suppliers, as well as fuel availability and storage, current refuelling infrastructure is better placed either in close proximity to the biomethane production stations or the public transport and freight companies adopting the fuel and receiving continuous supply from the biomethane suppliers.

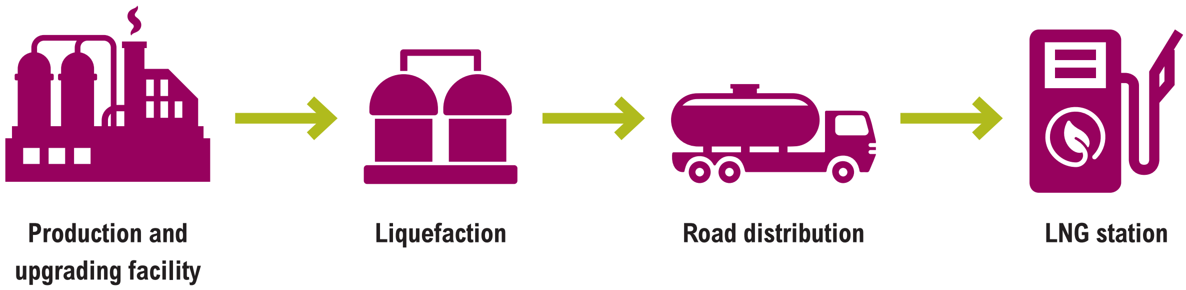
GAS SUPPLIED BY TRUCKS IN GASEOUS FORM



When transported by trucks, biomethane is usually carried or stored in high-pressure cylinders in a range from 200 bar to 250 bar. This option is more energy and cost intensive due to additional operations added to the value chain. This process is more commonly used for long distance transport, such as by heavy duty vehicles or maritime transport.[52]

[52] www.irena.org/-/media/Files/IRENA/Agency/Publication/2017/Mar/IRENA_Biogas_for_Road_Vehicles_2017.pdf

GAS SUPPLIED BY TRUCKS IN LIQUIFIED FORM



4.3. Refuelling: the cost of alternative infrastructure

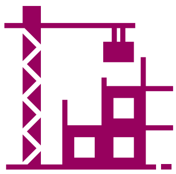
It is also possible to liquefy biogas in order to increase the energy density (three times in comparison to compressed biogas at 200 bar). This option is considered the most expensive and is most suited to installations with a biomethane rate of over 1,000 m^3/h. This process delivers additional benefits, however, in the form of larger storage capacity and vent capture equipment that are usually incorporated in well-designed LNG stations.[53]

Planning:

Currently, innovation within the financial planning stages of AD are helping to reduce costs. Since manual feasibility studies can be expensive and time consuming, new modelling software is being developed to quickly provide an insight into new projects. By inputting key variables, including feedstock and plant capacity, the software aims to model a project's financial viability, where multiple scenarios and proposals can be easily explored. Providing appropriate legislative support, this powerful tool could help farms, cities, councils, and businesses realise their AD potential.

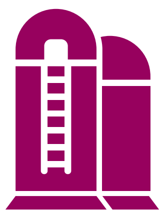
Similarly, funding from the EU is being used to develop a 'portable AD plant'. By visiting sites, both potential and existing operators can test their feedstocks inside a 1,000L digester. New operators can explore the energy and financial potential of developing a plant, and gain practical training in AD management, while existing operators can investigate different feedstock mixes and digester conditions on a small-scale before implementing them within their main digester. In both cases, this portable plant offers a cheap way of exploring AD, to minimise the financial risks involved with new installations and changing practices.

Construction:



The bespoke nature of many AD plants invariably increases their construction costs. In the future, standardisation of plans and parts, where significant portions of a plant may be factory made and pieced together on site, can significantly reduce the capital expenditure of a plant. As shown above, construction, and to a lesser extent planning, account for the vast majority of costs before commissioning energy. Reducing these costs would make turning a profit far more achievable at all scales. AD could be incorporated as a standard agricultural practice in the medium- to long-term, where standardised parts would also minimise the cost of repairs and increase a plant's operational lifetime.

Digestion:



AD plants are often described as "concrete cows". While the processes therein are somewhat comparable, a cow is more than 20 times more efficient at converting organic matter into energy. Research is currently in the process of unlocking more energy from AD's feedstocks, and therefore, making plants more cost efficient. Latest reports from laboratories suggest that innovation in the microbial mix used inside a digester can increase biogas yields by up to +50%, i.e. for the same input, a plant will generate 50% more energy (and revenue). Initial trials scaling-up findings from the lab to the field have proved promising, and if successful, could be available to plants within the next couple of years.

[53] https://bit.ly/2HoIEsJ

Biogas yield can also be improved through innovation in computer monitoring technology. Knowing exactly what's going on inside a digester can optimise its biological processes, making sure ideal conditions are maintained and feedstock/microbes are added as and when needed. Improving monitoring efforts also helps ensure safe operations. If conditions inside the digester exceed certain limits, monitoring technology can quickly identify, warn and potentially prevent a serious incident. By reducing the physical risks of AD, insurance costs are reduced, making it cheaper to run and again more attractive to investors.

Digestate:

Innovation to digestate is looking to create new markets and open it up as a potential source of income. Some agricultural plants already separate and/or dry their digestate, using the residual heat from the AD tank and/or CHP units, selling bags for domestic garden use. In such cases, the key nutrients (NPK) are typically cheaper per kg than manufactured fertilisers and growing mediums. Research is also exploring the cultivation of algae using digestate's key nutrients. The goal is to subsequently use the algae as an animal feed, thus helping to decarbonise livestock production. Overall, innovation can increase demand for digestate, and with it, associated revenue streams from this valuable resource. Encouraging this shift would also reduce the demand for finite resources currently used in artificial fertilisers such as phosphorus and peat.

Energy export:

The centralisation of biomethane injection negates the need for individual plants to connect to the national gas grid. Depending on the plant's proximity to the network, this would significantly cut capital expenditure. Additionally, the annual costs of operation, maintenance and risk management at the AD plant is reduced, as these costs are deferred to the centralised injection site. Portsdown Hill (see Section 3.5) also demonstrates that central biomethane injection sites can remove the need to enrich the biomethane with fossil-derived propane gas to meet the grid's calorific value target. In this case, the high volume of gas flowing through the grid rendering the biomethane's influence on the calorific value negligible.

Integration with hydrogen:

As previously stated, AD has a crucial part to play in the UK achieving its net zero target, specifically in its ability to decarbonise agriculture and displace fossil-based natural gas. As such, future legislation must support AD within these two sectors. Recent innovation is looking to integrate AD with wind and solar farms to optimise their respective strengths. During summer, high solar and wind energy production can exceed the UK's electrical demand, yet there is no means of storing this electricity at scale. AD offers an opportunity to utilise and store this excess energy, through the production of additional biomethane. In short, surplus electricity can be used to produce hydrogen (via the electrolysis of water) which, when mixed with AD's biogas, combines chemically with the CO_2 to generate extra biomethane; upgrading biogas to grid-ready biomethane, and minimising the venting of bio-CO_2. Here, innovation can help farms make the best-use of their energy output. Depending on what is most profitable, wind/solar electricity may be fed into the grid or used to support biomethane production at any given time.

Post 2030, as the energy networks develop to become hydrogen-ready, hydrogen generation through wind/solar hydrolysis can be used directly as an energy source rather than used to generate biomethane, which is already compatible with our existing infrastructure. Going forward hydrogen is expected to become one of the primary fuels for domestic heating, alongside biomethane, to heat homes and fuel transport.[54] Furthermore, biomethane itself could act as a renewable supply of hydrogen gas, if hydrogen became the dominant energy source further down the line. With a molecular structure containing four hydrogen atoms (CH_4), using biomethane to create hydrogen gas requires much less energy than splitting water (H_2O) molecules through electrolysis.

