The potential for renewable gas in the UK

A rent-seeking anatomy

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Introduction/Summary

In January 2009, National Grid published a report titled *"The Potential for Renewable Gas in the UK*", produced for them by Ernst & Young (NG/E&Y).[1] The report argued that renewable gas could make a major contribution to the UK's gas requirements by 2020: 15% of domestic gas as a "baseline", up to 48% in their "stretch" scenario. It estimated the cost at £10bn, and claimed this would require a similar level of support to that offered to offshore wind.

This was not merely a piece of academic or market research. A government measure to encourage renewable heat seemed likely finally to materialise. The NG/E&Y paper was intended to influence the development of that measure, and was effective in that regard.

The paper's estimates for the potential production of renewable gas for grid injection were unrealistic. We are now in their target year, and actual performance is way below even their "baseline" projection.

million m^3 p.a.	*2009 Projection of 2020 Potential*		*Estimated 2020 Actual*
	National Grid	*Credible*	
Digestion			
Sewage / waste water	270 - 629	0 - 100	20[2]
Manure – dairy and cattle	254 - 507	0 - 350	5
Agricultural waste	234 - 967	0 - 100	5
Food waste	729 - 1,333	250 - 750	250
Biodegradable waste	1,042 - 8,328	0 - 100	0
Energy crops	-	250 - 2,500[3]	250[4]
Gasification			
Biodegradable waste	-	0 - 1,600	0
Wood waste	1,253 - 2,697	0 - 500	0
Miscanthus	1,845 - 3,971	0 - 1,600[3]	0
Total	**5,625 - 18,432**	**500-6,000**	**530**
% total UK gas demand	*5 - 18%*	*0.5 - 6%*	*0.7%*[5]
% residential gas demand	*15 - 48%*	*1.4 - 17%*	*1.9%*[5]

[1] No longer available at: http://www. nationalgrid.com/NR/rdonlyres/9122AEBA-5E50-43CA- 81E5-8FD98C2CA4EC/32182/renewablegasWPfinal1.pdf. Uploaded to https://www.c4cs.org.uk/sites/default/files/2020-01/renewablegasUK.pdf

[2] Sewage biomethane plants identified at Didcot, Bristol, 5 Severn & Trent Water sites, and Howdon. Some co-digesting with food etc. Estimated share for sewage.

[3] The upper limits for energy crops for digestion and miscanthus for gasification are mutually-exclusive, i.e. there is a limit to the total amount of land that can be diverted to energy crops without excessive impact on other sectors. The total reflects this mutual exclusivity.

[4] 57,000 ha of maize for digestion in 2018. Proportion for biomethane vs electricity/heat unknown.

[5] Gas demand turned out lower than National Grid projected, so the proportion is slightly higher than the credible minimum projection, even though the total is close to the minimum.

This is not just with the benefit of hindsight. We look in detail in this report at the information that was available and the maturity/credibility of the technologies at that point, and illustrate that no reasonable person would have projected such high figures for either their “baseline” or their “stretch” scenarios.

The report argued that, whilst total investment of £30bn was required, the net cost was only £10bn because £20bn would be required anyway for upgrading our waste disposal systems. There was a disconnect between this figure and the estimated £100/MWh that was required to deliver the higher end of the projection. Accounting for wholesale values, that implied an unmentioned subsidy-requirement of around £15bn p.a., a far cry from the £10bn capital cost on which the report focused. And that was on the basis of costings that were not realistic.

Two of the feedstocks (food waste and biodegradable waste) were costed so cheap that they were expected to contribute substantial quantities of gas at energy costs below market values. The fact that they had not already done so should have been an obvious indicator that the assumptions that produced these numbers were wrong. In the event, the RHI showed that food waste needed something over £40/MWh to be viable within the limited resource constraints, and support has never yet reached the level at which the gasification and methanation of biodegradable waste is viable.

The estimated energy values required for some other feedstocks were both unsubstantiated (how could one cost non-commercial technologies like gasification and methanation?) and unjustifiable (the implicit level of support far exceeded any credible carbon price). Sure enough, these feedstocks and technologies, which constituted the majority of NG/E&Y’s projected gas, delivered almost nothing by 2020.

In reality, the likely contribution of biomethane from AD, under conditions where most easily-putrescible material was digested, was not hard to estimate. We show how the 2020 outturn could have been estimated easily to a reasonable degree of accuracy in 2009.

The report was nevertheless highly influential. It was cited in numerous academic papers, pressure-group studies and government publications.

In mid-2008, the British government held a consultation on a Renewable Energy Strategy. Amongst a host of supporting research, biomethane was only mentioned once, and that was to dismiss it as “not commercially competitive”.

The NG/E&Y report was published in Jan 2009. The government’s response to the consultation (and further supporting research) was published in Feb 2009. In that response, the government had changed its position on biomethane, which was now expected to contribute a few TWh at modest cost.

The design of the Renewable Heat Incentive (RHI) evolved over the following two years before its launch in Nov 2011. Over that period, expectations of the contribution of biomethane were increased, and the level of support was almost doubled, both beyond what the government’s research had indicated was credible. Those involved at National

Grid, their counterparties in government, and third-party observers all felt that they had been influential in the process.

By the late 2010s, experience showed how far from reality had been the projections in the NG/E&Y report. Far from recognising that motivated modelling is a bad way to approach policy design, National Grid and Cadent produced new reports claiming to show how their grids could be decarbonised and play the dominant role in decarbonising heat. Academics and government happily cited these studies as they did the 2009 report as credible projections to build into the UK's plans for decarbonising heat and the gas network.

There is no such thing as institutional learning or memory; only the continuous repetition of the same mistakes.

1 Context

British governments had accepted the need to reduce carbon emissions to address climate change since the late 1980s. When privatisation revealed that nuclear electricity was not actually "too cheap to meter" but rather too expensive to sell, global warming provided a useful pretext for subsidy.

Calling the support scheme the Non-Fossil Fuel Obligation (NFFO) had the unintended effect of making it difficult to explain why nuclear was eligible but renewables were not. And so the first support scheme for renewables was introduced by accident with an exclusive focus on electricity technologies.

NFFO was replaced by the Renewables Obligation (RO) in 2001. The RO (and other government analysis of energy) retained the British government's myopic focus on the 20% of our energy that we consume as electricity.[6] But the pressure mounted during the 2000s to do something about the other 80% (roughly 50:50 heat and transport).

The Royal Commission on Environmental Pollution's 22nd report (*Energy – The Changing Climate*), published in 2000, highlighted technologies such as renewable heat, which had so far been ignored by government policy.[7] The government accepted the report. No action was immediately forthcoming, but the need eventually to tackle the subject had been established.

An Early Day Motion (signed by 238 MPs including Boris Johnson) in November 2004 noted the lack of action and called for the Government "to extend the renewables obligation to support renewable heat".[8]

By 2005, the introduction of some mechanism to encourage renewable heat seemed sufficiently certain that the debate on its structure was under way. The early frontrunner – an obligation mirroring the RO – was dismissed as "unworkable" by "Farmer" Ben Gill, the leader of the government's Biomass Task Force.[9]

The UK's Energy Review of 2006 was mirrored in the EU.[10] Both recognised the need to go beyond electricity. The European review led in 2007 to a proposal (enacted in 2009) to

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[6] The Cabinet Office Performance and Innovation Unit's (PIU) 2002 Energy Review observed that "The potential for switching to low carbon fuels for heating is probably limited." The ambitions were limited at that time to a domestic ambition to reduce CO_2 by 20% relative to 1990 levels, exceeding its 12.5% Kyoto commitment, which could be achieved by a primary focus on electricity. Energy security was considered an equal priority and domestic gas heating was seen as largely unassailable for that purpose. http://www.gci.org.uk/Documents/TheEnergyReview.pdf

[7] https://webarchive.nationalarchives.gov.uk/20110322143813/http://www.rcep.org.uk/reports/index.htm. The most significant recommendation of the report was to aim for a 60% reduction in greenhouse gas emissions by 2050, relative to 1990 levels. Once the government accepted this target, it was inevitable that they would have to look beyond the 20% of final energy consumption and 1/3 of carbon emissions attributable to the electricity sector.

[8] https://edm.parliament.uk/early-day-motion/178/renewable-heat-obligation

[9] https://www.endsreport.com/article/1563335/biomass-task-force-says-heat-obligation-unworkable

[10] https://europa.eu/documents/comm/green_papers/pdf/com2006_105_en.pdf
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/272376/6887.pdf

replace the 2001 Directive on Renewable Electricity with a broader Renewable Energy Directive (RED). The RED obliged countries to set out their intentions to encourage renewables in heat and transport as well as electricity.

Two decades after the UK recognised the need to reduce carbon emissions, some mechanism to encourage that in the heat sector was becoming imminent and inevitable by the late 2000s.[11] The consultation (published in June 2008) on a Renewable Energy Strategy included detailed consideration of the barriers to development of the market to date, and how they might be overcome, with a view to bringing forward concrete proposals.[12]

This was the environment into which National Grid launched its "Potential for Renewable Gas" paper.

2 The evolution of ideas on decarbonising heat

The earliest British thoughts on renewable heat focused on biomass.[13] The PIU's 2002 Energy Review, in broadly dismissing heat decarbonisation, suggested that "the main possibilities seem to be some limited use of biomass, and in the much longer term, the possible use of hydrogen". They also considered that "if low carbon electricity were cheap enough, it could be attractive to switch to electricity from direct sources of heat, but this is at present a distant and uncertain prospect." Other than waste heat (e.g. CHP and EfW), no other technologies were considered.[14]

This dismissive attitude contradicted European experience, where renewable heat was already a substantial contributor, dominated by biomass. The government came under pressure to reconsider its assessment.

To this end, reflecting the assumption that biomass was the key technology, it formed a Biomass Task Force in 2004, chaired by former NFU President Sir Ben Gill. With good agricultural forthrightness, the Task Force's 2005 report was robustly critical of the assumptions about and dismissal of renewable heat in energy policy to date.[15]

It estimated the potential of biomass heat (and/or CHP) as 44-51 TWh of "dry" material (i.e. favouring thermal technologies) and 4-5 TWh of "wet" material (i.e. favouring biological

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[11] The Stern Review of 2006 provided an additional impetus to strengthen and broaden climate measures, particularly as it placed a high social cost on greenhouse-gas emissions, which could be used in Treasury Impact Assessments to place a nominal net social benefit on relatively expensive measures.
[12] https://www.gov.uk/government/consultations/progressing-our-renewable-energy-strategy
[13] The earliest British thoughts were around two decades later than the earliest thoughts on the subject in some of the UK's neighbours. Despite (or perhaps because of) its proximity to Russia and its cheap gas supplies, renewables already provided more than half of Sweden's heat by the mid-2000s, while gas provided almost none of their heat. See Sweden's National Renewable Energy Action Plan, https://ec.europa.eu/energy/sites/ener/files/documents/dir_2009_0028_action_plan_sweden.zip
[14] CHP = Combined Heat and Power. EfW = Energy from Waste.
[15] https://www.cla.org.uk/sites/default/files/A4809049.pdf
The task force's report was slightly fore-shadowed by a short report on *Biomass as a Renewable Energy Source* by the Royal Commission on Environmental Pollution in 2004: https://webarchive.nationalarchives.gov.uk/20110322143813/http://www.rcep.org.uk/reports/sr-2004-biomass/documents/BiomassReport.pdf

technologies). On grounds of efficiency and availability, it argued that conventional biomass-heat combustion technologies were much the largest opportunity,[16] but also advised that the limited potential of anaerobic digestion of "wet" material could be improved by a focus on / incentivisation of greater efficiency. It assumed that the gas would be used to generate electricity, with heat recovery where possible, or a possible alternative use as a vehicle fuel. Injection into the gas grid was not considered, unsurprisingly as (a) the potential was considered insignificant relative to the national demand for gas, and (b) to achieve even that limited amount it was assumed a substantial proportion of the market would be small, on-farm units (i.e. likely off-grid).

Around the time of the Task Force's report, the government was reconsidering its attitude to another set of energy (including heat) technologies encompassed by its Microgeneration Strategy.[17] A supporting report by Element Energy for the Energy Saving Trust judged that renewable heating (by which it meant biomass heat and ground-source heat pumps) "has significant potential for CO_2 reduction".[18]

Driven by the government's objective to decarbonise more than could be achieved through electricity alone, the hitherto-ignored potential of a suite of renewable-heat technologies was being recognised. All of the technologies under consideration were alternative rather than complementary to the dominant heating technology: natural gas. Deep decarbonisation required more than the 20% of heat that was off the gas grid to be decarbonised.

Gas heating had many benefits, such as cost, air quality, customer satisfaction and supplier convenience. Many groups foresaw considerable pain switching users from gas to other heat sources. Customers would not like giving up the convenience. The government were not keen on the political impacts of imposing something unpopular, nor the cost to the economy and/or the Exchequer of driving people away from the cheapest solution (ignoring social costs of carbon) to more expensive and difficult options.

But even more directly concerned were the companies whose income was dependent on the gas market – gas suppliers and gas network operators. The suppliers at least had limited fixed costs and could relatively-easily scale back their gas-supply activities and branch out into other heat sources if the market (steered by government interventions) dictated. But the network operators faced high fixed costs to set against dwindling revenue if gas heating were displaced by renewable heat. For them, it was an existential matter to persuade the government to follow an alternative path that delivered decarbonisation through their network.

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[16] The emphasis was on conventional heat technologies because the Task Force noted, with agricultural realism, that the industrial-policy efforts (e.g. under the Bio-Energy Capital Grants Scheme) to leapfrog mature technologies developed in other countries by subsidising research efforts into technologies that maximised electricity production had by-and-large failed.