[54] www.energynetworks.org/assets/files/gas/Navigant%20Pathways%20to%20Net-Zero.pdf

Bio-CO_2:

When biogas is upgraded to biomethane, bio-CO_2 is separated out. Currently, this is seen as a simple by-product of AD. However, CO_2 forms a crucial component within many other industries and sectors so these existing markets may be sources of demand for renewable bio-CO_2, thus offering the potential of new streams of income to AD plants that upgrade biogas to biomethane. The following describes some of the uses of bio-CO_2:

- **Food and drinks manufacturing:** most commonly, CO_2 is required to create fizzy drinks and is used within packaging to extend the life of perishable products.
- **Greenhouse agriculture:** to promote photosynthesis, and thus plant growth, commercial greenhouses often pump in additional CO_2 to elevate its levels.
- **Medicine:** certain medical practices require inert gases, such as CO_2; as a non-combustible gas, it is typically used to prevent damage to healthy tissue during operations.
- **Creation of syngas:** biogas can be reformed to syngas (CO and H_2) which, in turn, can be converted into bioethanol and biomethanol. Chemically identical to its fossil-based counterparts, these compounds form the building blocks to many currently petroleum-based products, such as polymers.

4.5. Grid injection: the cost of alternative models

Biomethane is the expected direction of travel for the AD industry but most plants are currently producing electricity through CHP. It is therefore important to consider the best use of current sites and how future ones should be developed. Converting CHP plants to biomethane production would be expensive – upgrading equipment can be costly – but what's more, many sites do not have access to the national gas grid for injection.

Centralised injection sites could significantly reduce the infrastructure costs to plants. As previously discussed, the hub and spoke model may present new opportunities for plants to inject their biomethane at a centralised site, foregoing the need of any one plant to invest in costly grid connections. These costs have previously presented a significant barrier to biomethane production at smaller-scale AD plants. With an average capacity of 3 MWe-e, biomethane-to-grid has only been financially viable at larger plants. The growing use of centralised injection sites may pave the way for smaller plants to also produce biomethane.

For the most part, biogas would still be required to be upgraded on-site. Due to the differing physical properties of CO_2 and biomethane, raw biogas cannot be easily compressed, and hence transported cross-country. Therefore, the addition of small upgrading units could enable smaller, more remote AD plants to produce biomethane ready for injection. Some companies are currently experimenting with gas collection methods akin to a milk bottle delivery. In this model, canisters of biomethane could be collected from smaller plants on a weekly basis and replaced with empty ones. This renewable gas can subsequently be processed centrally at scale.

As Portsdown Hill demonstrates, centralised injection at specific points within the gas network can also forego the need to add propane to the biomethane. In the longer term, as the proportion of biomethane in the grid increases and starts to impact the overall calorific value of the network's gas, it has been proposed that smart meters will measure the calories of gas used, rather than volume, to negate the need for propanisation. However, the impact on variability of gas supply would have to be assessed as this could impact businesses that depend on a consistent calorific value for their industrial processes.

Centralised biogas upgrading is currently only feasible when multiple plants are located less than ~5km from each other. In this scenario, biogas can flow under the natural pressure from the digesters through simple pipelines to a central upgrader. Where possible, the centralisation of upgrading and injection can significantly cut equipment and infrastructure costs.

Centralisation could save AD plants a lot of money – reducing equipment, operational and maintenance costs. Consequently, the cost per kWh of energy will be bought down, increasing plants' profit year-on-year. Again, reducing the initial capital investment required for new plants will act to reduce financial risk and bolster future investment. To realise AD's full UK potential, we need more plants at all scales. Moreover, innovation in gas storage can further increase efficiency of these systems, making it possible to transport biogas by road. New technology has the potential to increase the amount of gas stored within tanks by +90%, nearly doubling the storage of canisters already available. This could halve the number of trips/collections to a centralised injection site, and thus cut the associated costs and risks.

4.6. The cost of uncertainty: bringing down the cost of finance

Uncertainty increases the interest rates placed on investments. The AD industry is often subject to very high interest rates, often between 13-15%, suggesting that financiers view the industry as being fairly high risk. This is because projects may encounter unforeseen circumstances that cause delay, or result in plant downtime, if they are not operating according to industry best practice. These higher interest rates are costly to a plant, making it more difficult to be financially viable, particularly for smaller plants which do not benefit from economies of scale.

As an industry, AD can reduce risk, and therefore interest rates and costs, by building and operating plants which follow best practice. When done correctly, operations can closely match the financial plans. Well-built plants work efficiently and consistently over their lifetime, and well-trained operators optimise processes and maintain safe conditions on-site. In terms of its construction and management, the better the plant, the less uncertainty there is and the cheaper it is to finance and insure. However, here lies the paradox, to lessen uncertainty (and interest rates), how can a plant prove that it will be well-run prior to being operational?

Investors can now request that new plants be accredited by the Anaerobic Digestion Certification Scheme (ADCS). Having been developed with regulators, this scheme aims to guarantee that certified plants comply with policy and represent the industry's commitment to achieving high standards. To be accredited, a plant must demonstrate environment, health and safety and operational performance best practice – for more information see Section 3.3. By incorporating the scheme into the plans of future developments, investors can be assured that plants will be optimally built and run, with markedly lower risks of expensive incidents, such as injuries, environmental leaks and damaged equipment. Again, less risk means lower interest rates, and lower cost, benefiting the AD industry as a whole.

Plants that are already constructed and are employing industry best practice could also seek ADCS accreditation to bring down costs. Certification demonstrates to insurers that a plant is actively minimising potential risks, thus reducing insurance premiums.

Accreditation also showcases a plant's commitment to improving the standard of AD nationwide, enabling the process' full environmental and socio-economic benefits to be realised. The government already recognises the advantages of AD, however by garnering public awareness and support, AD can be more widely recognised as a vital part of the UK's path to net zero emissions.

4.7. How we value the environment: incorporating the cost of carbon

Our economy sits within the natural environment around us, and investment decisions have a significant impact on the health of our planet. In our current system, the cost of these decisions on our environment are not factored into financial models, i.e. we do not effectively price or monetise the value of our environment. It is hotly debated whether our environment can, or should, be effectively monetised to reflect its true value, but to overcome the problem of this misallocation of financial resources, there needs to be a better method to incorporate the environmental cost or benefit of investment decisions. From a climate perspective, the urgent necessity is to effectively price carbon emissions to incorporate their impact.

An effective carbon price could significantly alter the financials of the anaerobic digestion sector. There are two alternative mechanisms to price carbon, a tax on emissions and a system of tradable carbon quotas. The aim of these policies is to increase the cost of carbon-intensive activities making green alternatives more cost competitive. Both mechanisms are in use in different parts of the world and for different sectors, but in all cases the policy is not working effectively to transition the global system away from fossil fuels towards a green economy. The price of carbon credits is still too low to accurately reflect the environmental impact and divert funds away from fossil fuels in anything like sufficient volumes to achieve the necessary shift.

The EU Emissions Trading Scheme (ETS) is the first and largest emissions trading scheme. It assumes that biogases (if not mixed with fossil materials) have an emission factor of zero, meaning that resultant carbon emissions do not count towards the capped allowance. This is because any emissions from the renewable gas were first removed from the atmosphere when the biomass used in the anaerobic digestion process were grown. Therefore, in the energy sector, the price of purchasing additional allowances would make biogas a more competitive energy source, and in other sectors, biogas and biomethane can be used to decarbonise energy use. Though the price of permits has recently hit an 11 year high of €28, after a decade of single digits price figures, this still does not appear to be sufficient to incentivise a transition to green energy at the scale necessary. A recent study suggests an optimal global price of carbon of around $100 to fully reflect the environmental impact and price in the cost to our planet, which would decline over time as uncertainty about the damage of climate change is resolved.[55] The UN emissions trading scheme, for parties with commitments under the Kyoto Protocol, works in much the same way but at the country level and is compatible with the EU ETS.

In addition to carbon pricing policies from international and national bodies, market solutions have emerged to address the problem that carbon is not effectively priced into the financial equation. By separating the green element of the gas from the gas itself using a certificate, its greenness can be sold at a premium as a market for these tradeable certificates develops. There are a number of alternative registries for biomethane certificates, including the Biomethane Certification Scheme run by Green Gas Trading and the Green Gas Certification Scheme run by REAL. The price for this green element of the biomethane generated has recently seen a significant increase from around £1.75 in 2014 to £9.00 in 2019, primarily driven by a stabilisation in supply of biomethane, due to reduced policy support, and a significant increase in demand as more companies seek to decarbonise their heat in the face of rising pressure from the public, to show they are acting on climate change. Similar markets can be established as a government policy, for example the Renewable Transport Fuel Certificates (RTFCs) under the Renewable Transport Fuel Obligation.