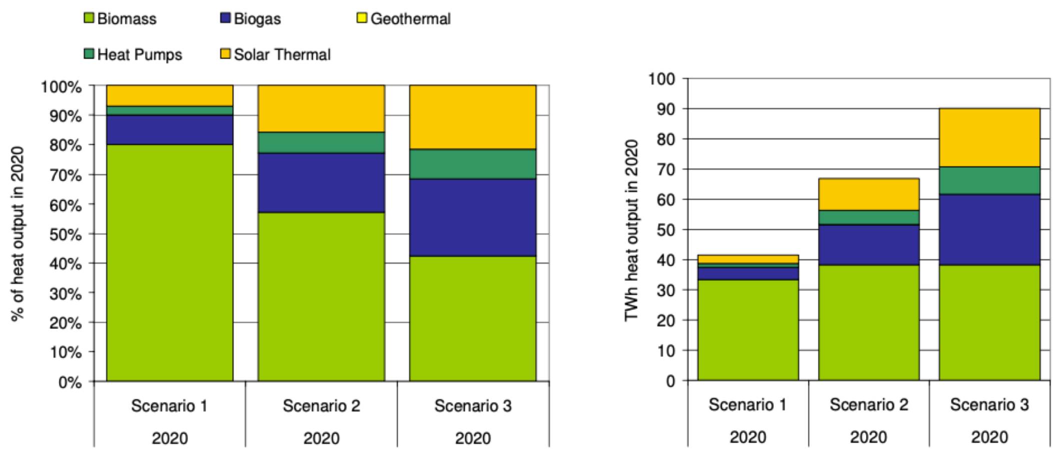
[17] https://webarchive.nationalarchives.gov.uk/20070603203111/http://www.dti.gov.uk/energy/sources/sustainable/microgeneration/strategy/page27594.html

[18] https://webarchive.nationalarchives.gov.uk/20070603203111/http://www.dti.gov.uk/files/file27559.pdf The main report also considered the potential of solar thermal, although it noted it was further from viability.

It was less important for that path to be realistic. It would solve their problem simply by diverting government support from the technologies that would eat their market, whatever the split between green gas and fossil gas ended up being transported in their network. To serve its purpose, it simply had to make the potential sound large and painless enough that the plans for alternative (more politically painful) technologies were scaled back.

The supporting studies for the 2008 consultation on a Renewable Energy Strategy looked in more detail at the potential for biogas for the first time. They found that the potential was greater than previously thought in the most optimistic scenario: around 24 TWh in 2020.[19]

Figure 2 Output mix in 2020



Source: BERR and Enviros.

However, the aggressive assumptions required to achieve this figure caused enough discomfort that Enviros sounded a note of caution:

> *The level of biogas use illustrated in Scenario 3 above represents our view of the maximum potential heat output from biogas by 2020. It is built on extremely strong assumptions for the level of feedstock available for renewable heat including: 100% of sewage arisings; a gradual shift from CHP to heat use for landfill gas; approximately one third of theoretical food waste arisings; and energy crops grown on 157,000ha of land.*

Despite these aggressive assumptions, the best that was hoped for biogas was around 25% of renewable heat in 2020. Total renewable heat in 2020 was expected to contribute at most around 15% (90 TWh) of total heat demand, putting biogas's greatest conceivable contribution to the total at under 4%.

The potential was expressed as 24 TWh rather than 2.4 billion m^3 of gas (the rough equivalent) because the analysis indicated that "Biogas upgrade to bio-methane does not appear commercially competitive due to the costs of upgrading and distribution."[20] The gas

[19] Chart from Enviros Consulting, *Barriers to Renewable heat – Executive Summary*, p.9

[20] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/42959/1_20090501125256_e____4BiogasFinalReportv40.pdf p.5

was expected to be used on-site to generate heat and/or power where feasible, but as those opportunities were thought to be "niche", the main use would be CHP feeding district heating.

Biogas was now on the radar for support as a heat fuel, but this was no consolation to the gas network operator, as it had simply been added to the list of technologies that would compete with the gas supplied over their network. Even if they argued successfully that the economic assessment of grid injection was unduly pessimistic, the resource assessment was unhelpful, because <4% (at best) of the UK's heat would not be enough to avoid the need to encourage other technologies that would eat their market, and they could not claim that their network could be decarbonised to any significant extent.

They needed a report that claimed that a large enough proportion of the UK's heat could be decarbonised by injecting biomethane into their grid that the government's appetite for encouraging alternatives was significantly reduced. Ernst & Young agreed to supply it.

3 National Grid / Ernst & Young's claims for biomethane vs reality

3.1 The claims

National Grid and Ernst & Young concluded that:

> *Renewable gas has the potential to make a significant contribution to the UK's renewable energy and carbon reduction targets for 2020. And in the longer term, with the right government policies in place, renewable gas could meet up to 50% of UK residential gas demand.*
>
> *In terms of the cost to the UK of delivering renewable gas, it is estimated that the marginal cost… would be in the region of £10bn. This cost compares well with the likely cost of delivering other large scale renewables such as wind. The unit cost of renewable gas would be of a similar level to the cost of other sources of renewable energy which are currently supported with subsidies.*

They petitioned for the following policy measures:

> ◆ *A commercial incentive for renewable gas producers to upgrade and grid-inject their gas rather than generate electricity which is currently incentivised under the RO scheme despite being a generally much less efficient use of the valuable waste stream;*
>
> ◆ *A comprehensive waste management policy for the UK to ensure that each waste stream is directed to the most appropriate technology to maximise energy recovery and recycling*

> ◆ *A regulatory framework to provide incentives and to clarify the roles and responsibilities of the gas transporters with respect to renewable gas connections;*
>
> ◆ *Continued support for R&D in renewable gas production and upgrade technologies.*

And they highlighted that the purpose of the report was to persuade the government to reduce its expectations of other technologies:

> *Renewable gas…is a unique, large scale solution which unlike other options such as district heating and heat pumps utilises existing heat infrastructure (i.e. gas grids) already largely paid for by the consumer. So renewable gas does not require consumers to find the money for new heating installations*
>
> *in the home and also avoids the disruptive road works that would be required to build more network infrastructure.*

There was nothing subtle about the rent-seeking. Nor was there much credible analysis underpinning it.

The core of their claims was an analysis of the resource, which claimed much larger numbers than previous research. The biggest factor in this was the inclusion of gasification gas as well as digester gas, as this allowed them to count feedstocks that could not realistically be converted to gas by AD. In the table below, the last two items were intended for gasification. But they also upgraded significantly the claimed potential for biogas.

> *The "Baseline" scenario considers a world where a significant proportion of waste still goes to landfill, is not sorted appropriately or is still used for electricity generation – rather than being used for renewable gas production. The "Stretch" scenario aims to see what could be achieved with renewable gas if policies are put in place to ensure that all waste is directed towards renewable gas production and that the most appropriate (high yielding) technology is used for each type of waste.*

Potential renewable gas production scenarios - volume of upgraded biomethane

	2020 (baseline) million m³	2002 (stretch) million m³
Sewage / waste water	270	629
Manure - dairy and cattle	254	507
Agricultural waste	234	967
Food waste	729	1,333
Biodegradable waste	1,042	8,328
Wood waste	1,253	2,697
Miscanthus	1,845	3,971
Total	**5,625**	**18,432**
As % total UK gas demand (~97bcm)	**5%**	**18%**
As % residential gas demand (~35bcm)	**15%**	**48%**

How does this compare with reality?

3.2 Sewage / waste water

NG/E&Y potential: 270 - 629m m^3

Credible potential: 0 - 100m m^3

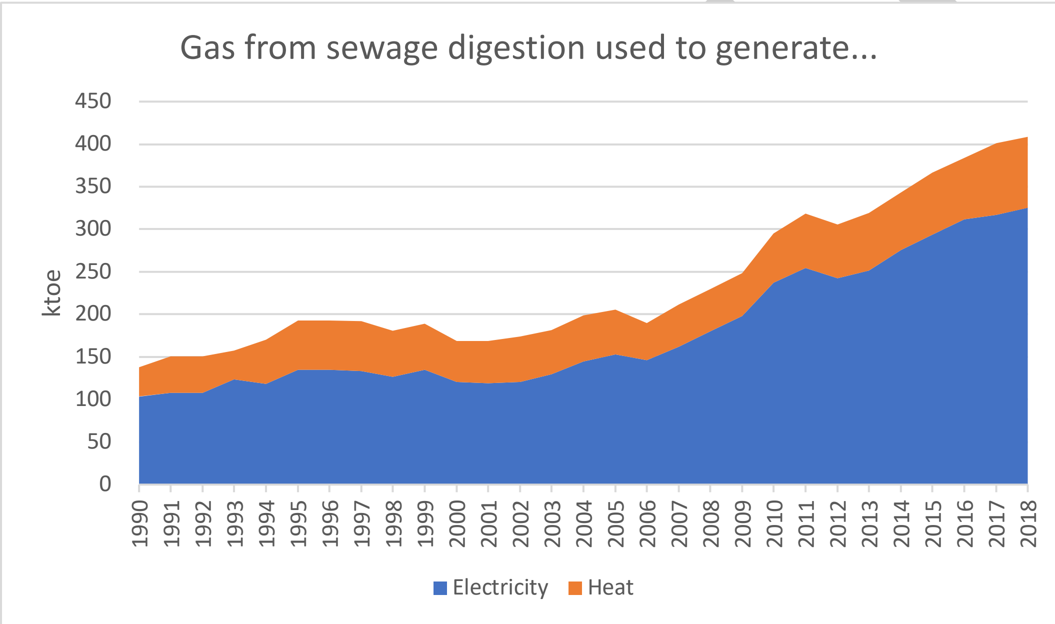
At the time, approximately 180 ktoe (2.1 TWh) of gas was being produced by sewage digestion for electricity generation, and another 50 ktoe (580 GWh) of sewage gas was being produced for heat.[21] That is around 247 million m^3.

Waste-water processing needs a considerable amount of heat and power. CHP is a good fit, as much of the energy can be used on site. None of the above gas was being scrubbed and injected into the grid (even assuming there was a grid connection at the sewage works to inject into). There was no reason for the water companies to change their process, so that

[21] ktoe = thousand tonnes of oil equivalent. TWh = tera watt-hour = 1,000,000 MWh. Data from Digest of UK Energy Statistics (DUKES) 2019, Table 6.1.1. https://www.gov.uk/government/statistics/digest-of-uk-energy-statistics-dukes-2019. It is not clear from the statistics if the gas for electricity and for heat was separate or the same gas with additional energy extracted where CHP was deployed. We assume here the most generous case for E&Y's model, though the methodology for calculation of the values suggests that it is actually the same gas.

they would export their scrubbed biogas and import some other forms of energy to run their processes.

Water companies had had practical reasons to produce their own energy for a long time, and had additionally been incentivised to do so under the NFFO and the RO. Consequently, they started from a relatively high level and had already expanded their production considerably by 2009.



Gas production is only practical at the larger sewage works, most of which were already doing so. The question of scale would be doubly significant for grid injection, as the smaller, more remote sewage works were less likely to be on the gas grid, as well as being less suitable for gas production. And to the extent that there was some remaining potential, new sites would have the same reasons as existing sites to deploy CHP rather than grid injection.

By 2018, sewage gas production had increased to 325 ktoe (3.8 TWh) for electricity and 83 ktoe (965 GWh) for heat. That is equivalent to around 438m m^3. Despite the incentives being skewed to favour biomethane, almost none of it was being injected into the grid.[22]

[22] The Renewables Obligation was modified in 2009 so that new sewage gas plants received only ½ a ROC per MWh (previously 1 ROC per MWh). The value depended on the buyout price and the recycled value, but roughly this equated to a cut from around £48/MWh to £24/MWh. Sewage gas was not eligible for Feed-In Tariffs.

Biomethane (e.g. grid injection) received £68/MWh regardless of scale when the RHI was introduced in late 2011. Biogas heat (e.g. the heat from an AD CHP scheme) also received £68/MWh, but only for a small amount of heat, upto 200 kW, above which biogas initially received nothing. This was subsequently modified to offer lower tariffs for larger schemes, as was the biomethane support.

As the RO and RHI for biogas heat were paid after conversion, whereas the RHI for biomethane was paid before conversion (e.g. in houses, or power stations or wherever the gas was used), around 2012/13, a sewage plant producing 2m m^3 of biogas (≈ 800,000 m^3 of CH_4) p.a. could receive around £560,000 p.a. of RHI for biomethane, £83,000 of RO for electricity generation and/or £113,000 of RHI for heat production. Yet water companies opted almost universally for CHP rather than biomethane.

There was never much prospect that 270m m^3 would be diverted from CHP to grid injection. There was even less prospect that 629m m^3 of sewage gas would be produced by 2020, let alone be diverted 100% to the grid.

3.3 Manure – dairy & cattle

> **NG/E&Y potential: 254 - 507m m^3**
>
> **Credible potential: 0 - 33% of high-gas feedstocks**

One of the first commercial AD plants in the UK, Holsworthy Biogas, was originally obliged to take 80% of its feedstock from farm slurry. It was not economic under this constraint, and went into administration. It only became viable when its new owners (Summerleaze) broke the obligation and switched the plant to mostly food waste.

Cattle manure and slurry produce a fraction of the gas per tonne of (wet) feedstock, compared to food waste, and less still than energy crops. Waste attracts a gate fee (albeit significantly diminished nowadays due to over-capacity), whereas farmers will not generally pay to get rid of their manure. The manure intake therefore represents a cost not an income, because it has to be transported to the digester.

On-farm digesters may mitigate some of these disadvantages by minimising the transport distance and utilising the energy on-site, which offers a higher value than export as gas or electricity. Specialist farm digesters can also be cheaper, as they can be simpler than digesters that handle waste. And digestate disposal directly on the farm may be cheaper.[23] However, they will tend to be smaller, and will often not be located on the gas grid. In the rare cases where the benefits of localism are sufficient to outweigh the poor economic fundamentals of slurry digestion, the opportunities for grid injection may be limited.

There is thought to be a substantial resource of manure and farm slurry. In England and Wales, it is estimated that approximately 72m tonnes is collected for spreading, and another 73m tonnes is deposited directly in the fields by the animals.[24] Of this, dairy and beef accounts for nearly 60m tonnes of the spread material and 42m tonnes of the directly-deposited material. At around 15 m^3/tonne, this implies a theoretical potential of 900m m^3 of methane from AD, if all the collected dairy and beef manure/slurry were digested before spreading.

[23] Depends on the nitrate vulnerability of the land, but digestion is unlikely to make the problem worse than the previous way that slurry was handled on the farm. Larger, centralised AD systems will need a wider area over which to spread their digestate, and the process will be more complex and expensive if the centralised system also took food waste.

[24] Nicholson, F.; Chambers, B.; Lord, E.; Bessey, R. ; Misselbrook, T. (2016). Estimates of manure volumes by livestock type and land use for England and Wales. NERC Environmental Information Data Centre. https://doi.org/10.5285/517717f7-d044-42cf-a332-a257e0e80b5c

Yet the production of biogas from this material was negligible at the time of the NG/E&Y report, and remains insignificant today, despite the stimulus efforts. A 2017 report by Ricardo for ClimateXChange identified:[25]

> *eight slurry/FYM facilities in the UK. Co-digestion is far more common, although slurry and FYM inputs are low in these facilities*

They speculated that the ban on landfilling biodegradable material might increase the opportunities for co-digestion of slurry/FYM with more economic feedstocks but:

> *the amount of slurry and FYM that could be treated in this manner is likely to be modest and there is a current declining trend in food waste production.*

Bioenergy Europe note that:[26]

> *The utilisation of agricultural residues such as manure is particularly important in countries such as Denmark, France and Italy*

Yet biogas as a whole constitutes 2.1%, 0.4% and 1.3% of those countries' primary energy consumption. Agricultural residues constitute 51%, 68% and 49% (by mass) of their biogas feedstock. Given the lower gas-producing potential of the feedstock, that means that in the European countries that have placed greatest emphasis on manure as a biogas feedstock, it is responsible for around 0.75%, 0.2% and 0.4% of their primary energy consumption. That is particularly striking in Denmark, which is noted for its successful promotion of renewables, has the infrastructure (e.g. municipal district heating schemes) to maximise the value of AD plants, and has large quantities of pig (and other) slurries to digest.

If we combine the fact that farm slurries are generally uneconomic but may have limited potential as a complement to higher-gas feedstocks, with the experience in the countries that have tried hardest to use this material, we may conclude that the maximum practical proportion of the feedstock is around 50% by mass, which equates to around 25% of the gas potential (i.e. if we work out the potential of other feedstocks, we could add up to 33% for co-digestion of this material).

The reality of digesting manure is that, while the theoretical potential is quite large, the economic potential is small and always has been. NG/E&Y were not making abstract claims about the theoretical potential. They were claiming not only that biomethane could supply nearly half our domestic gas, but that the level of support needed to achieve that was modest. The combination of these two claims with regard to manure is disingenuous.

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[25] Ricardo Energy & Environment, "Farmyard Manure and Slurry Management and Anaerobic Digestion in Scotland – Practical Application on Farm" https://www.climatexchange.org.uk/media/2977/farmyard-manure-and-slurry.pdf

[26] Bioenergy Europe, Statistical Report 2019 https://bioenergyeurope.org/statistical-report.html
2018 biogas production (ktoe): DK: 389; FR: 899, IT: 1,898. 2018 primary energy consumption (from https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nrg_bal_s&lang=en): DK: 17,958; FR: 238,910; IT: 147,244)

3.4 Agricultural waste

NG/E&Y potential: 234 - 967m m^3

Credible potential: 0 - 100m m^3

Agricultural waste was brought within waste management regulations in 2006. The vast majority of agricultural waste was the slurries and manures. Of the remainder, the focus was on handling the plastics.[27]

There was growing consideration of anaerobic digestion, and more limited consideration of on-farm non-slurry agricultural waste, but little consideration of the two together, perhaps reflecting the reality that the quantities were modest and already used for practical purposes (e.g. animal feed or composting).

In the Anaerobic Digestate protocol produced by WRAP in Feb 2009, for instance, agricultural waste was treated as though it was entirely about slurries and manure.[28]

The 2007 report by the Biomass Task Force (chaired by a former NFU chairman) focused strongly on the role of agriculture, but did not identify any "wet" agricultural wastes other than slurries suitable for digestion.[29] It did highlight significant volumes of "dry" agricultural waste such as straw, suitable for thermal processes (e.g. gasification).

The Environment Agency's recommendations for Agricultural Waste, published in 2001 offered the following figures:[30]

Waste milk:	23,993 tonnes
Vegetable & cereal residues:	1,091,984 tonnes
Animal carcasses:	231,785 tonnes
Animal tissue:	111,972 tonnes

It is likely that a lot of the animal material would have needed to go to rendering. 100m m^3 of biomethane looks like a stretch as the potential of this resource if it were all digested. And there was no reason to think that it would all be digested, rather than continuing to be used for the valuable and environmental uses (e.g. animal feed) to which it was being put.

It has not been possible to identify any quantification, nor much reference, to non-slurry agricultural wastes being used as AD feedstocks at the time of E&Y's report. A small number of on-farm digesters fed primarily with slurry/manure were noted, and it is reasonable to infer that they would also have use any other putrescible material available. But it is hard to

[27] e.g. DEFRA, *Waste Strategy for England* (2007), ¶ 43 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/228536/7086.pdf

[28] http://www.organics-recycling.org.uk/uploads/category1060/Financial_impact_assessment_for_anaerobic_digestate.pdf

[29] *UK Biomass Strategy 2007*, Annex A refers generically to food wastes, but note 11 makes clear that this refers to municipal and other off-farm waste streams.

[30] EA, *Towards sustainable agricultural waste management*, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/291600/geho0003bieo-e-e.pdf

see on what basis a researcher could have concluded that there was any significant current contribution from this material in 2009, from which to project a large contribution in 2020.

Yet E&Y estimated the ***baseline*** contribution at 234m m^3, and the "stretch" contribution at 967m m^3 – nearly double the "stretch" contribution of the slurries and manures that dominated the statistics and analysis of the resource.

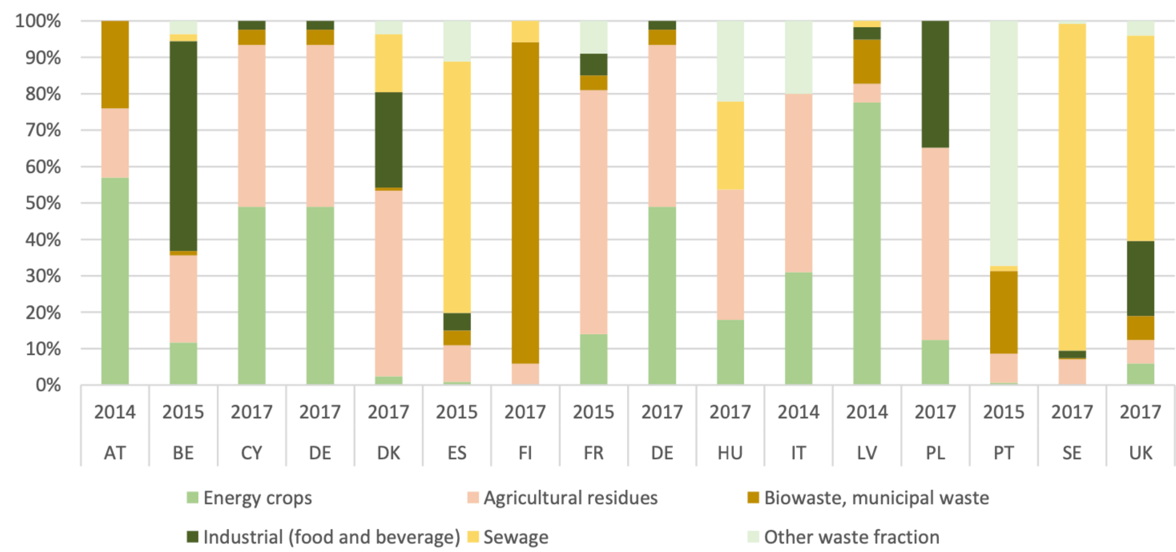
Fast forward to their target date, and WRAP recently estimated the amount of on-farm food waste and surplus produce as 3.6m tonnes.[31] Their objective, as always, was to minimise this waste, not to maximise its use for digestion. Most of it is already re-purposed, for example as animal feed. As the 2017 report for ClimateXChange, cited above, notes, there are few known instances of the digestion of this material to produce gas, whether for on-site use or grid injection. There is little reason to think now that a significant amount of gas will be produced from this material as efforts to minimise it proceed, and there was little reason in 2009 to expect much either.

3.5 Food waste

NG/E&Y potential: 729 – 1,333m m^3
Credible potential: 250 - 750m m^3

Other than sewage, food waste (post-farm-gate) is the main feedstock (around 50%) of anaerobic digestion in the UK, because it has a good gas yield and historically some waste-disposal income (i.e. gate fee).[32]

Figure 6 Feedstock Use for Biogas Production in European Countries (excluding landfill - expressed as a mass percentage)



There was very little anaerobic digestion (other than sewage and landfill gas) in 2009. This was one area where there was genuine potential for a material increase in gas production,

[31] http://www.wrap.org.uk/content/food-surplus-waste-primary-production-costs-uk-more-£1-billion
[32] Bioenergy Europe, *Statistical Report 2019*, Biogas section, Figure 6, p.12.

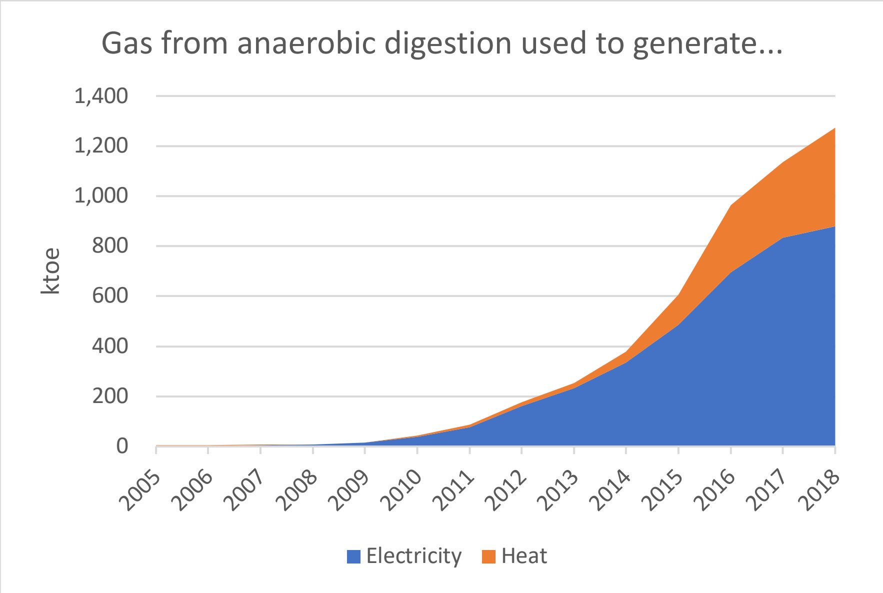
whether for electricity, heat or biomethane. If policies had directed all the material to biomethane, E&Y could reasonably have claimed all the gas potential from this material.

Food waste was a hot topic in the years up to 2009. On the upside, the resource was large. 3.6m tonnes of domestic food was thought to be wasted annually.[33] Estimates of Commercial & Industrial (C&I) food wastes varied widely, depending on reporting and definition, but pointed to around 3.5m tonnes excluding compostable/garden waste.[34]

On the downside, the policy preference for this material was not to utilise it for energy, but to reduce it.[35] That, of course, would reduce its potential as a feedstock for AD. Half the resource (the domestic element) was not available to digesters unless councils chose to implement separate collection, and would depend on the efficiency with which the public separated their waste.

With full source-separation and collection, and no waste-reduction, this material had the potential for up to around 750m m^3. A prudent assessment would have assumed some minimisation and incomplete collection, and some use for the generation of electricity and/or heat (e.g. where large food-waste producers produced their own gas for their own processes on site).

History bares out the prudent judgment. Significantly more of the resource went to electricity and heat than to biomethane.[36] Separate collection remains incomplete. Significant efforts are being made to reduce the volume of food waste, or to divert the material to other uses perceived as higher value.



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33 http://news.bbc.co.uk/1/hi/uk/7389351.stm. DEFRA figures suggested English municipal waste contained 5m tonnes of food waste. The discrepancy can possibly be explained as recoverable vs total. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/142005/wrfg18.csv/preview

34 Enviors for WRAP, *Commercial and industrial organic waste arisings – a gap analysis* (2009) https://www.wrap.org.uk/sites/files/wrap/Gap%20analysis%20-%20techical%20report%20-%20Aug%202009.pdf . The larger numbers included all animal and vegetal waste, including garden waste and other material more suitable for composting.

35 https://www.telegraph.co.uk/news/earth/earthnews/3312730/Help-the-environment-reduce-food-waste.html

36 The chart uses data from DUKES 2019, Table 6.1.1. It is subject to the same proviso mentioned in a previous footnote, that the gas for heat and electricity is treated as separate, but probably represents, at least in part, increased efficiency in the use of the same gas.

WRAP are actively promoting the diversion of material that currently goes to anaerobic digestion to uses such as animal feed.[37]

> *Arla have worked with their partners to send 100% of surplus food from their largest factory to animal feed, instead of anaerobic digestion*
>
> *Tesco and SugaRich have worked together to divert 80% of surplus bakery products from anaerobic digestion to animal feed.*
>
> *By diverting surplus soft drink products away from anaerobic digestion to redistribution and animal feed, Coca-Cola Enterprises have created net cost savings*

WRAP announced recently that food-waste volumes fell 7% between 2015 and 2018, an acceleration of the trend from 2007-15, when volumes fell around 11%.[38] They nevertheless note that a significant proportion remains uncollected and the public continue to under-estimate the significance. The Committee on Climate Change's recent report on and plan for land-use envisages another 20% reduction by 2030.[39]

Reality is demonstrating what could reasonably have been inferred by a knowledgeable analyst in 2009: there was plenty of scope to increase the digestion of food waste, but it was a declining resource that was unlikely to be captured fully for the purposes of generating biomethane. A range of 250 – 750m m^3 represents an optimistic assumption that one-third to 100% of it would be captured and used for biomethane, and the decline would not be significant. It is hard to understand how one credibly arrives at a higher figure than that.