It is important to consider the impact of effectively pricing the environmental impact on the consumer. When the environmental impact of our energy system is truly reflected in the price, whether that be by properly remunerating those generating green energy or through an inflated price for carbon-intensive energy sources, there will be a significant impact on consumers and implications for fuel poverty. However, this can be resolved by considering the property rights for emission allowances. In the EU ETS, there is a mix of free allowances allocated to companies and the sale of allowances at auction. Companies that are given the right to emit but are better at cutting emissions can sell their permits, securing additional revenues for their company. This generates a flow of capital from carbon-intensive industry to those that are effectively cutting emissions, enabling greener companies to be more cost competitive. This is such that in the round the energy price would not be pushed up, but resources just redirected towards more sustainable companies. The sale of permits at auction on the other hand will push up the cost of carbon-intensive industries without necessarily reducing the price of greener technologies. However, the auctions generate revenue for member states, which can be used to support a just transition to a green economy and protect citizen's vulnerable to fuel poverty. Over 80% of auction revenues generated from the scheme have been used for climate and energy spending.[56]

[55] Daniel, K.D. (2018): www.worldbiogasassociation.org/wp-content/uploads/2019/10/carbon-pricing-paper.pdf

[56] https://ec.europa.eu/clima/sites/clima/files/ets/auctioning/docs/auction_revenues_report_2017_en.pdf

5. Creating a supportive policy environment

5.1. Introduction

Biomethane must urgently become a fundamental part of our energy system, to cut emissions in the hardest to decarbonise sectors of heat, transport, waste management and agriculture. The AD industry has a huge untapped potential, but for it to flourish and achieve its potential the government must create a supportive policy environment. Coordinated support will be required to deliver the spectrum of benefits AD provides. Policy needs to be designed in a clever way to build the industry we need. Although financial incentives are initially required to restart the industry and deliver the urgently needed deployment, support must be better targeted at stimulating demand for the many co-products and environmental services of biomethane generation, to create a more independently viable industry.

It is therefore necessary for policymakers and stakeholders to be better coordinated across the following areas to realise the potential of the AD industry:

- waste management;
- agriculture and the food system;
- the national grid, energy transmission systems and the companies involved in those activities;
- research, development and innovation; and
- industry regulation, including environmental standards, permitting and health and safety, including risk management and implications for insurance and finance.

While biomethane generation is a ready to use technology, the above factors need to be addressed to trigger the changes that will propel the industry forward. Above all, our sector will thrive from a long-term government commitment to creating a supportive environment for biomethane generation, and AD more generally. This should be backed up by sustainable policy objectives that commit the UK to more stringent controls on GHG emissions released into the atmosphere.

Policy recommendations:
Delivering the pathway to 2030 depends entirely on the objectives and policies the government enacts now and stands by. It is important that a long-term strategy with specific targets is put forward for the next 10 years. Investors must feel confident that they are operating in a stable environment to invest the necessary resources to unlock the full potential of AD. This needs to be accompanied by a supportive policy environment to deliver the long-term industry strategy and stimulate demand for the many co-products and environmental services of biomethane generation to create a more independently viable industry.

The policies needed to overcome the current barriers to industry growth need to be well coordinated across the different policy areas, to deliver the greatest impact from the public resources involved and to unlock AD's full potential. They should also be accompanied by the removal of tax breaks for the fossil fuel industry, with more targeted measures to address fuel poverty focused on low-income households rather than blanket support to reduce the price of fossil fuels; and the introduction of a robust and ambitious carbon pricing system for the UK.

Our policy recommendations for the AD industry are organised in line with the different policy areas: heat, transport, agriculture and waste management.

HEAT:

- **Immediate interim support beyond March 2021** in the form of an energy tariff to urgently increase deployment, closer to the rates seen in 2013-2015 which delivered deployment of around 100 plants per year, while more tailored policy is developed. Lessons learnt from the RHI and FiT should inform the design of this interim policy, including length commissioning deadlines and tiering of the tariffs.
- **A green gas obligation on the gas grid**, with gradually increasing targets to stimulate demand and a minimum price for certificated gas to provide a level of certainty to investors.

TRANSPORT:

- **Commitment to extending RTFO beyond 2032.**
- **Infrastructure funding** for the development of alternative refuelling networks, delivering biomethane as a transport fuel.
- **Align classifications of waste between government departments** to simplify the participation across multiple incentive schemes, such as RHI and RTFO.
- **A price guarantee should be introduced within the Renewable Transport Fuel Obligation** to provide greater certainty to investors and to ensure a more stable supply of biomethane for transport.

AGRICULTURAL:

- **A renewable biofertiliser obligation** to stimulate the market for digestate and transition towards a more circular use of fertilisers based on nutrient recovery.
- In line with legislation requiring all digestate and manures stores to be covered by 2027, **appropriate support, such as grants, are required to effectively prevent emissions** and draw value from captured gas, without adversely impacting farmers and operators.
- **AD should be included in the Environmental Land Management Policy** in the Agricultural Bill to recognise the benefits it can deliver in terms of reduced on-farm emissions, alongside generating renewable energy and generating renewable biofertiliser.
- **Tighten the end-of-waste standards for digestate**, including restrictions on feedstock contamination, to give farmers greater confidence in the quality of digestate.

WASTE MANAGEMENT:

- **Support for small business and community projects** on circular economy, transforming local waste into local heat and power.
- Encourage the **treatment of all organic wastes through AD**, including manure and slurry, by developing hierarchies, like the food and drinks material hierarchy, for all organic material, and introduce mandatory measures to ensure these hierarchies are enforced.
- **Urgently implement separate collection of food and green waste** and diversion to AD as the optimal treatment method, with the possibility of co-mingled collection in localities with dry-AD infrastructure. Increase producer responsibility for waste collection, reuse and recycling.

OVERARCHING:

- **Targeted innovation funding** to unlock key aspects of the AD industry that reduce cost, including digestate upgrading; biomethane yield; and utilisation of bio-CO_2.
- **Increased administrative capacity in Ofgem** and streamlining of processes to ensure there is confidence that payment will be made on time and accreditation will be received in a timely manner, such as accreditation for innovative new feedstocks.
- **Lower business rates** for the AD industry and review of other tax allowances that could be offered to incentivise deployment.
- **Support best practice by tying policy to independent certification schemes**, such as the Anaerobic Digestion Certification Scheme, to ensure plants are adhering to environmental standards, plant optimisation and health and safety, thus minimising risks and costs.

5. Creating a supportive policy environment

5.2. The existing policy framework: an overview

The United Kingdom is well integrated into the global political structure, participating and at times leading certain trends and commitments towards decarbonisation. There are initiatives at the international, EU and National level that contribute to the overarching policy landscape for biomethane.

UN

As one of the founding members of the UN and one of five permanent members of the UN Security Council, the UK has been part of the United Nations Framework Convention on Climate Change (UNFCCC) that aims to prevent dangerous human interference with the climate system. The 1995 Kyoto Protocol also legally binds the UK and other countries to address the GHG emission reduction targets of 20% compared to 1990 by 2020. Another layer to the UNFCCC is the Paris Agreement that, above all, calls for countries to be transparent in reporting their actions on climate change, as well as implementation efforts and achievements.[57] The UN secretariat has also adopted a 10-year climate action plan, pledging to reduce greenhouse gas emissions by 45% and source 80% of electricity from renewable energy by 2030. The plan commits the UN secretariat to achieve absolute and per capita greenhouse gas emission reductions of 25% by 2025 and per capita reductions in electricity consumption of 20% by 2025. It also pledged to sourcing 40% of its electricity from renewable energy before 2025.[58] Biogas, specifically, is viewed as a bridging technology that will guarantee GHG reductions and promote circular economies.

Another important UN ruling was to impose accountability on businesses and industry. The big multinationals have accumulated large amounts of economic power and influence, including control over natural resources. Value chains are, therefore, to be reorganised in a manner which will avoid a temperature rise above 1.5°C. The construction sector will need to implement zero carbon buildings models. Solutions are also required for the agricultural sector to boost biodiversity and ensure people's diets do not contribute to deforestation but instead enhance natural ecosystems.

The UNFCCC's Global Climate Action Manager, Niclas Svenningsen, recently declared at the World Biogas Summit that biomethane-producing AD is a 'win-win-win-win-win' industry providing all the features of the next generation technology.[59] Support for the industry at this high level must now translate into support at the member state level in practical policies to deliver deployment, and from industry as they make plans to deliver net zero emissions.

EU

At the EU level there are dozens of Directives setting out greenhouse gas monitoring and reporting, the EU emissions trading system, carbon capture and storage, regulation of transport and fuels, ozone layer protection laws, measures on fluorinated gases and activities in agriculture and forests.

The Renewable Energy Directive (RED), first published in 2009, is currently the main piece of legislation that provides an overview of policies referring to production and promotion of energy from renewable sources in the EU. It calls for 20% of all energy needs to originate from renewables by the end of 2019, with at least 10% accounted for from transport fuel. The updated version of the same legislation published in 2018 sets the target of at least 32% of renewable energy before 2030, with a possible revision of targets in 2023. It is, of course, up to the Member States to create concrete policies that best respond to these targets. The EU, however, developed a whole framework that serves as a basis for the Member States. Below is the overview of the most relevant points in the RED for biogas:

- The Commission must consider the inclusion of additional feedstocks, such as waste feedstock and new feedstock innovations, that go beyond bioenergy crops.
- Innovation in advanced biofuels must be encouraged and assessed in terms of GHG performance and sustainability criteria.
- In the case of co-digestion of different substances in a biogas plant, the calculations of GHG emissions must be based on the default formulas provided in the legislation and as per the feedstocks listed.
- Biogas for electricity values from specific feedstocks must be in accordance with the default values set out in the legislation.

Under the current conditions, the UK is obliged to incorporate these directives into national law. Nonetheless, in the context of Brexit it is still unknown how the current legal structure will be impacted.

[57] www.un.org/en/sections/issues-depth/climate-change/

[58] www.climatechangenews.com/2019/10/02/world-promised-un-climate-action-summit/

[59] www.world-biogas-summit.com/press-release-biogas-can-fill-important-place-in-climate-emergency-agenda-says-un-climate-change/

UK

On 27 June 2019 the UK Government passed its commitment to achieve net-zero emissions by 2050 into law as per the Paris Agreement. Reflecting their respective circumstances, Scotland set a net-zero GHG emissions target for 2045 and Wales set its target at 95% reduction by 2050, all relative to 1990.

The CCC[60] appointed to evaluate this policy has assessed the variety of factors contributing to this target and concluded that, fundamentally, the foundations are already in place. This is because a lot of the components required to achieve the net-zero commitment have already seen policy developments. These components are as follows:

- Low-carbon electricity (which must quadruple its supply by 2050);
- Efficient buildings and low-carbon heating (needed throughout the building stock and on a large-scale);
- Electric vehicles (displacement of petrol and diesel cars and vans must be achieved before 2040);
- Carbon capture and storage (CCS);
- Diversion of biodegradable waste from landfill;
- Phase-out of fluorinated gases;
- Increased afforestation (targets of 20,000 hectares/year must be complied with; less than 10,000 hectares planted on average over the last five years); and,
- Measures to reduce emissions on farms.

However, the government is currently not on track to meet its targets. It is clear that these policies must be strengthened through concrete strategic objectives and planning. In particular to support the AD sector in delivering its full decarbonisation potential, policy certainty for heat beyond March 2021 is urgently required, and amendments to electricity, transport and agricultural policy, in the areas set out above, are necessary to provide a supportive policy environment for the AD sector to thrive. Below are some of the policies already in place. These are subdivided into different energy sectors: heat, electricity and transport. Each of these sectors is also attached to other regulations on matters of waste management, environmental permitting and sustainability criteria, animal by-product regulations, and other.

Heat

Support for the Heat sector is primarily in the form of the Renewable Heat Incentive policy, for which spending is only confirmed to the end in March 2021. The scheme is subject to degressions, whereby new applicants to the scheme could experience tariff reductions or increases while the plant was in development. Existing participants on the scheme, who have started commissioning, receive their set tariff for the next 20 years. Under the conditions imposed on 22 May 2018, a Tariff Guarantee was introduced allowing new applicants to secure a tariff rate before their installations are commissioned and fully accredited. The Tariff Guarantee was proposed for 1 year but has been extended until 31 January 2021. There was no degression in July 2019, announced alongside the Tariff Guarantee extension, or in October 2019.

Policy to support renewable heat and biomethane beyond March 2021 remains uncertain.

Transport

To support decarbonisation of the UK's transport sector, the Renewable Transport Fuel Obligation (RTFO) was introduced in 2007. This obligation ensures that a specified proportion of total fuel supplied to transport is renewably sourced. Each year, this quota increases. Renewables must account for 9.75% of a supplier's total fuel in 2020, rising incrementally to 12.4% by 2032[61]. To meet these obligations, fuel suppliers can either source renewable fuels themselves or purchase Renewable Transport Fuel Certificates (RTFCs) from eligible biofuel producers, including AD biomethane plants.

For every kilogram of biomethane supplied, 1.9 RTFCs may be claimed by a plant. However, to reward low-carbon waste management strategies, biomethane derived from waste and residue feedstocks are granted double RTFCs; i.e. 3.8 RTFCs per kilogram of biomethane. The price of each RTFC is market driven, and hence variable over time, yet a ceiling price of 30p/RTFC ensures that the additional costs required to satisfy the RTFO does not overly impact the consumer.

Biomethane producers can earn money from both RTFCs and RHI schemes within a single year. However, a producer must choose one or the other for each quarter; for example, claiming RHI for Q1, and RTFCs for Q2-4.

[60] www.theccc.org.uk/publication/net-zero-the-uks-contribution-to-stopping-global-warming/

[61] https://bit.ly/39zuuRx

Electricity

Support for the electricity sector was in the form of the Feed in Tariff (FiT) and the Renewables Obligation (RO). Both schemes have been closed, on 31 March 2019 and 31 March 2017 respectively. Currently, the Smart Export Guarantee (SEG) is in place for the electricity sector. This initiative will enter into force on 1 January 2020 and is expected to better address the levelisation cost of electricity produced by different renewable technologies. While variability may not be good news for the new developers of AD plants, it will still be possible to submit applications for agile rates to Ofgem. These are intended to guarantee specific arrangements that will reflect the special circumstances of each plant.

Alternatively, there is also a possibility to agree fixed rate tariffs with suppliers, depending on the size of the plant. Power supply companies Octopus and Bulb have already made their tariffs available.

We strongly believe that the SEG will not stimulate, by itself, any new investments in AD in the short term as it does not provide price guarantees, or replace the FiT's generation tariff, making the scheme far less generous and only applicable to electricity that is exported to the grid. It also does not recognise the non-energy benefits of AD (GHG emission reduction, soil health, public health etc.) or support local circular economy projects generating power for local use, from local organic waste.

5.3. Greening the gas grid: incentivising biomethane injection

To increase the proportion of biomethane injected into the grid, it is important to consider the barriers to deployment and grid injection and how a policy can be designed to effectively overcome these barriers. The key barriers to growth of biomethane supply have been identified throughout this report, including:

- the amount of waste feedstocks that is currently not being separately collected, either due to lack of producer responsibility for the waste that they generate and accountability for ensuring it is effectively reused or recycled;
- limited awareness or due diligence regarding the need to separate food waste in both households and industries;
- complexity of guidelines on environmental sustainability, and health and safety criteria, as well as limited administrative capacity within Ofgem to deliver policy for the industry;
- inappropriate business rates for AD as a growing industry;
- the complexity and cost of grid injection;
- no coherent long-term strategy for biomethane form government, leading to stop-start policy support;
- the value of nutrient recycling through digestate and the environmental services provided are not effectively priced into financial decision-making; and
- the high cost of finance and uncertainty around the level of future revenue streams.