3.6 Biodegradable waste

NG/E&Y potential: 1,042 - 8,328m m^3

Credible potential: 0 - 100m m^3

The greatest mystery about NG/E&Y's figures for biodegradable waste is exactly what material they had in mind, and how they expected it to be used. The main biodegradable components of municipal and commercial wastes are food wastes. But these are considered separately.[40]

Other technically-biodegradable components of the waste stream include garden waste, paper, card and wood. None of these is very suitable for digestion. Wood waste is also

[37] https://www.wrap.org.uk/content/using-surplus-food-animal-feed
[38] https://www.letsrecycle.com/news/latest-news/food-waste-down-by-7-wrap-says/
[39] https://www.theccc.org.uk/publication/land-use-policies-for-a-net-zero-uk/
[40] It is possible that their "food waste" referred only to commercial food waste, and their "biodegradable waste" is short for Biodegradable Municipal Waste, including municipal food waste. But they do not describe them as so, and their figures for food waste would be even less explicable if they excluded the municipal component. It would, however, help to explain the largely inexplicable figures for biodegradable waste, though not remotely enough to make 8,328m m^3 a possibility.

considered separately, but for wont of an alternative explanation, the rest must be the core of what NG/E&Y had in mind for this category.

Garden waste was and continues to be composted primarily. There is an established infrastructure and market for this product. It is unsuitable for digestion, because of the amount of fibre/lignin/non-putrescibles. It could be suitable for gasification (see below) if suitably prepared, but it is doubtful that the challenge is worth the reward compared to the straightforward and commercial option of composting. Were it diverted from composting, then there would be a danger of the market resorting to less environmentally-friendly options such as peat.

Paper and card are also not suitable for digestion, at least without significant technological breakthroughs that were not in prospect in 2009 and have not materialised since. They are eminently suitable for thermal processes, and form (along with plastics) the bedrock of the UK's significant expansion of Energy-from-Waste. They could be gasified instead of incinerated, if the technology were sufficiently mature and competitive (see below). Much of it can also be (and substantially is) recycled.

The recycling rate for paper and cardboard is widely reported to be around 80%.[41] Government statistics provide only partial information, and are structured in such a way that it is difficult to get a complete picture.[42] The real picture appears to be around 7.5m tonnes of paper recovered from around 10.8m tonnes of paper and cardboard consumed.[43] The unrecoverable proportion is thought to be around 22%, which leaves around 970,000 tonnes available for gasification, if it can be recovered and converted to a useful fuel economically, without diverting material from currently-preferred recovery options.

The recycling rate for paper and card was already high by 2009.[44] And total volumes were higher, as the cyclical and structural declines in paper consumption had only just begun.

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[41] https://www.letsrecycle.com/news/latest-news/uk-achieved-45-7-recycling-rate-in-2017/

[42] For example, the Let's Recycle report relied, like many on DEFRA's, *UK Statistics on Waste*, Mar 2019 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/784263/UK_Statistics_on_Waste_statistical_notice_March_2019_rev_FINAL.pdf. This reports that, of 4,749,000 tonnes of waste paper and cardboard produced in 2017, 3,754,000 was recycled/recovered. Paper and card would also have been a substantial proportion of the 700,000 tonnes that went to Energy-from-Waste. However, this appears to be the subset of paper that is used for packaging, within a report that is focused on household waste.

[43] 7.5m tonnes from https://paper.org.uk/the-paper-industry/key-statistics/. 10.8m tonnes is from the CPI's most recent annual report, for 2017/18 (https://paper.org.uk/PDF/Public/Publications/Annual%20Reviews/CPI%20Annual%20Review%202018.pdf). The CPI do not seem to have published a more recent report. 22% unrecoverable is from the same source. The figures for total consumption appear to include an extra category (transit packaging) compared to the figures below for pre-2010. We can compare, for instance, the figures for 2010 consumption: 13m tonnes according to CPI's 2017/18 annual report, but 10.7m tonnes according to their 2012/13 annual report. Without transit packaging, UK consumption of paper and board is probably around 9.5m tonnes.

[44] Government data is hard to find for the years before 2010. The archived spreadsheet at https://webarchive.nationalarchives.gov.uk/20100403161511/http://www.defra.gov.uk/evidence/statistics/environment/waste/wrpaper.htm indicates a recycling rate of 71% in 2007 (8.6m tonnes recovered vs 12.1m consumed), rising rapidly from 65% in 2006 and 50% in 2003. The Confederation of Paper Industry's annual report for 2012/13 suggests the rate was closer to 80% by 2009, largely because consumption (10.3m tonnes) had fallen faster than recovered material (8.1m tonnes) because of the Crash and increasing use of electronic

However, over half of the recovered material was exported, mainly to China. There were problems with demand from both native and foreign recyclers.[45] NG/E&Y might reasonably have assumed that most of the exported, some of the native-recovered and some of the unrecovered material could be available for gasification – perhaps as much as 5-6m tonnes. This would have turned out to be much too optimistic, but the availability of feedstock is anyway one of the lesser problems with this option to increase the volumes of green gas (see below).

3.7 Gasification (wood waste, miscanthus, etc)

NG/E&Y potential: 3,098 - 6,668m m³
Credible potential: 0 - 3,700m m³

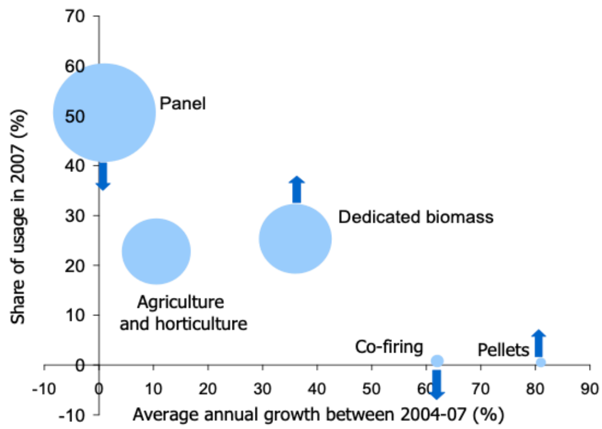
Of the waste streams listed by NG/E&Y, at least two – wood waste and miscanthus – must have been envisaged as feedstock primarily for gasification, not digestion. As explained above, we should probably add (despite its name) the biodegradable waste, as effectively the paper and card waste stream.

Of approximately 4.5m tonnes of waste wood produced in the UK, around 2.1m tonnes is currently going to biomass energy projects.[46] 1.35m tonnes is reused and 0.3m tonnes is exported.

The total amount of waste wood was not dissimilar in 2009.[47] The majority was from construction and demolition waste, which introduces challenges of identifying and handling the treated wood. WRAP estimated that only around 1.4m tonnes was "clean solid wood".

WRAP seem to indicate that almost all of it was already being recovered, driven primarily by the wood panel industry.[48] Nevertheless, WRAP expected recovery to increase overall, and energy-use to

Figure 20: Use of recovered wood by various industries[1,2]



Source : Pöyry Forestry Industry Consulting

[1] Arrows indicate expected direction of movement in share of usage.

[2] Bubble size reflects usage in million tonnes.

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media. (https://paper.org.uk/PDF/Public/Publications/Annual%20Reviews/CPI%20Review%202012-13.pdf). Comparing recovery with consumption over-states the amount of residual paper available for other uses, as not all paper that was consumed would appear in the waste stream (e.g. if burnt on-premises). Around 20% of paper and card is thought to be unrecoverable.

[45] https://www.dailymail.co.uk/news/article-1104741/Recycling-crisis-Taxpayers-foot-UKs-growing-waste-paper-mountain-market-collapses.html

[46] https://www.letsrecycle.com/news/latest-news/biomass-demand-waste-wood-soars-2018/

[47] WRAP, *Wood waste market in the UK* (2009), https://www.wrap.org.uk/sites/files/wrap/Wood%20waste%20market%20in%20the%20UK.pdf

[48] "In 2007, just over half of wood waste was used by panel manufacturers. Dedicated biomass energy generators used a quarter; agricultural or horticulture product manufacturers used a fifth; and pellet

increase (driven by the RO, i.e. for electricity generation) while panel manufacturers' share fell.[49]

Barring the complete implosion of British panelboard manufacturing, it was reasonable for NG/E&Y to assume that a material proportion of the clean waste wood would continue to go to this use. Likewise, animal bedding and other existing forms of re-use.

Around 2m tonnes of waste wood available for energy-use, seems to be a recurring figure from the studies, which would have been a reasonable top-end figure for gasification assuming it displaced all other energy-uses. It is also consistent with what happened in practice under the incentives of the RO and RHI, although of course it went almost entirely to mature combustion technologies and not to gasification.

We set out below what might be credible if the UK made ambitious efforts to produce energy crops for digestion. The constraining figures are the same for gasification feedstocks. The same amount of land is available, and the uses are mutually exclusive.

A key difference is that the technology for digestion is mature. We might therefore prioritise energy-crop land-use for digestion rather than gasification. Nevertheless, not all land is equally suitable for all crops, so there might well be a mix. Some proportion of the figure estimated below for energy crops might have been available for gasification instead of digestion. In practice, 7,000 ha produced around 71,000 odt of miscanthus in 2018.[50]

So we have a maximum potential gasification feedstock of around 5-6 million tonnes of paper and cardboard, 2 million tonnes of waste wood, and perhaps 6 million tonnes of energy crops.[51] That's around 63 TWh of feedstock (which does not mean 63 TWh of potential biomethane, because of conversion efficiencies, as below). Around 27 TWh of that is mutually exclusive with the upper estimate for digestion energy crops.

The true problem for gasification starts when we consider how this would be used. Gasification technology is in one sense very mature. It has been known and used for

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producers and co-firing energy generators the remainder." Although this refers to wood waste as a whole, one suspects they were referring to shares of the proportion that was recovered.

[49] One way to make sense of the figures is that WRAP's figures referred to the recovered quantities of waste wood, although that seems to conflict with the fact that the majority of their 4.5m tonnes was hard-to-recover construction and demolition waste. But perhaps the relatively-low figures for those components reflected the fact that they were the recoverable element. In an earlier analysis, WRAP had put the figure significantly higher at around 10.6m tonnes of waste wood in total (DEFRA, *Waste Wood as a Biomass Fuel*, 2008, https://www.forestresearch.gov.uk/documents/2078/DEFRA_Waste_wood_as_a_biomass_fuel_2008.pdf). WRAP's 2009 report also noted that volumes were in decline because of the Crash and its impact on panelboard manufacturers and others, and that their tonnages for construction and demolition waste might be incomplete. But they also noted that theirs was a more detailed study. The true figure is presumably somewhere between 4.5m and 10.5m tonnes. Despite the higher total, the 2008 report nevertheless envisaged an ambition of around 2m tonnes for energy-use.

[50] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/856695/nonfood-statsnotice2018-08jan20.pdf

[51] 6m tonnes of energy crops is calculated on the basis that 2.5bn m3 of biogas is around 27 TWh, which is around 6m tonnes of low-moisture wood (at 4.5MWh/tonne).

decades.[52] But in another sense, it is still immature. Despite many attempts in recent decades to commercialise it, no offering has succeeded to any significant extent.

One problem relevant to this report is the nature of the feedstock. Gasification was only ever deployed at scale for the conversion of coal, which is a homogeneous fuel. Recent efforts have focused on more heterogeneous feedstocks, such as waste. But the process needs very precise control of energy-feed-rate, air, etc. Many gasification projects have foundered on the front-end.

Another major problem for these purposes is that gasification does not produce biomethane. It produces a mixture of methane (CH_4), carbon monoxide (CO) and hydrogen (H_2), to name the three main combustible elements of the gaseous product. In the days of town gas, this mixture was permitted in the gas network. Nowadays, there is a very tight specification for the gas that can be accepted into the network: largely methane with a small amount of more-complex alkanes. For operational and safety reasons, gasification gas could no longer be added to the gas network. So one immature technology (gasification) would have to be complemented by an even less mature technology (methanation) to convert the gasification gas into a gas that could be distributed to users.

Considerable effort has been invested in recent years in gasification + methanation to produce a Synthetic Natural Gas (SNG). But (a) it is 2020 and none of those are commercially mature, and (b) NG/E&Y could not reasonably have predicted that they would be, given the state of technology and the market in 2009. Decades of efforts around the world had resulted in no commercial options to date. The prudent assumption was that 10 years was not long enough for the problems to be ironed out and the technology commercialised.

Yet NG/E&Y included the following quantities of biogas from gasification in their **baseline** projection: 1,253m m^3 from wood waste, 1,845m m^3 from miscanthus, and (probably) 1,042m m^3 from biodegradable waste. This constituted 74% of the 5,625m m^3 of biogas that they envisaged would be available as a minimum in 2020.

Of all their imprecisions, this is the most egregious. The only reasonable figure to use for this technology in the baseline scenario was zero. Decades of effort had so far delivered almost nothing. And sure enough, from the perspective of 2020, we find that the most recent decade also produced almost no commercial SNG production, not just in the UK, but globally.

As for the "stretch" scenario, how much biogas might those 63 TWh of feedstock have produced? The conversion efficiencies of gasification and methanation are both typically estimated at around 80%, so we will assume the combined efficiency would be 64%. That implies a maximum of around 40 TWh of biomethane from this source.

At 10.83 kWh/m^3 of methane, that's around 3.7bn m^3 of biomethane. NG/E&Y had 2,697m m^3 from wood waste, 3,971m m^3 from miscanthus, and 8,328m m^3 from biodegradable

[52] Coal gasification was the source of the town gas used in the UK before natural gas displaced it during the 60s. It was an essential part of the technology used by the Germans during the War to convert their plentiful reserves of coal to compensate for their inadequate supplies of petroleum.

waste (probably). This technology now accounted for 81% of the total 18,432m m^3 of biomethane anticipated in the "stretch" scenario.

In other words, gasification and these feedstocks, were NG/E&Y's *deus ex machina* to convert what was obviously an inadequate potential of digester gas, to an apparently-significant potential of biomethane. Unfortunately, it was not just a misestimation; it was a fiction with no basis for reasonable expectation given the knowledge available at the time.

3.8 Energy Crops for Digestion

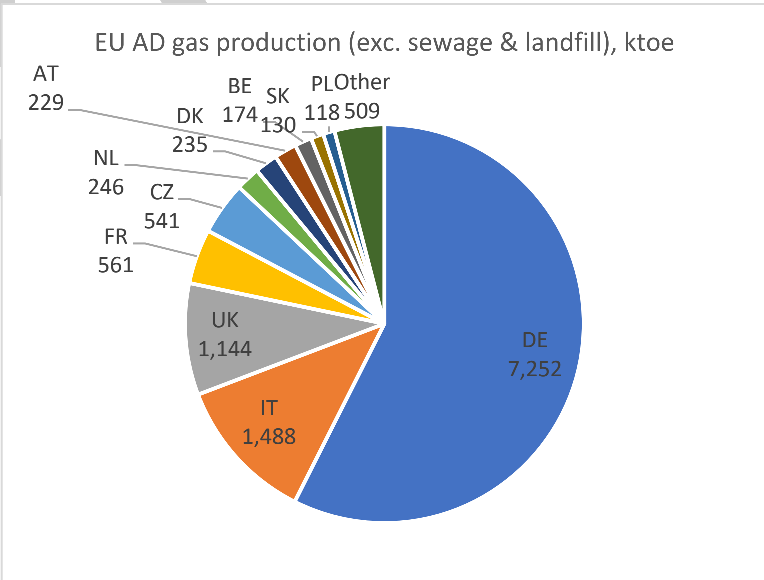
NG/E&Y potential: N/A
Credible potential: 250 – 2,500m m^3

Ernst & Young considered only "a possible limited contribution from sustainable energy crops" for gasification (none for digestion), even though Enviros had relied heavily on it in their most ambitious scenario for the potential of biogas.[53] The "food vs fuel" debate was a hot topic, and E&Y no doubt judged that it would raise political resistance to rely on energy crops.[54]

In practice (and in theory to most analysts, then and now, other than E&Y), energy crops are the only way to expand biogas production beyond the limited potential of waste resources. But there is a practical limit even to the grandest ambitions.

Germany has made by far the largest effort to develop biogas.[55] It has relied heavily on energy crops to do so.[56]

Germany has devoted 14% of its agricultural land (2.35m ha, 8% of its undeveloped land) to energy crops. Of this, nearly 60% (1.37m ha) is for biogas feedstocks. Yet biogas represents 2.2% of Germany's



[53] See above: 157,000 ha of land for energy-crop production, contributing to total biogas production equal to <4% of total heat demand.

[54] e.g. David J Tenenbaum, "Food vs. Fuel: Diversion of Crops Could Cause More Hunger", Environ Health Prospect, Jun 2008. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2430252/

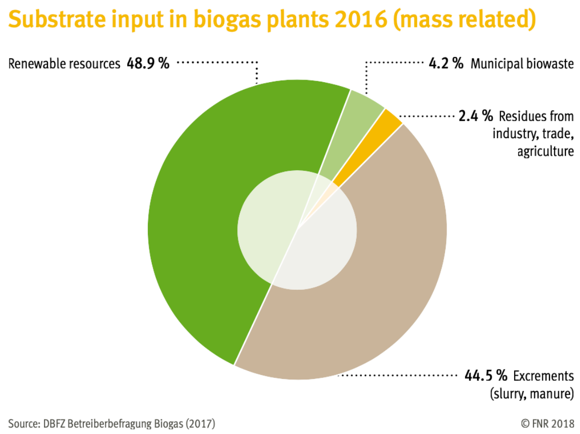
[55] Bioenergy Europe, *Statistical Report 2019*, Biogas section Table 2

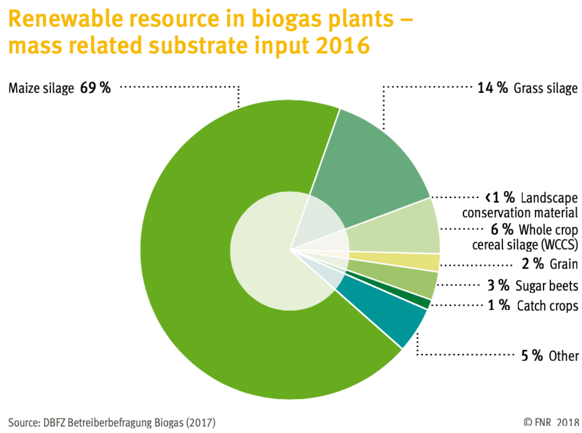
[56] Fachagentur Nachwachsende Rohstoffe, *Bioenergy in Germany, Facts & Figures 2019*, http://www.fnr.de/fileadmin/allgemein/pdf/broschueren/broschuere_basisdaten_bioenergie_2018_engl_web_neu.pdf

primary energy consumption.[57] Biogas represents around 5% of Germany's electricity and around 1.4% of its heat, and an insignificant proportion of their transport fuels.[58]

Germany illustrates the competition for land where significant reliance is placed on energy crops. Most of the rest of the energy-crop land (964,000 ha) is for the production of liquid fuels (biodiesel and bioethanol). Liquid fuels are hard to replace in some uses, such as aviation fuel. Biofuels are not currently used much for aviation in Germany (or elsewhere). They represent 4.7% of the fuel consumption for land transport.[59] If used for aviation, this volume would represent around 24% of Germany's requirements.[60]

Nearly one-third of Germany's land is forested, compared with 13% of the UK's land. The Germans have utilised solid biomass (primarily wood) to a greater extent than the UK. The Germans do not waste so much of this resource as the UK generating electricity at around 35% conversion efficiency. Most of it is used to produce heat (direct or as CHP) at around 80% efficiency.[61]





Given the different gas potential of energy crops and excrements, this means that energy crops are responsible for around two-thirds of Germany's biogas.

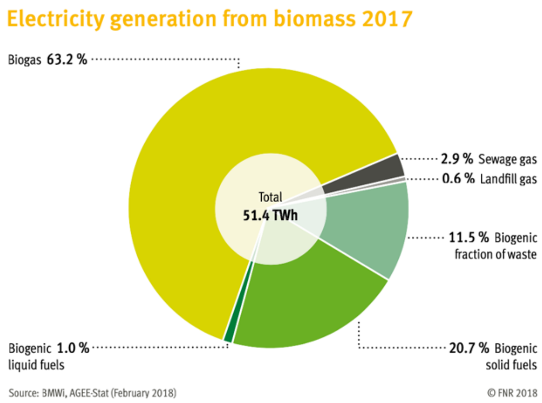
[57] *Bioenergy in Germany, Facts & Figures, p.39*: used share of biogas primary energy potential: 273 PJ = 75.8 TWh. Eurostat, T2020_33, Primary energy consumption. Germany (2017): 298.31 ktoe = 3,469 TWh https://ec.europa.eu/eurostat/databrowser/view/t2020_33/default/table?lang=en

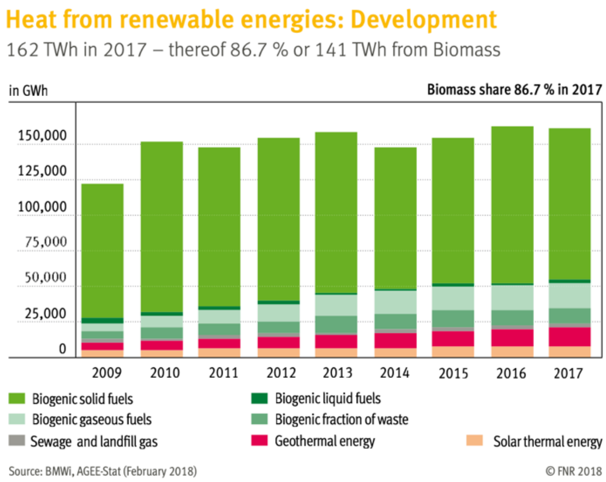
[58] Data from *Bioenergy in Germany, Facts & Figures 2019*. Gross electricity generation: 654.8 TWh. Electricity generation from biogas: 63.2% of 51.4 = 32.5 TWh. Renewable heat (162.2 TWh) share of final energy consumption for heat: 12.9%. Biogas share of renewable heat: 10.6%

[59] *ibid.* p.28. Total land transport fuel consumption: 57.6 Mtoe = 670 TWh. ∴ Biofuels = 31.5 TWh

[60] Germany's jet fuel consumption 2018: 221,010 barrels of oil per day = 131.3 TWh p.a. https://www.theglobaleconomy.com/Germany/jet_fuel_consumption/

[61] *ibid.* pp.5-6.





The UK has a lot less land than Germany dedicated to the production of solid fuels (e.g. wood), liquid fuels (biodiesel/ethanol) and gaseous fuels (biogas). If we focused on expanding one aspect (e.g. energy crops for biogas), we would miss the contributions of the other types of energy. And all of them compete with the traditional use of agricultural land for food production.

Enviros envisaged the use of 157,000 ha for the production of energy crops for AD in their most ambitious scenario. Ernst & Young discounted the possibility altogether.

	Germany	*UK*
Total land area (k ha)	35,700	24,400
Woodland area (k ha)	11,400	3,200
Agricultural land area (k ha)	16,700	17,500
Energy crops area (k ha)	2,350	94
Area for AD feedstocks (k ha)	1,374	57
Area for biofuel feedstocks (k ha)	964	27
Area for solid energy crops (k ha)	11	10
Primary energy consumption (TWh)	3,469	2,056
Total gas consumption (TWh)	937	880
Household energy consum. (TWh)	658	431
Household gas consumption (TWh)	279	309
Heat from solid biomass (TWh)[62]	107	44
Heat from biogas (TWh)[63]	17.2	4.6
Liquid biofuels (TWh)[64]	31.5	5.9

[62] Excludes biogenic fraction of waste. UK figure based on DUKES 6.1.1 depends on highly-suspect estimates of domestic wood burning. Reality is probably roughly half.
[63] Excludes sewage gas and landfill gas
[64] UK: 599m litres @ 9.8 kWh/litre. Germany: 4.7% of 57.6m toe total land transport fuel consumption.

94,000 ha are used to grow energy crops in the UK, out of a total utilised agricultural area of 17.5m ha.[65] We have 3.19m ha of woodland.[66] Our total land area is 24.4m ha.

Germany has 2.35m ha growing energy crops (out of 16.7m ha of agricultural land) and 11.4m ha of forest, out of a total land area of 35.7m ha. Yet Germany meets only a small proportion of its energy requirements from these fuels. Is there (and was there ever) a credible model for the UK to produce a material proportion of its energy requirements from a smaller area of land? And if not, what is the model for biogas to make a material contribution to the UK's energy supplies, given that it can only be stretched to Germany's modest contribution through orders of magnitude higher use of land for energy production than we currently deploy?

Let's imagine that the UK increased the level of energy crop production to the same as Germany. 14% of UK agricultural land = 2.45m ha. 58% of this (1.43m ha) is used to produce AD feedstocks, while 41% (1m ha) is used to produce liquid biofuels. The German experience suggests around 45MWh/ha p.a. for biogas from energy crops.[67] We could produce 64.35 TWh of biogas, i.e. around 5.9bn m^3. That represents around 17% of domestic gas consumption or 6% of total gas demand, according to Ernst & Young's projections. In practice, gas consumption has fallen somewhat, and this amount would represent 21% of domestic gas consumption and 7% of total gas demand.

We need additionally to allow for the reforestation that is (a) part of this government's policy, and (b) required to match the German model. To bring us up to German levels of afforestation, we will need to switch another 4.6m ha from agricultural use to forestry. Our agricultural land area would be reduced from 17.5m ha to 10.5m ha.

Or we might choose to have less forest than Germany. In that case, we will either have to import more solid biomass fuels, or use less solid-biomass heat, which currently makes up approximately two-thirds of Germany's renewable heat.

For reasons of climate policy, the UK (like many countries around the world) plans to increase significantly its forested area. Without deforestation or a substantial reduction in agricultural production, the potential for energy crops in the UK will have to be kept within reasonable bounds that constrain the potential of digestion or other conversion technologies.

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[65] 27,000 ha are for liquid biofuels. 57,000 ha are for AD (primarily maize). 10,000 ha are for solid biomass. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/856695/nonfood-statsnotice2018-08jan20.pdf
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/747210/structure-jun2018prov-UK-11oct18.pdf

[66] https://www.forestresearch.gov.uk/tools-and-resources/statistics/statistics-by-topic/woodland-statistics/

[67] This assumes mostly the highest-yielding crop – maize silage – is grown, but some land is not suitable and requires lower-yielding crops.

4 An alternative method for estimating the potential

NG/E&Y potential: 5,625 - 18,432m m^3
Credible potential: 1,000 - 3,300m m^3

There is a simple way of estimating the gas-producing potential of a large proportion of the wastes under consideration, which was available and almost as accurate in 2009 as it is now.

Most of our putrescible waste has been going to landfill for decades. For around 30 years, they have been engineered to contain the gas (so far as possible), regulations have required the control (i.e. extraction) of the gas, and incentives have encouraged the collection of the gas as an energy source. Landfill gas was an early success of British renewables policy, and one of the few forms of renewable energy in which Britain genuinely led the world. Containment and collection have therefore been increasingly efficient and complete for many years. The figures for landfill gas electricity production therefore represent an increasingly accurate picture of the gas produced from the putrescible material in the landfilled waste streams.

Gas is produced much more slowly in a landfill than in a digester, of course. The production pattern is thought to be roughly three years of rapid exponential growth to peak production, followed by slow exponential decline for decades. But if one adds the output from cells in the first year of their production to those in their second year to those in their third year, etc., the annual output is similar to the output if the material were digested rapidly in an AD plant, once enough years of waste are within properly-engineered cells.