The fundamental barrier is that together the factors listed above mean that the financials do not currently stack up for new biomethane projects without support from the government. Urgent action is needed to increase deployment of biomethane projects to help decarbonise the grid. As a ready to use technology, biomethane needs to be an urgent priority to ensure that we can cut emissions as much as possible, as soon as possible. This needs to be done by diverting government spending towards support for biomethane projects. Initially infrastructure spending, or support in the form of a tariff, is necessary to provide certainty to financiers that their investment will pay off in order to increase deployment in the immediate future. Between 2013 and 2015, FiT rates of 10.2-17.5p/kWh and RHI rates of 7.9p/kWh inspired an industry boom, with over 100 plants opening each year. While encouraging, this growth is not sufficient for AD to reach its full potential by 2030. These incentives' rates dropped over time. At its closure, the FiT rate had dropped to just 1.4-4.5 p/kWh and the RHI rate currently sits at 2.2-4.9 p/kWh, significantly slowing industry growth. Since 2018, less than 20 plants have opened each year. Higher incentives are necessary to catalyse plant deployment, attracting international investment and expertise to the UK as well as developing a high-skill industry that can be exported overseas. To inspire industry growth sufficient to reach our 2030 potential, incentives closer to the 2013-15 rates are initially required.

In the short- to medium-term, policy must be designed to significantly improve the financials of biomethane projects to ensure that available funding can be used across as many projects as possible, leading to widespread deployment. To do this it is important to consider how to overcome the barriers identified above, as well as learning from the limitations of the major supportive policies.

There is a clear need to collect all organic waste separately from other waste so that it can be diverted to anaerobic digestion for the production of biomethane. This includes all food and garden waste from households and businesses. There are challenges in collecting all these wastes due to space, cost or feasibility, but all waste that can be collected separately should be, as set out in the Government's food and drink material hierarchy, while new innovative solutions are developed for collecting the more challenging waste streams.

In the early half of the past decade, favourable tariff rates enabled the AD sector to grow substantially. Financing new plants could be precisely planned, where a plant's development and operational costs could be modelled against the available tariffs' price per kWh produced. This certainty and predictability offered by tariff rates strongly promotes investment in the sector, providing the economic security necessary to assure a return on investment. Although the primary objective of increased deployment was well met when tariff rates were sufficient, these schemes did have limitations that need to be resolved as new policy is developed. The following outlines these primary issues and the lessons we have learnt from the RHI and FiT schemes:

- **Rigid commissioning deadlines and degression acted to incentivise the fast construction of AD plants to secure favourable tariff rates, sometimes at the expense of constructional and operational best-practice.** While FiT rates varied over time, it soon became clear that the tariff rates would overall decrease over time. Therefore, since a given rate would be locked in for the following 20 years, there was a significant, long-term financial incentive for a plant to be operational as soon as possible. Less than a decade later, some of these rushed AD plants have deteriorated and face costly repairs if they are to continue operating efficiently and safely. Making the Anaerobic Digestion Certification Scheme (ADCS) a condition of policy will ensure that plants are built and operated according to best practice. In addition, providing longer commissioning deadlines that better reflect the industry standard for developing a plant according to best practice, and restructuring the tariff rate so that plants built quickly are not advantaged, e.g. locking in the tariff rate at the start of the project with a policy equivalent to the Tariff Guarantee.

- **Degression was not very effective at incentivising innovation and cost reduction.** There are a number of stubborn costs in the biomethane sector that need for proactive intervention. It is estimated that the divergence in connection requirements between different gas distribution companies increases the cost of injection by £90,000.[62] The complexity and cost of grid injection can be significantly reduced by standardisation of connection requirements for low-carbon gas generation.[63] The GDNs have already committed to a programme of standardisation, which now needs to be implemented to help reduce this cost. Certain capital costs fundamental to the development of AD, such as concrete, are difficult to reduce, but innovation that moves small digesters towards factory produced units may help to circumvent this cost. Innovation is already providing avenues to cut costs, for example through centralisation of injection. The pilot project at Portsdown Hill was built using innovation funding and this can play a significant role in facilitating falling costs. This is explored in more detail in section 5.5.

- **Lack of government commitment to ongoing support created uncertainty in the industry.** Knowing that the FiT and RHI schemes ended/ will end in 2019 and 2021 respectively, investors have been increasingly reluctant to start new AD projects, waiting for future incentives to be outlined by the government. The favourability of RHI/FiT's replacement schemes will demonstrate the government's level of confidence in the AD industry to help accomplish its environmental targets (e.g. 2050's net zero). Consequently, investors are currently waiting for details of the next schemes to determine the financial and legislative support for the industry, and hence offer certainty regarding AD's long-term future. With stop-start development, growth plateaux can lead to market stagnation and a loss of expertise being passed down to the next generation of AD plants.

- **The tariff schemes based solely on energy production fail to reward the wide-ranging environmental benefits AD offers and does not effectively incentivise the capture of all available feedstocks**, in particular the 91 million tonnes of manures and slurries not treated through AD and the green waste not being captured by dry-AD. The advantages of AD are not limited to the generation of renewable biomethane and/ or electricity. AD also acts as a sustainable waste management system and AD's nutrient-rich co-product, digestate, provides a renewable substitute to artificial fertilisers. The use of digestate as a natural fertiliser can provide significant benefits compared to typical artificial ones: its high organic carbon content improves soil structures; its production is carbon neutral (potentially carbon negative); the presence of trace elements provides essential soil nutrients; and, the costs of key nutrients (NPK) per kg are significantly lower. Overall, AD's ability to cut emissions from the waste and agricultural sectors and provide nutrient-rich fertiliser has not be rewarded through government support schemes. If the value of digestate and other environmental services cannot be effectively priced into the financial equation, it will continue to be very challenging for the financials to stack-up. It is also important that these aspects of the technology are priced properly so that there is a focus on maximising these benefits in a project rather than solely focusing on energy generation. This includes incentivising all available waste feedstocks to prevent their methane emissions, rather than focusing solely on energy production. Policy to price the environmental element of AD is explored in more detail in section 5.6.

[62] Element Energy (2017), Distributed gas sources, Final Report for National Grid Distribution Ltd., SGN, Wales and West Utilities.

[63] www.energynetworks.org/assets/files/gas/Navigant%20Pathways%20to%20Net-Zero.pdf

- **The blanket tiering system disincentivised economies of scale.** While tiering incentives attempts to balance the economies of scale, support schemes can obtain more renewable energy (per £ spent) from larger plants. Where possible policy should be implemented to remain neutral to plant size. Centralised plants fed by a community or cooperative network of farmers can both maximise the feedstocks processed and minimise the financial/ energy costs of building a plant. Overall, less government money would be required to substantially increase the production of biomethane. Alternatively, policy should be designed to more effectively incentivise the appropriate plant size for the situation, such as smaller plants for manure processing and larger plants for municipal waste.

To reduce the cost of finance and increase investor confidence in the sector, the government needs to commit to a long-term sector strategy that sets out their continued support for the industry and an ambitious deployment schedule to meet the industry's full potential to play its part in decarbonising heat, transport and agriculture. Alongside immediate support in the form of infrastructure investment or tariff support, this should set out how to improve market demand for all co-products of the anaerobic digestion process, namely biomethane, bio-CO_2 and digestate, as well as the use of these as feedstocks for biorefinery. This strategy should also set out how to maximise biomethane generation both in terms of capturing all available feedstocks and ensuring that the technology used generates the maximum volume of biomethane from the feedstock available. A major part of this will of course be increasing industry capacity to increase the volume of feedstock processed.

The cost modelling demonstrates the influence of economies of scale on AD finance. Specifically, high capital costs per kW installed and incentives which solely reward energy generation prevent smaller plants, processing 'low biogas yield' feedstocks, from being economically viable. To address this, the government can either: increase revenues of smaller plants by preferentially rewarding waste processed over energy produced; or, reduce the capital expenditure by providing construction grants (and certifying their use over time) and tax breaks.

However, policy must still be designed in a way that encourages the processing of all types of waste feedstock, each of which needs tailored intervention according to the existing regulatory environment, market drivers and financials, as set out below. It is also vital that policy incentivises the adoption of innovative technology that increases the biomethane yield from the input feedstock. Section 5.5 looks in detail at how policy can incentivise innovation.