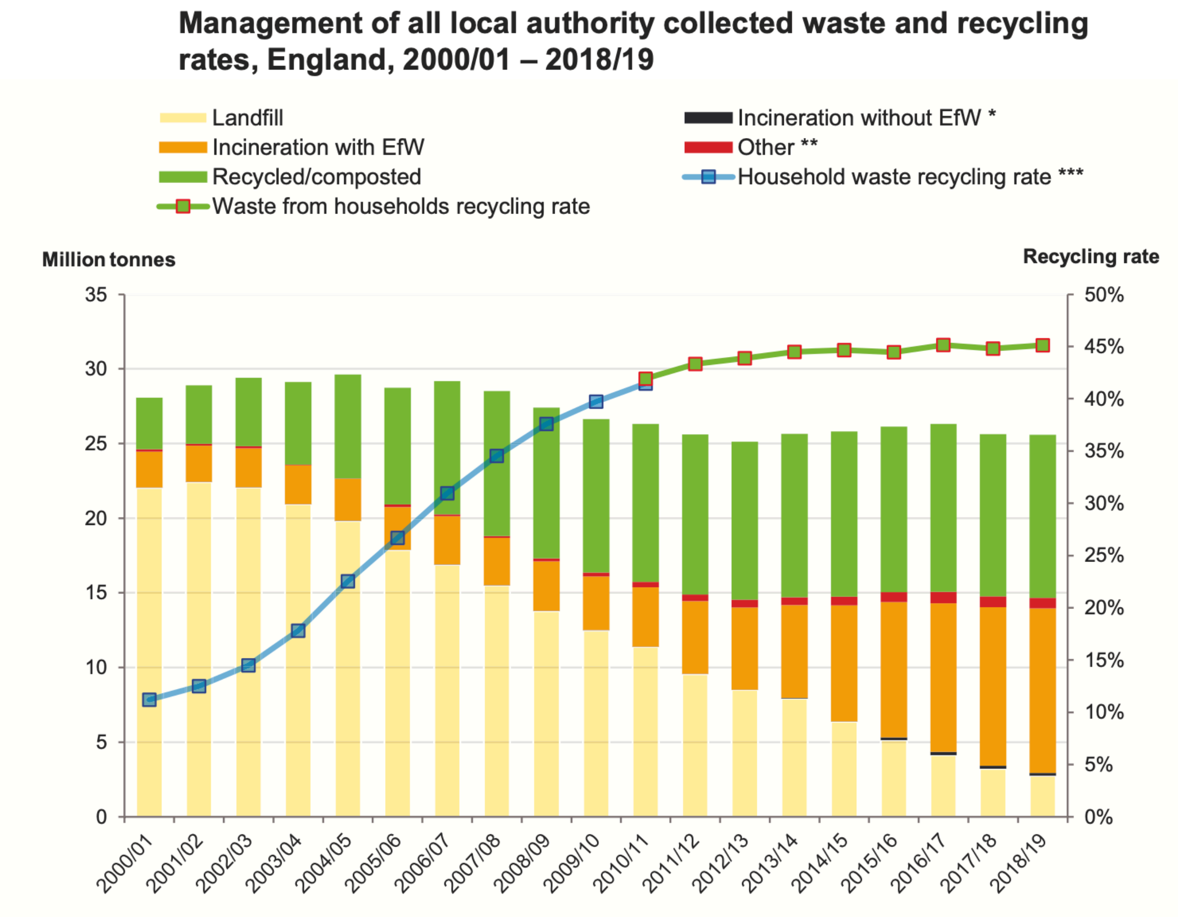
One has to make allowances for some differences. The academic and regulatory opinion on the proportion of gas that has been captured by landfill-gas extraction has declined over the years, to the significant benefit of the government's calculations of its performance in reducing greenhouse-gas emissions. This was largely a change in the assumptions, as the quantities of fugitive gas are not amenable to measurement.

But landfill gas has a distinctive odour and most people know when even small amounts of it are present. Gas migration is therefore usually detected and dealt with promptly because of the regulatory threats from inaction. Usually, if you smell landfill gas in the air, it is obviously coming from the open face of the landfill, not seeping out of the ground some distance from the landfill via a leak in the liner.

A more reasonable assumption than is applied nowadays is that most of the gas is captured once a cell is sealed. Extraction is required and incentivised, creating negative pressure within the fill, so gas is unlikely to leak in significant volume even if the liner is damaged. We may assume that a significant proportion of the gas from an open cell escapes. But gas production in the first year or two is a small proportion of the total gas that will be released, and cells will typically be finished in that timescale.

AD plants convert the feedstock to gas more efficiently than landfills, so one may allow for a greater capture of gas by AD because of more complete conversion as well as more complete capture. On the other hand, the largest proportion of putrescible material in a landfill is slowly degrading (e.g. paper, card and wood), and it is likely that this will contribute to some extent over (say) 30 years of landfill-gas extraction, but won't contribute to AD because it will not normally be used as a feedstock.

Not all of the potential feedstocks for AD were going to landfill previously, but some of the key ones were. We can exclude manure, slurries and other agricultural waste (mostly), and of course sewage. But most of the food and biodegradable waste was going to landfill. Some municipal food waste may now be collected separately and sent to AD, which was previously burnt as part of the mixed municipal waste stream going to Energy-from-Waste plants. But the rise of Energy-from-Waste is a recent phenomenon in the UK, and the majority of food waste is not municipal and was never going to EfW.[68] Larger quantities of municipal biodegradable (non-food) waste may have gone to EfW, but as discussed above, this was always more suitable for thermal than biological treatment if we have inferred its definition correctly.



The uncertainties are not orders of magnitude. We may allow for AD producing around 25% more gas than from the same material being landfilled, give or take another 25% (i.e. 0-50%). But the uncertainty over the conversion and capture efficiency is whether it is 60 or 80% not 10 or 40%, given the processes and incentives involved. And the uncertainty over differences in feedstock is also marginal not exponential. We will not be an order of

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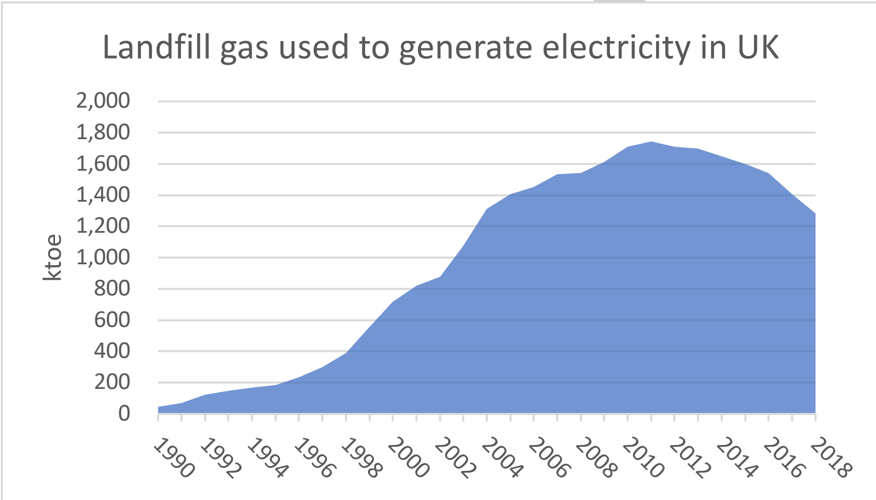
[68] Chart from DEFRA, *Statistics on waste managed by local authorities in England in 2018/19* https://www.gov.uk/government/statistics/local-authority-collected-waste-management-annual-results

magnitude out if we estimate the potential of municipal and commercial food waste and any other putrescible components of biodegradable waste on the basis of the landfill-gas figures at the peak of national production, before the efforts to divert putrescibles from landfills really took hold.



Landfill gas production peaked in 2011 at 1,744 ktoe, but if 2007 or 2008 were the last figures available to E&Y, it wasn't too far off its peak, at 1,540 ktoe.[69]

It could reasonably have been predicted to be peaking. The Landfill Directive was introduced in 1999, with an objective to divert reusable material (including putrescibles) from landfills. As the previous chart illustrates, volumes going to landfill started to decline from around 2003, although initially that was more about the diversion of conventional recyclables rather than energy recovery. But increased separate collection of food waste and energy-recovery through AD or EfW was on its way in order to comply with the Directive. It was a trivial assessment to judge that gas production was close to its peak (given the roughly 3-year lag between filling and peak production). For example, Summerleaze sold its landfill-gas generation business in early 2007, partly because a decline in production was expected in the not-too-distant future.

One could therefore do a simple calculation to estimate the gas that would be produced if the putrescibles being landfilled were digested instead. If one assumed that the latest figures available in 2009 represented the peak, and adjusted upwards by 25% for greater efficiency in AD, the annual potential of these types of feedstocks was around:

1,925 ktoe (22.4 TWh), within a range of 1,540 ktoe (17.9 TWh) to 2,310 ktoe (26.9 TWh).

By now, we can see that it might have been a little higher:

[69] DUKES 2019, Table 6.1.1. The figures provided for the energy content of the fuel used to generate electricity (first section of Table 6.1.1) appear to be calculated simply by applying a conversion efficiency (presumably net of parasitics, flaring etc) of 26.2% to the figures for landfill-gas electricity generation (fourth section of Table 6.1.1). This methodology is probably necessary. It is hard to see how the gas production could be measured directly. But it seems unduly pessimistic. LFG gen-sets should be running at 35-42% conversion efficiency. Parasitic and flaring losses should not drag it down so far as 26.2%.

It seems likely therefore that the figures for landfill gas used for electricity production are materially over-stated. This can be set against the other uncertainties described in the text above, if it is thought that the efficiency-adjustment for AD is insufficient. It is one reason why we give an uncertainty range from 0% upwards, rather than assuming some efficiency benefit from AD as a minimum.

2,180 ktoe (25.4 TWh), within a proportionately similar range (20 – 30 TWh).

To this one would need to add the biomethane potential of sewage gas and farm slurries, and the potential for gasifying solid feedstocks. As explained above, the realistic potential of each of these for material quantities of biomethane was very limited. History has substantiated what should have been a reasonable expectation in 2009. None of these technologies is contributing material quantities of biogas to our gas networks.

We can discount sewage gas because the economic opportunities are mostly deployed to the most practical use: CHP for on-site requirements.

The problem with manure and slurries is and always was the economics of a low-gassing feedstock with a cost rather than a gate fee to import. As the Ricardo report cited above notes, it is most likely to be used as one of the minority feedstocks, supplementing the main gassing potential of food and other putrescibles in the commercial and municipal waste streams. If the amount of manure increased the total feedstock (by mass) by 50%, it might add 20% to the amount of gas to be expected from the main feedstocks.

Gasification for grid injection is about the economic maturity and cost of the technology. As discussed above, any reasonable assessment would have been extremely cautious about the prospects of this technology. Gasification itself had failed to develop a commercial offering after decades of research and high expectations. In the case of grid injection, we must also consider the immaturity and cost of the technology to convert gasification gas (CH_4, CO and H_2 plus non-combustibles) to methane, or the establishment of a standard and infrastructure in every building to revert to a modern version of town gas.

Though we are as sceptical about the claims for hydrogen as biomethane, we may concede that, if one were going down this route, it would make more sense to convert the gases and network to hydrogen, as it facilitates CCS, rather than go to all this expense to produce a "green" gas whose carbon could not be captured. Hydrogen was already perceived in 2009 as a likely long-term option for heat, as illustrated by the quotes above. There was little reason for E&Y to include gasification gas within the potential for biomethane, other than that they needed it to make the total sound significant enough to affect policy.

So we get a range for the biomethane that could be produced if all the feedstocks in the report that were credible and economic were used for that purpose of around 25 – 36 TWh, i.e. around 2.3 – 3.3 bn m^3 of biomethane p.a. As E&Y anticipated gas demand in 2020, this represents around 6.6 – 9.4% of domestic gas, or 2.4 – 3.4% of total national gas demand.[70]

These are effectively the realistic versions of the "stretch" scenario, i.e. using all the feedstock that is realistically available and economic. The "baseline" scenario assumed a material amount of the feedstock continued to go to other uses. For instance, the figures

[70] As it turned out, gas consumption was somewhat lower by 2020 than they envisaged. As a proportion of the current levels of gas consumption, this estimation of the potential of biomethane would constitute 8-11.6% of domestic gas, and 2.8-4.1% of total UK gas supply. But it is really only fair to compare their projections for biomethane with their projections for gas consumption, to understand the policy implications of their message in 2009. And still, if we were carrying out the same exercise today, these proportions are not enough for biomethane to be a credible option for decarbonising the gas grid.

above, like E&Y's "stretch" figures, assume that no putrescible material remains available for power and/or heat production from AD (other than sewage), and all the current output of that technology would be lost.

Alternatively, in the "baseline" scenario, we may assume that much of this feedstock continues to be used for the existing purposes. We therefore retain much of the 2.7 TWh of electricity generated by AD, but can only rely on a minority of the biomethane calculated above, perhaps 10 TWh (around 1bn m^3 or 1% of national gas demand).

Would the government have worked hard to deliver a technology that was likely to deliver <1% of our gas requirements, and might stretch to 3.5% at best? What was the long-term decarbonisation strategy that justified heavy subsidy to deliver this marginal contribution?

This figure could be increased materially if one assumed a substantial contribution from energy crops for digestion, not considered as an option by NG/E&Y. It represents the discrepancy between the 3.3bn m^3 upper limit by this method, and the 6bn m^3 suggested in the analysis of the individual feedstocks above. The proportions nevertheless remain too small to make a persuasive case that the gas grid could be decarbonised to a material extent.

5 Costs

NG/E&Y estimated £10bn for the marginal capital cost of delivering their "stretch" scenario, i.e. the cost above expenditure that would be required anyway for other reasons, for the infrastructure to produce 18.4bn m^3 of biomethane p.a.

Most of this was with technology that was not mature enough to obtain a credible market price (gasification and methanation). But the AD component alone was 3,436m m^3 p.a. Very roughly, one might expect an AD biomethane facility to cost £2 per m^3 p.a. capacity, so the 20% of the "stretch" scenario gas that would be produced by AD would cost around £7bn. Perhaps they imagined that most of this could be covered by the waste disposal income? If so, they were predictably wrong (see below).

Capital cost is only one part of the cost. Unlike wind and solar, the operating cost of biogas production is a material part of the overall costs. The marginal capital cost is therefore a misleading indicator of the overall cost.

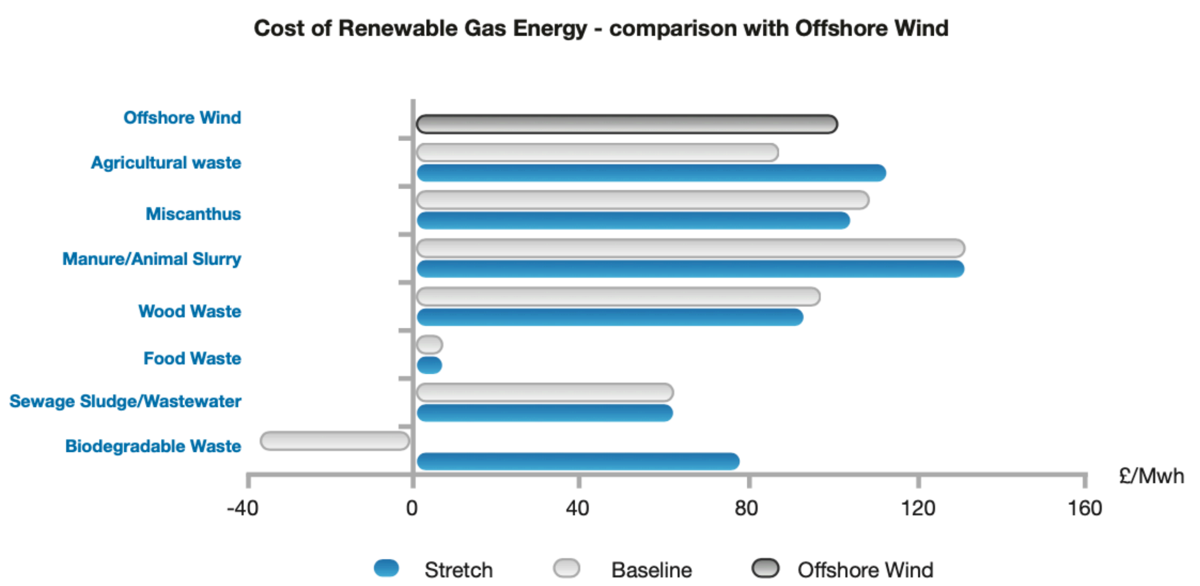
NG/E&Y highlighted only two costs: the marginal capital cost, and the gross revenue required. They compared the gross cost per MWh required by biomethane and by offshore wind, and judged them roughly equivalent. This obfuscates some key differences, such as the difference in the (unsupported) wholesale value of the product, and the amount of carbon displaced per MWh. It also implied that the purpose of supporting the technology to the level required to achieve this gross revenue was to cover the modest marginal capital cost of £10bn. They did not overtly translate the proposed level of support into an annual cost.

Their “stretch” total of 18.4bn m^3 equates to just under 200 TWh. With gross energy income of around £100/MWh as proposed, this would imply energy revenues of around £20bn p.a.

That includes some wholesale value for the gas, because they were obfuscating the true cost.[71] But one would not realistically project more than £25/MWh (in practice, it has recently fallen below £10/MWh). So around £15bn p.a. of their estimated gross revenue requirement is to support their cost above the competitive value (excluding social benefits) of their product.

If they had highlighted that their “stretch” scenario required support of £15bn annually or (say) £300bn over 20 years, it would have been received very differently than the emphasis on £10bn of net capital cost.

That is assuming their costings were accurate. They were not. The following was their estimate of the costs of producing biomethane from various feedstocks, compared with the cost of offshore wind.



Costing biomethane production from food waste at <£10/MWh implies that it offered substantial returns without any support, which was self-evidently not the case, as it had not happened. They assumed that such a small value was required for the energy because the rest of the costs would be covered by the “gate fee” for disposal of the waste. But:

(a) that gate fee was already applicable in the conditions in which no biomethane plants had been built despite gas values well above £10/MWh, and

[71] The wholesale value of each MWh of electricity delivered at a nominal cost of £100/MWh was materially higher than the wholesale value of each MWh of biomethane delivered at a nominal cost of £100/MWh. Focusing on the gross rather than net figure implies a false equivalence. £100/MWh of biomethane represents a higher level of support, even before one compares what each MWh delivers in terms of carbon displacement.

(b) a basic understanding of the law of supply and demand could predict what actually happened when the government incentivised even a fraction of the food-waste digestion envisaged by NG/E&Y: competition for the feedstock collapsed the value of the gate fee.

The same point applies to the negative estimate of the cost of using biodegradable waste in the baseline scenario. Even if producers had to pay £35/MWh to dispose of their gas, they expected to get 1bn m^3 of biomethane from this source by 2020. Such compelling economics should have meant a significant installed base by 2009, and the baseline 1bn m^3 by 2020.

In reality, it was providing nothing in 2009 and still nothing in 2020, given that the main feedstocks for AD were the separate categories of food waste and energy crops, and gasification for grid injection is insignificant. If we are right that this must refer to the slowly-putrescible elements of the waste stream such as paper and board, and therefore requires gasification, no rational analysis could have predicted substantial volumes at negative cost by 2020, given the state of maturity of the required technology in 2009. Synthetic Natural Gas (SNG) was eligible for the RHI biomethane tariff from its introduction in 2011. Support was initially at £68/MWh. It stimulated no significant amount of SNG production.

A price of £130/MWh of biomethane from manure may have been a reasonable guess in 2009. Holsworthy Biogas was not viable at £60/MWh of electricity while running primarily on manure.

With hindsight, it was an underestimate. When the Germans wanted to encourage more farm-scale digestion of this feedstock in 2012, they offered €250/MWh. As the ClimateXChange report noted, the RHI tariffs delivered very little of this, other than modest amounts for co-digestion.

Even if NG/E&Y's estimate of £130/MWh had been right, it was unjustifiable at that price by any recognised method of comparing the social cost and benefit. NG/E&Y themselves noted that it was more expensive per MWh than offshore wind. They did not add that the carbon intensity of grid electricity at that time was roughly double that of gas and was expected still to be significantly higher than gas in 2020. £130/MWh implies a carbon benefit (from displacing natural gas with this source of biomethane) of around £650/tCO_2e. No credible study has proposed a shadow carbon price anywhere near that level for 2020. Any mechanism to encourage this source at this price would have failed a government Economic Impact Assessment.

Their costing of the largely uncostable SNG option is mystifying. Miscanthus and wood waste definitely fall into this category and so too (probably) does biodegradable waste. The technology was not commercially available in 2009, yet they predicted a mid-range price, lower than digesting manure, and similar to the cost of digesting agricultural waste sufficiently in advance of 2020 that it would be massively deployed and competitive by that date. These elements were such a large proportion of the total that a moderate cost-estimate, however fanciful, was essential to the inflated estimate of the potential.

The RHI provided some insight into the true costs and potential when it was implemented. It delivered biomethane mainly from food waste and energy crops. Other feedstocks (besides sewage) were not significantly viable at RHI rates. The success with food waste and energy crops led to the RHI tariffs being degressed. The degression revealed the minimum level of support required to encourage projects of this type. New projects stopped being brought forward as the RHI tariff was reduced to around £40/MWh.[72] Reversing the degression to £50/MWh had little impact, revealing that other issues (i.e. feedstock availability) were now an issue as well as the energy value.[73]

The under-estimation of the cost of these sources of biomethane was a double-edged sword. It was helpful to persuade the government to put its heat-decarbonisation eggs in this basket, because the cost appeared more limited than it really was. But it led the government (and others) to believe that it could get more for its money than it really could.

6 The influence of the NG/E&Y report

The paper was cited by numerous academic papers, as though it was itself a rigorous piece of academic research.[74] In this way, it became adopted as part of the academic basis for policy development, without much investigation of its credibility.

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[72] c.£40/MWh for the first 40,000 MWh/yr, £25/MWh for the next 40,000 MWh/yr and £19/MWh for the rest.
[73] £57/MWh for the first trier, £34/MWh for the second tier and £26/MWh for the rest. 3 projects were accredited when the tariffs were raised in May 2018, three more followed in Jun and Dec 2018 and Jun 2019, but this was a dramatically-lower deployment rate than the peak in 2015/16.
[74] e.g. Dodds & MacDowell, "The future of the UK gas network", *Energy Policy*, Vol.60 (Sep 2013) https://doi.org/10.1016/j.enpol.2013.05.030
Floris van Foreest, "Does natural gas need a decarbonisation strategy? The cases of the Netherlands and the UK" (May 2011), Oxford Institute for Energy Studies, https://www.oxfordenergy.org/wpcms/wp-content/uploads/2011/05/NG-51.pdf
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https://spiral.imperial.ac.uk/bitstream/10044/1/30993/2/biogas%20manuscript%20accepted%20but%20not%20yet%20published.pdf

Lobby groups cited it, whether because it suited their interests or because they naively believed it and developed their views on the back of it.[75]

It was even cited by the Intergovernmental Panel on Climate Change (IPCC) as evidence for the potential and ease of integration of renewable gas, in their Dec 2009 report on *Integration of Renewable Energy into Present and Future Energy Systems*.[76]

One likely psychological factor in this credulous citation was that National Grid may have been seen as the sort of altruistic, impartial player that state-owned operators of national infrastructure are often wrongly perceived to be, long after National Grid became a private company with obvious commercial priorities.

Successful rent-seekers adopted the report as a marketing and lobbying tool.[77] Ecotricity promoted notional "green gas" from their supply business, on the basis of plans for their

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[76] https://archive.ipcc.ch/pdf/special-reports/srren/drafts/SRREN-FOD-Ch08.pdf
[77] Dale Vince, "'Green Gas' is here", Zero Carbonista blog (21 Nov 2009) http://zerocarbonista.com/2009/11/21/green-gas-is-here/
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production business to make major investments in the technology, given credibility by the potential indicated in the NG/E&Y report. In the event, almost none of the planned investment materialised, but the notional product remained available from their supply business.

Zero Carbon Britain (a cooperative project involving academia, NGOs, and the public and private sector) published *Zero Carbon Britain 2030, A New Energy Strategy* in 2010.[78] On renewables, they explained

> *As our basis, we use the UK Energy Research Council's (UKERC, 2009) £18 million research into electricity scenarios and integrate this with the work of NERA Economic Consulting and AEA (2009) for DECC on heat, and work from the* ***National Grid (2009) on biogas****, as well as further specialised research from an array of academic sources. With this, we create a vision of how the energy system could look like in 2030.*

The report was endorsed by many individuals and organisations who were influential in energy policy.

National Grid also self-referentially cited it in applications to the regulator as evidence of the potential of the technology.[79] They also, incidentally, published an equivalent study for the other region (USA) in which they had significant business interests.[80]

The breadth of this report's citation naturally led to its inclusion within government publications as a credible source.[81]

E.ON, Lend Lease proposal for Elephant and Castle (Mar 2012), http://www.energyforlondon.org/wp-content/uploads/2013/04/Heygate-Energy-Strategy.pdf
Renewable Energy Association, "Renewable Electricity and Heat Tariffs, preliminary blueprint" (Mar 2009) https://www.fitariffs.co.uk/library/regulation/0903REA_Blueprint1-1.pdf
Stephen Tindale for Center for European Reform, "How to meet the EU's 2020 renewables target" (Sep 2012) https://issuu.com/centreforeuropeanreform/docs/120902162817-e047a61a4a764309b37f1c8e4c07f4df

[78] https://www.cat.org.uk/app/uploads/dlm_uploads/2018/11/zcb2030-A-new-energy-strategy.pdf

[79] National Grid, Gas Network Innovation Competition Screening Submission Pro-forma, https://www.ofgem.gov.uk/sites/default/files/docs/2015/05/gas_isp_power_to_gas_project_0.pdf

[80] https://www9.nationalgridus.com/non_html/ng_renewable_wp.pdf
https://www.gasfoundation.org/wp-content/uploads/2019/11/agf-renewable-gas-assessment-report-110901.pdf

[81] E4Tech for DECC and NNFCC, "The potential for bioSNG production in the UK" (Apr 2010), https://www.build-a-gasifier.com/PDF/BioSNG-final-report-E4tech-14-06-10.pdf
Houses of Parliament Library Research Briefings, "Decarbonising the gas network" (2017), http://researchbriefings.files.parliament.uk/documents/POST-PN-0565/POST-PN-0565.pdf
Energy & Climate Change Committee, *Low carbon technologies in a green economy: 4th report of Session 2009-10*
Sustainable Development Commission Scotland, *Renewable Heat in Scotland* (Jul 2009), http://www.sd-commission.org.uk/data/files/publications/SDC%20Renewable%20Heat%20Report.pdf
DECC/Ofgem, *Energy Markets Outlook Report* (Dec 2009)
Scottish Enterprise, *Low Carbon Heat Foresighting Discussion Paper* (Mar 2015) http://www.evaluationsonline.org.uk/evaluations/Documents.do?action=download&id=751&ui=browse
Ricardo-AEA Report for the Task Force on Fuel Efficient, Low Emission HGV Technologies, "Opportunities to overcome the barriers to uptake of low emission technologies for each commercial vehicle duty cycle" https://www.lowcvp.org.uk/assets/reports/Opportunities%20for%20low%20emission%20HGVs%20-%20final%20report%202012.pdf

7 The impact on policy

Those involved were in no doubt about the reports' direct influence on policy. Their lead within National Grid (Janine Freeman, Head of Sustainable Gas Group at the time) notes in her LinkedIn profile that she:[82]

> *Led an influential piece of analysis to consider the potential for renewable gas (biogas) in the UK. Then went on to work with government and industry to create the appropriate incentives for investment in renewable gas infrastructure in the UK and the US.*

The report of Ms Freeman's appearance before the London Assembly's Environment Committee in July 2009 illustrates the impact of National Grid's work and the limited expertise of policymakers discussing the analysis.[83]

A 2009 article in Biomass Magazine similarly records National Grid's own positive assessment of its influence.[84]

> *The January 2009 report, titled "The Potential for Renewable Gas in the U.K," has been delivered to the U.K.'s Department of Energy & Climate Change.*
>
> *"After we published the report, the phones were red-hot with waste companies and local waste management authorities contacting us," says Isobel Rowley, press officer for National Grid. "It certainly rang a bell."*

A 2019 study into actor influence on the UK's heat strategy confirmed National Grid's influence on heat policy at this time.[85]