Manure and farm waste

Manure is the largest untapped feedstock available, but it has a lower energy content than other feedstocks as it has already been digested once in an animal's stomach. Although new technologies are emerging that are significantly improving the energy generation potential from manure, this lower energy content makes it recognising the wider environmental benefits of treating manure through AD particularly important. Farmers need to be incentivised to process manure collected from livestock through AD to avoid the consequent methane emissions, alongside any other farm wastes. Grant funding to support the initial capital investment necessary for on-farm AD or farm subsidies tied to the environmental impact of farm practices, including the capture of this methane, can help to transition farming into a more circular system that generates biogas. This could be linked to the legislation due to be introduced in 2027, that will mandate the covering of manure and slurry stores. Rather than investing in infrastructure to cover the slurry pit and pipe off the gas, small-scale AD could be used instead to maximise the environmental benefit of the investment. There is also scope to incorporate this funding into the Agriculture Bill on exit from the European Union.

Where on-farm AD is too small to justify the capital investment in biomethane upgrading, options to centralise upgrading and injection facilities, using a hub-and-spoke approach, should be explored, including ways that this could be facilitated by government. For larger on-farm AD plants that can upgrade on-site, centralised injection like at Portsdown Hill can help to spread the cost. Another option is to support the development of central AD plants, a model that has been used in Denmark to capture feedstock from a surrounding cluster of farms. This would reduce the cost of processing due to economies of scale and the resultant digestate could be sent back to the farms in returning trucks. This model could also be incentivised by incorporating appropriate management of farm waste into the farm support scheme in the Agricultural Bill.

Food and green waste

A major driver for the food waste AD sector is the supply of feedstock. The most effective way to improve this is by providing funding for the separate collection of food waste and green waste across the UK, whether at the local, regional or national level. It is imperative that these waste streams are collected separately so that a high-quality stream of organic waste can be supplied to AD plants that will generate high-quality digestate, while also minimising the amount of food waste generated.[64] Complementary policies that remove plastics and other contaminates from our food system and consequently from food waste will also help to improve the quality of digestate. This will increase demand for the nutrient-rich natural fertiliser, improving the price received by anaerobic digestion plants for the product. This can also be incentivised by tightening the end-of-waste standards for digestate, PAS110, to give farmers greater confidence in the quality of digestate.

In additional, AD plants which accept food waste are spread unevenly across the UK, failing to match the availability of food waste regionally. There are fewer AD plants per capita in London and south east, compared to the north and devolved nations. Better matching of food waste plant capacity to local waste streams will level out the gate fees received around the country and improve the stability of this revenue stream, making it more dependable over time. Similarly, long-term contracts for feedstock can also reduce the risk of running the plant below full capacity and give investors greater confidence in the project's future revenue streams.

Like with manure, green waste has a lower energy content than food waste so when support focuses strongly on energy generation there is less incentive to incorporate this feedstock in plant operations. However, green waste can be treated through the dry-AD process, which produces a compost-grade digestate. This prevents issues with ammonia and removes the need to use high cost spreading techniques. Coupled with support for energy generation, creating a renewable biofertiliser obligation will increase the market price for high-quality renewable biofertilisers such this and incentivise greater deployment of dry-AD. Capturing green waste introduces a new feedstock into the mix, increasing the total biomethane generation potential if all feedstocks are utilised. Green waste has a higher gate fee than food waste so facilitating a shift to dry-AD could also increase this revenue stream for plants, reducing their dependence on government support, or reduce the gate fee and therefore the cost to local authorities of getting this waste processed.

Sewage

Wastewater treatment is very energy intensive, specifically using a large amount of electricity. The sewage sector, uses 1% of all electricity generated in the UK.[65] Because of this, the majority of sewage AD plants use CHP units, but there are an increasing number of plants opting to upgrade their biogas to biomethane and import electricity from the grid instead of generating it themselves. There are also a number now using a more advanced method of AD, thermal hydrolysis process, which requires heating that cannot be achieved by the residual heat from the CHP process. It therefore makes sense to utilise the biogas to generate biomethane rather than electricity and heat for use in the wastewater treatment process, as this can cut emissions in harder-to-decarbonise sectors than electricity. To incentivise this switch, the total price received from exporting the biomethane needs to be higher than that which they would have to pay for the electricity to power the sewage plant. This will be very dependent on the tariff received for biomethane generation, but also on the electricity price as renewable electricity generation becomes more cost competitive. At this point in time, biomethane generation in the sewage sector will be best incentivised by a comparatively favourable tariff rate.

Recent deregulation of the water industry, as part of Ofwat's Water 2020 Strategy,[66] has promoted new markets in bioresources from sewage and water resources to drive innovation, efficiency and greater resilience. This opening up of the market for sewage sludge has a number of benefits. This is expected to encourage risk to be managed in the best place; deploy skills and expertise better; facilitate economies of scale; extend the range of feedstocks utilised; and encourage a more efficient use of assets. This is expected to lead to consolidation, specialisation, new entrants to the wastewater industry, and the adoption of optimal technology.

Some wastewater companies are incorporating decarbonisation into their business strategies, but this is not happening across the board. The Asset Management Plans (AMPs) that set out the service delivery plans for wastewater companies focus heavily on price controls, and only set out five-year strategies. This short timeframe does not encourage companies to consider the climate impact of their business plans and focuses heavily on the profits for that period. Considering a 15-20-year strategic view; ringfencing funding for a bioresources strategy; and incorporating carbon saving targets into these AMPs would help to divert this waste to the most carbon and resource efficient treatment, AD.

[64] https://wrap.org.uk/sites/files/wrap/Food%20waste%20collections%202020%20report.pdf

[65] www.parliament.uk/documents/post/postpn282.pdf

[66] www.ofwat.gov.uk/wp-content/uploads/2015/12/pap_pos20150520w2020.pdf

Bioenergy crops

Sustainability criteria within biomethane policy needs to have a wider consideration of the way in which bioenergy crops can be sustainability integrated into our agricultural system. The sustainability requirements within the RHI and FiT are fit for purpose if the aim is to limit the use of bioenergy crops in favour of waste feedstocks. It is important that this forms part of sustainability criteria to ensure that waste feedstocks are captured, but this fails to recognise the diversity of possible bioenergy crops. Bioenergy crops can be integrated into a sustainable agricultural system, promoting more diverse crop rotations and sequential cropping, in which three crops might be grown over a two-year period. This can be facilitated by an industry led scheme to certify the sustainability criteria of the feedstock used, similar to the Biogas Done Right Scheme used in Italy. There could then be a differential allowance within the sustainability criteria for policy, making it preferable to grow certified sustainable bioenergy crops. Feedstock innovation is another area that needs to have more effective policy support. The regulatory process to get a new, innovative feedstock certified for use with Ofgem can be subject to significant delay, which has been known to result in plants missing the opportunity to take on the new feedstock. Streamlining this process will facilitate better use of feedstocks, whether new sources are classified as waste or bioenergy crop.

5.4. Incentivising environmental services: beyond pure energy generation

A supportive policy environment for the anaerobic digestion sector must go beyond support for energy generation and consider the environmental services that the industry delivers. These environmental services are set out below, with recommendations for how policy can be designed to better support them.

- **Prevention of methane emissions from organic waste:** Food waste, farm wastes, wastewater and any other organic waste matter emits methane when it breaks down. It is critical that these emissions are avoided, as they are when these organics wastes are treated through AD. AD is already recognised as the optimal technology for recycling food waste within the food and drink material hierarchy. This approach needs to be extended to sewage, farm wastes and green waste, and these waste hierarchies need to be more effectively embedded in our waste treatment systems using mandatory measures to ensure that all unavoidable organic waste is diverted to AD where possible to prevent the associated methane emissions. In addition, a shadow carbon price should be introduced by Defra to pay for methane emission mitigation, such as AD treatment.

- **Nutrient recycling:** As well as preventing methane emissions from organic wastes, AD recovers vital nutrients in these waste streams. These are available in the digestate, a nutrient-rich renewable biofertiliser. As well as ensuring that all organic wastes are treated through AD, to recover the nutrients, nutrient recycling should be incentivised by encouraging the use of digestate and helping to develop the market for this biofertiliser. A renewable biofertiliser obligation is necessary to stimulate demand for digestate and other renewable biofertilisers that displace artificial fertilisers. It is also important that there is appropriate regulation of the market for organic waste recycling, so that there is confidence in the fertilisers generated from waste and that they deliver the necessary benefits to soil health. These standards and regulations should not be developed or implemented at a cost to the producer, as developing a market for the digestate is an important part of delivering AD's essential environmental benefits, and such a cost disincentivises the use of waste feedstocks. Innovation funding to support research into digestate upgrading would also increase the marketability of this nutrient-rich fertiliser. This should include the use of dry-AD to treat food and green waste together, which generates a compost-grade digestate.

- **Creating a circular agricultural system:** AD must be positioned at the centre of new, circular farming systems, ensuring that nutrient cycles are not disrupted and that soil health is prioritised. In addition, treatment of farm residues through AD will cut agricultural emissions and generate local renewable energy. Better regulation of on-farm emissions, such as the upcoming regulation that requires the covering of all manure and slurry pits by 2027, will help to create behavioural change. In addition, AD should be included in the Environmental Land Management Policy in the Agricultural Bill to recognise the benefits it can deliver in terms of reduced on-farm emissions, alongside generating renewable energy and generating renewable biofertiliser.

- **Creating a circular food system:** AD can also sit in the centre of our wider food system, beyond food production, delivering a circular economy model. As far as is possible, food waste should be avoided but while there is still significant food waste generated, and beyond that to deal with unavoidable food waste, AD must be an integral part of our food system. As previously mentioned, policy is necessary to better embed the food and drinks hierarchy into our waste system so that all inedible food waste is recycled through AD. This not only recovers the nutrients but prevents methane emissions from the waste and generates renewable energy. For this to be achieved all food waste must be separately collected. Households and businesses need to be educated about the importance of separately collecting food waste, and how this waste is used to generate energy, cut emissions and recover nutrients to the soil. If this is not sufficient to deliver the necessary behavioural change, alternative models will need to be explored to ensure food waste is collected separately, such as small monetary benefits like discounts as an additional incentive, charging systems for waste collection that incentivises separation, and/or tax breaks for businesses who are dealing with their food waste sustainably.

- **Delivering environmental best practice:** AD plants can improve environmental outcomes by operating according to best industry practice. This can be in terms of environmental management and standards, and in terms of plant optimisation to minimise down-time and maximise yield, to generate as much biogas as possible. While the regulatory framework provides some of these standards, they only go so far and are not always straightforward. To ensure the industry is delivering to the highest standards, the Anaerobic Digestion and Bioresources Association (ADBA) has developed the Anaerobic Digestion Certification Scheme (ADCS) with regulatory stakeholders including the Environmental Agency (EA). The certification scheme provides an independent audit for plants to ensure they are meeting industry best practice for environmental management and plant optimisation, as well as health and safety. Policy can be used to ensure that plants are operating in line with best practice by creating conditional incentives that are tied to independent certification schemes, such as the ADCS.

5.5. Incentivising Innovation

Research and innovation drives evolution and growth within an industry; capable of optimising systems, enhancing efficiencies, and creating new market opportunities. There is a lot of potential to improve each stage of the AD process, from sourcing feedstock to distributing digestate (and everything in between), and hence create a more circular economy. However, experimentation can be risky to an individual operator. Financially, new equipment and infrastructure can be costly, and logistically, new techniques can affect operational productivity. Therefore, support is required to minimise the onus placed on operators to improve the sector.

The nature of research and innovation means that some projects will be successful, while others will not. While significant progress can be achieved through learning in either case, this uncertainty can be financially risky. Private investors may be apprehensive to spend on research and innovation that may 'fail', and operators may be unwilling to deviate from working processes. As such, economic incentives are required to promote this crucial research and reduce risk. These incentives must not be 'success'-dependent. The government can help facilitate this work through funding applications, whereby money is not expected to be repaid (at least in full), potentially in conjunction with tax breaks to ease operational expenditure while research is being carried out.

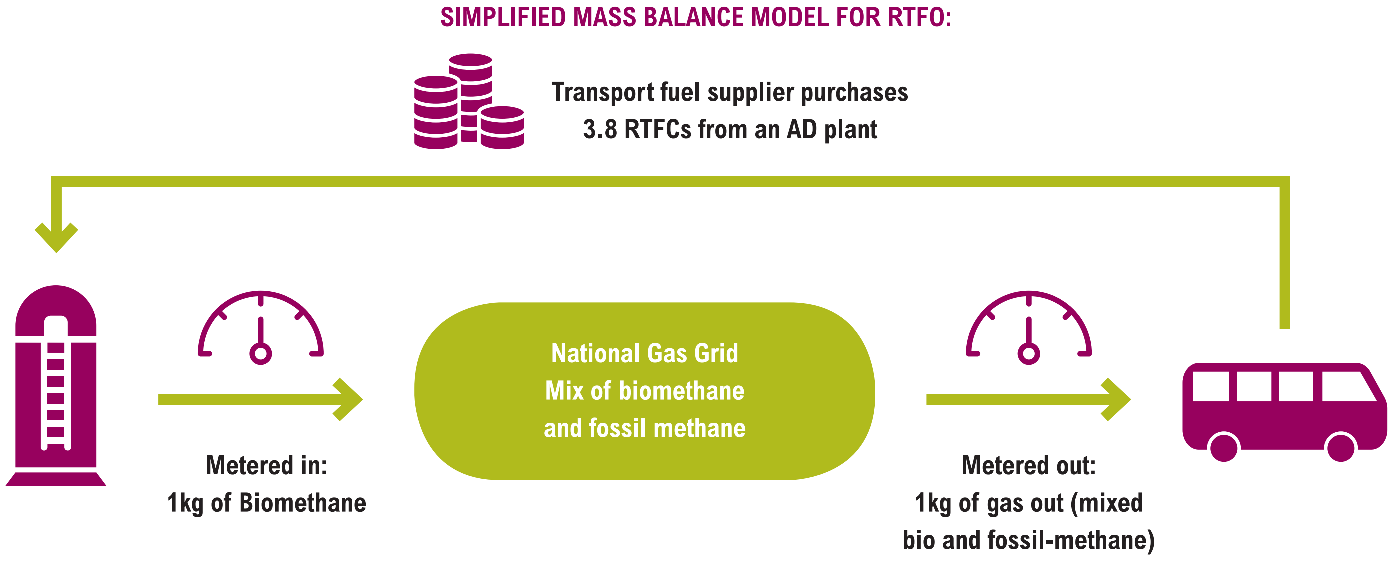
Government funding for scientific research or innovation projects can help bolster and improve the AD industry, working to secure a greater proportion of renewable heat for the UK. Independent research can unlock the full potential of waste, and develop new-and-improved practices. Research grants also provide high-skilled jobs within the bioeconomy, helping to ensure that the UK becomes a world-leader for renewable expertise and knowledge. It is subsequently important that findings from the academic community are communicated to the AD industry and commercialised, enabling their findings to be put into action. As previously discussed in Section 3.6, funding is also required to connect these communities, to propel AD to its full potential.

Every government policy attempts to address a specific issue yet can inevitably introduce different, sometimes unforeseen, issues. In these cases, innovation can also help overcome these new obstacles. To minimise capital requirements and investment risk, low-tech solutions and innovation may also offer more affordable, and hence profitable, waste management options. For example, recent legislation stipulates that all slurry pits and manure heaps are required to be covered by 2027 to cut ammonia emissions. Once covered, biogas may be pumped away and used as appropriate. At the very least, simple solutions, such as this, may support a more comprehensive and low-risk shift to biomethane nationwide. However, AD remains the most efficient means of producing biomethane from organic material and must remain the goal for available feedstocks.

5.6. Market mechanisms: certification, pricing and trading schemes

Financial incentives in the UK generally fall within one of two categories: a fixed tariff (e.g. RHI, FiT), or market-driven pricing (e.g. RTFC, SEG). As exemplified by the latter, there has been a recent shift in policy towards more market-driven support schemes. By placing an obligation on energy suppliers to meet green quotas, the demand for (and hence price of) renewable energy increases, creating an additional revenue stream for AD plants without committing government funding.