> *It was however suggested by a number of interviewees that National Grid is influential and that their modelling and their annual 'Future Energy Scenarios' 'puts them in quite a strong place' because of their ability to shape the energy debate (anonymous). Another interviewee explained that National Grid frame arguments based on their importance and role in the energy system, in the interviewee's words, the 'you need us' frame:*
>
> > *'They've [National Grid] got a lot of power. So the Government's got to talk to the Big Six, well God they have to talk to National Grid. Without National Grid on-side, everything stops.' (anonymous)*

82 https://www.linkedin.com/in/janine-freeman-21836716/

83 http://www.london.gov.uk/moderngov/Data/Environment%20Committee/20090709/Minutes/Appendix%20A%20RTF.rtf

84 http://biomassmagazine.com/articles/2619/her-majesty%27s-biogas

85 Richard Lowes, "Power and heat transformation policy: Actor influence on the development of the UK's heat strategy and the GB Renewable Heat Incentive with a comparative Dutch case study", Exeter University PhD thesis. https://ore.exeter.ac.uk/repository/bitstream/handle/10871/38940/LowesR.pdf?sequence=1&isAllowed=y

> *Another interviewee mentioned their 'crazy biomethane projections which still reverberate today and still get quoted' (anonymous).*[86]

The government's consultation on a Renewable Energy Strategy in 2008 shortly preceded the publication of the NG/E&Y report in early 2009. There were many supporting documents to the consultation (including one by Ernst & Young).[87] One of them considered alternative uses for biogas such as scrubbing and grid injection.[88] It concluded that:

> *Biogas upgrade to bio-methane does not appear commercially competitive due to the costs of upgrading and distribution. Although employing these delivery routes (rather than supporting the development of CHP) does yield greater quantities of renewable heat, it does not enhance the carbon savings – indeed these decline quite significantly. Also, the costs of overcoming supply-side barriers are higher than under the alternative option.*

Biomethane or biogas injection were notable by their absence from the other documents supporting the consultation.[89]

As early as Feb 2009 (a month after the NG/E&Y report), the position had changed to:[90]

> *[biogas] can be upgraded to make biomethane, which can be injected directly into the national gas grid. These technologies can play an important role in helping to achieve our ambitions on renewable heat. We will also carry out further work with the industry to overcome the particular challenges faced by these technologies. Given the special characteristics of this technology, the enabling powers in the Energy Act explicitly allow the RHI to support the production of biogas and biomethane.*

Industry lobbyists in parliament used the report to petition for more favourable treatment of biomethane in forthcoming legislation. In Lords questions, the minister (Lord Hunt) expressed scepticism about the upper end of NG/E&Y's projections, but agreed to subsidiary points that the technology should be taken into consideration.[91]

The government published its response to the consultation and the Renewable Energy Strategy itself in summer 2009, after the publication of the NG/E&Y report.[92] Biomethane

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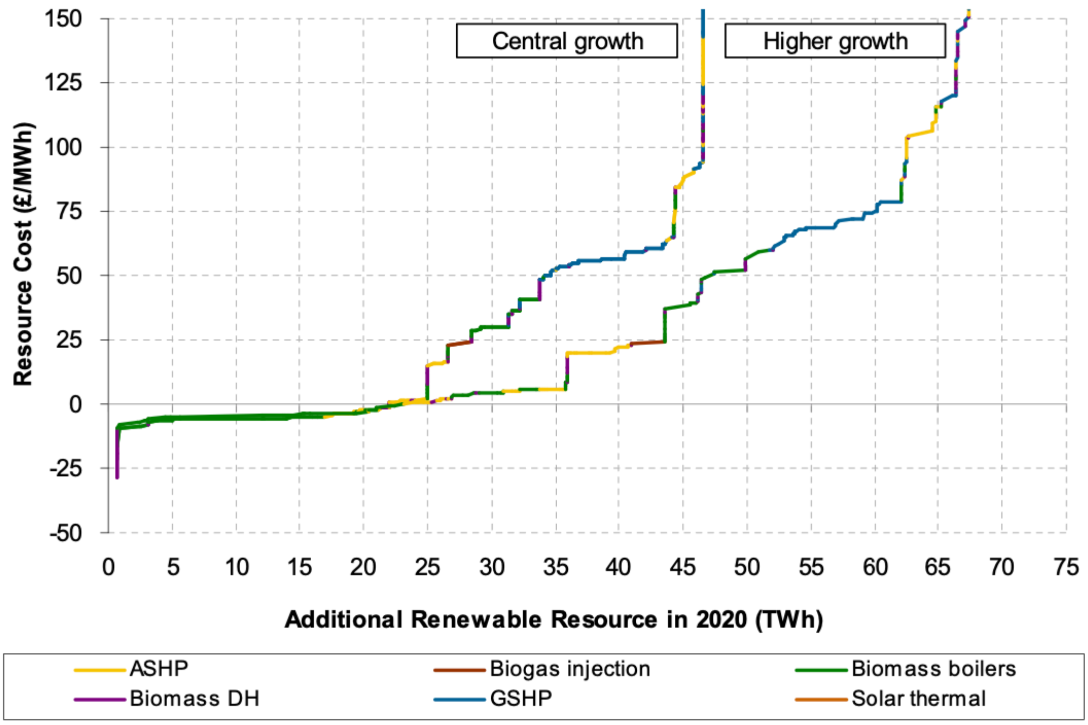
[86] Section 9.1.2.3, p.223 *passim.*
[87] https://www.gov.uk/government/consultations/progressing-our-renewable-energy-strategy
[88] Enviros, *Barriers to renewable heat part 2b: analysis of biogas options* (Sep 2008) http://www.decc.gov.uk//assets/decc/Consultations/Renewable%20Energy%20Strategy%20Consultation/Related%20documents/1_20090501125256_e_@@_4BiogasFinalReportv40.pdf
[89] The Impact Assessment for Renewable Heat refers in a few places to "upgrading biogas", but a comment on p.8 makes it clear this is referring to "upgrading electricity-only biogas plant to CHP".
[90] DECC, *Heat and Energy Saving Strategy Consultation* (Feb 2009) https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/243625/9780108508158.pdf
[91] https://www.theyworkforyou.com/lords/?id=2009-02-24a.104.0
[92] https://webarchive.nationalarchives.gov.uk/20100512180246/http://www.decc.gov.uk/en/content/cms/consultations/cons_res/cons_res.aspx

had become one of the favoured technologies, though its anticipated contribution remained modest. In NERA's associated study on the UK Renewable Heat Supply Curves, it was expected to contribute around 2.3 – 3.5 TWh at a resource cost of around £25/MWh.



That and the low cost put by the NG/E&Y study on biomethane from food and biodegradable waste probably explains why the original tariff proposed for biomethane in the RHI was relatively low at 4p/kWh.[93]

Richard Lowes describes in his thesis the substantial modifications to the RHI shortly before it was launched, driven by a desire to achieve more cost-effectiveness.[94] One of the changes was to increase the biomethane tariff to 6.5p/kWh, which (along with some other changes) nearly doubled the value of the RHI for this technology. That is not an obvious way to save cost. However, it accompanied a reduction in support (and delivery expectation) for solar thermal and some other changes for smaller (expensive) systems. The logic was presumably that it was better to encourage more large schemes, even if support had to be increased to achieve that, because it was still cheaper than many small schemes. This logic could hardly have applied if DECC had not been persuaded in the meantime that there was more biomethane potential to deliver than initially thought.

By 2012, scepticism was reasserting itself. The Committee on Climate Change's 2011 Review of Bioenergy expressed strong doubts about National Grid's estimates of the potential of biomethane.[95] Lowes records that government opinion began to swing in favour of a focus

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https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/228866/7686.pdf

[93] Lowes thesis, Annex 4

[94] Section 8.7: Policy episode 7 – RHI scheme implementation (2011)

[95] https://www.theccc.org.uk/publication/bioenergy-review/

on the electrification of heat. National Grid played a crucial part (as the operator of both key networks) in arguing (a) that full electrification was not practical because of peak demands, and (b) that the gas network was crucial for meeting those peaks.

Lowes queries what role NG would have played, given that they have interests in both electricity and gas. The obvious answers are that (a) they did (as he records), (b) there were other options involving neither grid, which would have been their primary objective to diminish, and (c) they would want to see an ongoing future for both of their networks. Whilst the electricity network was under no threat (given plans to electrify transport as well as heat), it was possible to envisage (because such a model was common in Europe) a heat-decarbonisation model in which gas utilisation fell materially and damaged their returns on that part of their investment. Indeed, Lowes concludes that it was:

> *clear that National Grid attempted to promote the role of their gas assets throughout the development of UK heat policies and interviewees saw them as an actor with some power in the heat policy debate*

8 Epilogue

By the end of the 2010s, the limits to the potential of biomethane, and the absurdity of NG/E&Y's 2009 projections were unavoidable. Biomethane was contributing 0.7% of the UK's gas. Electrification of heat wasn't doing much better. Solid biomass was dominating the relatively-limited amount of renewable heat that the UK had deployed.

Following the separation of the gas and electricity networks, Cadent were the successor to National Grid as the operator of the gas grid. They commissioned Anthesis and E4Tech to produce a "Technical Report" in 2017 on "Review of Bioenergy Potential".[96] Unsurprisingly, this judged that the potential was large and that most of that potential could be used to produce renewable gas.

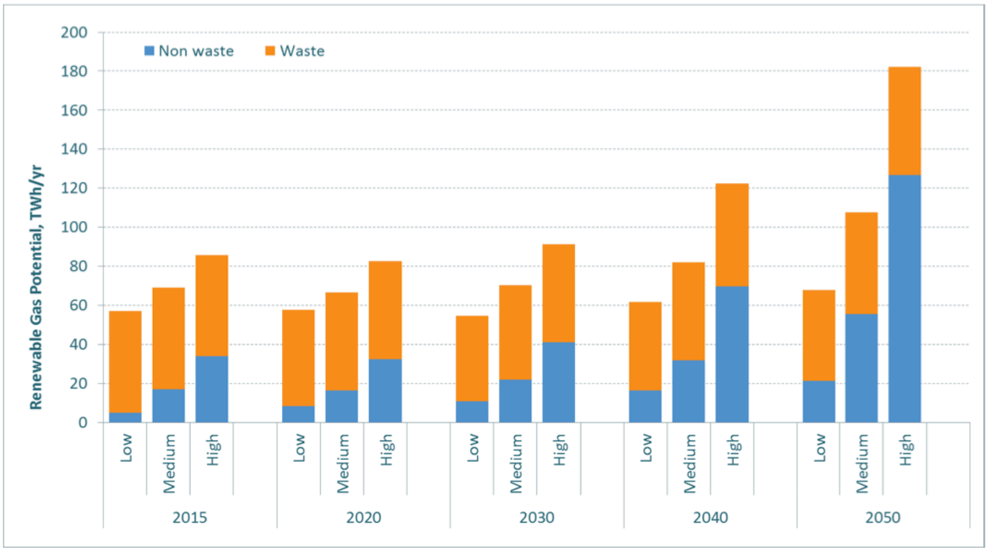

Figure 26: Renewable gas potential 2015 to 2050

[96] https://cadentgas.com/nggdwsdev/media/media/reports/futureofgas/Cadent-Bioenergy-Market-Review-TECHNICAL-Report-FINAL-amended.pdf

Despite attempts to re-stimulate the technology by reversing earlier RHI degressions, UK production of biomethane remains around 3 TWh p.a. as of early 2020.[97]

The study's range of 68-183 TWh in 2050 is composed of:

- 47-56 TWh from **waste feedstocks**, with 83% of this coming from bioSNG and 17% from biomethane via AD; and
- 21-127 TWh from **non-waste feedstock,** with 97% of this coming energy crops, short rotation forestry and wood/forestry residues converted to bioSNG and the remaining 3% from biomethane via anaerobic digestion of wet manures and macro-algae.

In other words, they are still hanging their hat on gasification for most of this gas, and have significantly beefed up the assumed contribution of energy crops for gasifying, presumably recognising that the claims for the potential of waste feedstocks had been falsified by events after the 2009 report.

Like the 2009 report, this new report is being cited in other studies as a credible piece of academic research.[98]

Meanwhile, National Grid is promoting a model of (roughly) 60% electrification and 40% hydrogen and biogas (replacing natural gas) for the UK's 2050 heat supplies.[99] This too is being cited in studies by academics, pressure groups, consultants and government bodies.

The annual output of heat pumps in the RHI is around 170 GWh (<0.03% of UK heat demand).[100] The only hydrogen heating in the UK is in experimental projects.

One could carry out a similar analysis of the claims in these studies, but ultimately only history will tell, as it did when we reached the 2020 forecast date for the 2009 study. As we have demonstrated, those projections were objectively improbable in 2009, as are the current projections from Cadent and National Grid ten years later. They also served the same, obvious commercial purpose.

Will our policymakers continue to believe self-serving projections simply because they are produced by operators of our national infrastructure, who are big enough to have the resources to produce and promote them? Or will they learn to rely instead on sound, technology-neutral economic policy that supports continuous market competition, discovery and innovation, and does not attempt to pick winners on the strength of motivated projections of the unknowable future?

[97] Comparing the cumulative totals for biomethane in copies of Ofgem's RHI Public Report downloaded in early 2020 and early 2019. https://rhi.ofgem.gov.uk/Public/ExternalReportDetail.aspx?RP=RHIPublicReport

[98] e.g. BEIS, *Clean Growth – Transforming Heating (Overview of current evidence)* (Dec 2018)

[99] e.g. *Future Energy Scenarios* (Jul 2019) http://fes.nationalgrid.com/media/1409/fes-2019.pdf and their *Future of Gas* studies (https://futureofgas.uk/homepage/).

[100] The Digest of UK Energy Statistics records 979 ktoe (11.4 TWh) by the expedient of adding around 1,000 ktoe to the previous total in 2018 (backdated to 2015) by redefining commercial air-conditioning units as "Reversible Air-to-Air Heat Pumps" and making ambitious claims for their efficiency and utilisation for heating purposes. The RHI figure indicates the amount of heat pumps heating that has actually been added since 2011.