Certificates, such as RTFCs, and verifying a plant's green credentials through licenses are the primarily means for verifying that the green energy bought and sold originates from renewable sources. They also ensure that the sustainable outputs are consistent and meet the quality standards of their fossil fuel-derived counterparts. Within a market of certificates and plants licensed to produce renewable energy, mass balance systems can be implemented. By tracking electricity and biomethane fed in and extracted from the national grid, suppliers can purchase energy from AD plants without the need to physically transport fuel around the country; i.e. the energy's green credentials are being bought to contribute towards a supplier's obligations. Overall, this system increases the network efficiency, making best use of the current infrastructure.



Market-driven pricing, however, negates the strongest advantage of fixed tariff rates – the financial stability and certainty required to secure the level of investment required to deploy new plants and deliver industry growth. This stability is also necessary to bring down the cost of investment, as it reduces financial risk, which is currently a significant cost for developers. Energy prices per kWh can fluctuate significantly according to countless geopolitical and commercial factors. While a government supports the market-driven system by setting the suppliers' renewable obligations, unforeseen circumstances may affect market prices in the near- and long-term, driving financial uncertainty. Given the severity of the climate emergency and the UK's commitment to net zero 2050, it is most likely that the demand for renewable energy will only increase – and with it, the value of certificates. AD is in a particularly strong position to de-carbonise difficult sectors, such as domestic heating and transport, where biomethane can provide a ready to use alternative to fossil natural gas. Nevertheless, this uncertainty can make securing investment based on certificates alone challenging and given the urgent need to significantly increase deployment, it is not enough to leave this to market forces.

To promote AD growth within a market-driven support scheme, it is important for the size of obligations to be balanced with the capacity of the renewable energy sector. If the obligations are too low, the demand and price for renewables are unlikely to be enough to sustain the industry. However, if the obligations are too high, the elevated demand and price for renewables may be unfairly passed on to the consumers, placing the onus to reduce emissions on the public. To prevent the latter, the RTFO has implemented a price cap of 30p per certificate. However, there is no policy currently in place to provide a minimum price per certificate, which would act to protect the income of renewable energy producers and minimise risk. A price guarantee would also support sustainable growth of the AD industry in the long-term, providing financial security to investors and operators alike. Other countries with similar schemes have delivered this kind of price certainty with premiums, a payment paid by the government on top of the market price; top-ups, a variable payment paid on top of the market price that maintains the overall certificate revenue at a particular level; or a minimum price that would prevent the market price dropping below a fixed level.

With regards to electricity production and the SEG, prices can vary substantially according to the supply and demand of electricity on a weekly and monthly basis. Without capacity to store electricity, prices can drop below zero if generation exceeds demand; typically, during summer periods with high wind and solar electrical production. This means producers would have to pay suppliers to export their electricity. However, here lies another advantage of AD energy generation: biogas can be easily stored, and its energy converted into electricity at periods of peak demand and price. Moreover, the SEG guarantees producers of renewable energy never have to pay to export their energy, placing a minimum price of zero p/kWh. This policy acts to prioritise this energy generation over that derived from fossil fuels and alleviates concerns of operators about paying to export.

The world is finally recognising the cost of emitting carbon into the atmosphere – realising its catastrophic impacts on every aspect of socio-economic and environmental systems. Consequently, economic policies are being explored and introduced to place value in carbon, reflecting the financial cost of its impacts when emitted. As discussed in Section 4.7, taxing carbon emissions and/or trading allocated carbon credits reflect the two primary mechanisms of incorporating carbon pricing into the current economic system.

Carbon pricing balances the field of energy production, improving the ability of renewable energy generation to compete with fossil fuels; increasing the cost per kWh of fossil fuels and, in the case of carbon trading, increasing the potential income per kWh of renewables. However, to be truly effective at cutting greenhouse gas emissions, carbon pricing schemes need to holistically consider the full carbon cycle, and not simply support low carbon energy. As discussed throughout this report, AD's ability to reduce greenhouse emissions go far beyond providing renewable gas and electricity. It prevents the release of methane, which is far more potent than CO_2 as a greenhouse gas, into the atmosphere from rotting waste and reduces the need to manufacture energy-intensive artificial fertilisers. Consequently, these carbon-cutting benefits across multiple sectors should be acknowledged and rewarded within future carbon pricing schemes.

In addition, blockchain, financial services and green certificates trading are becoming increasingly more relevant as the market for bioenergy certificates and carbon emissions, as tradeable commodities, develop. The government will be required to impose certain rules and regulations to guarantee the legitimacy of these services.

5.7. Infrastructure development

Our current infrastructure is very much based on the exploitation of fossil fuels and the transition to alternative infrastructure must be achieve with a minimal disruption to business, in a way that does not create an environment of uncertainty. Policymakers are in the best position to promote change by creating incentives, correcting market failures and strategically directing the market. Given the private nature of the energy and fuel distribution networks, the government is, above all, expected to orchestrate increased demand for renewables. Under today's conditions, energy originating from fossil fuels is cheaper than energy originated from the AD sector. Given that Ofgem takes decisions on price controls and enforcement, additional support towards the AD industry is required in order to promote its market competitiveness.

Infrastructure that can serve different communities must be put at the top of the government's agenda. Different regions within the UK have their economic activities organised in accordance with population density, business models and opportunities available, as well as cultural background and other historically determined factors. It is, therefore, worthwhile evaluating regional development on the basis of the existing resources and maximum utilisation of those resources. The UK gas grid is already very much ready to transport biomethane to consumers but certain barriers need to be overcome to reduce the cost, such as standardisation of grid connection requirements and restructuring of the metering systems. Refuelling infrastructure for biomethane as a transport fuel requires further incentives.

Tax reductions, grants, loans are essential for refuelling infrastructure development. The promotion of public-private partnerships to develop the sector can also significantly propel the transition, with the government serving as lender of last resort and allowing the use of state assets for free or at less than market price. Infrastructure funds are another route that can significantly propel investment, as well as higher rates of renewables obligations imposed on enterprises, which will stimulate demand for alternative infrastructure. Penalties on lack of compliance must also be implemented. Schemes to incentivise retrofitting of existing vehicles on the market will also increase demand for biomethane as a transport fuel and increase the demand for alternative infrastructure.

In addition, more can be done to utilise existing public infrastructure, such as schools, universities, and hospitals, etc. A lot of food waste is generated on these sites and these public institutions could showcase the numerous benefits of on-site AD, for local renewable energy generation, nutrient recycling and waste management, while also acting as a public education tool.

Smaller energy producers must also be incentivised to respond to local needs allowing the off-grid regions to ensure emissions-free energy autonomy. Small businesses should be allowed a certain competitive advantage on a regional basis in order for them to develop local business activity and common infrastructure. It is possible that this type of infrastructure will allow for smaller and medium producers of biogas with access to alternative sources of feedstock to emerge in order to respond to the local needs of their communities. This may potentially displace the existent structures of businesses based on fossil fuels that previously monopolised the supply.

Index of Terms

Anaerobic Digestion (AD)	the breakdown of organic matter in the absence of oxygen, which produces biogas and digestate
Bio-CO_2	carbon dioxide produced in anaerobic digestion, which makes up a component part of biogas (25-50%), and can be separated out in the biogas upgrading process for use in industrial processes
Bio-CNG	compressed natural gas made from biomethane, often used as a transport fuel
Bioenergy Crops	crops grown to generate nature-based, renewable energy
Biogas	a product of the anaerobic digestion process and is composed of a mix of methane (50-75%), carbon dioxide (25-50%) and small amounts of other gases.
Bio-LNG	liquefied natural gas made from biomethane, often used as a transport fuel
Biomethane	produced by upgrading the biogas created in the process of anaerobic digestion, which makes up a component part of biogas (50-75%) and can be injected directly into the gas grid or converted into bio-CNG or bio-LNG for use as a transport fuel
Digestate	the residual organic matter produced in the anaerobic digestion process, which is rich in nutrients and can be used as a natural fertiliser
Direct Air Capture	a process of CO_2 directly from the ambient air (as opposed to capturing from point sources) and generating a concentrated stream of CO_2 for sequestration or utilisation
Greenhouse Gases (GHG)	gases, such as carbon dioxide, methane and nitrous oxide, which drive climate change when emitted
Just Transition	a green energy transition that proactively manages this inevitable shift in a way that respects not just environmental urgency but also equality, social justice and democratic voice[67]

[67] https://neweconomics.org/uploads/files/Just_transition_FINAL_ONLINE.pdf

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