GAS USERS ORGANISATION

Labour Party Green Recovery Consultation

Consultation answers

1. What sectors do you believe are the priorities for investment from government, for a green recovery programme to build a stronger, more resilient future economy? How can this investment reduce regional inequalities as well as address the climate crisis and environmental degradation? And what science and technologies do we need to invest in?

It is our view that there is a pressing strategic need for government to support the development of a commercial biomethane sector, using gasification technology. This is the best option for meeting the UK's climate change objectives for the decarbonisation of heating, and once the biomethane manufacturing sector is mature it would support tens of thousands of well-paid jobs, across the regions and nations.

Heating accounts for over a third of the UK's greenhouse gas emissions. [i] The government claims to recognise that "*heat decarbonisation is a complex policy challenge, requiring a combination of approaches contributing to complementary goals, that will require a long term policy framework to incentivise and support the national transition required*". [ii] However, in reality, the government's approach to heat decarbonisation lacks coherent vision. The UK has failed to make a strategic commitment towards a future of the gas network, which currently supplies 85% of domestic properties. Lack of confidence in the future of gas is best seen by the ill-considered ban on gas boilers in new properties from 2025. Mandating the installation of hydrogen ready boilers would be more constructive.

The Government's position on long term heat strategy envisages Britain decoupling itself from gas as a heating source, i.e., that heat will be electrified over the next thirty years, without any clear appreciation of the scale of reinforcement that this would require for the electricity generating and transmission system, nor of the scale of customer resistance that they should anticipate.

One of the most constructive contributions to the debate about decarbonising heat was the publication in 2016, by the Parliamentary Labour Party Energy and Climate Change Committee of the Green Gas Book. [iii]

In the Green Gas Book, Tony Glover, of the Energy Networks Association (ENA) argued that the economic costs of any growth of the electricity network must be considered: "*Research commissioned by ENA has revealed that without a role for gas, the reinforcement of the electricity network to handle increased load and greater seasonal peaks from heat demand is projected to cost £16-28bn to 2050. The report found that if gas plays a role in a balanced transition to a zero carbon future it will reduce the cost of additional investment in the electricity network by £8billion. This figure does not consider significant additional costs of removing gas from the mix such as new generation capacity, decommissioning of the gas network or upgrading domestic appliances.*" [iv] Nor can it simply be assumed that the additional electricity capacity could easily be met from renewable sources.

However, the Green Gas Book did not just point out a flaw in the government's strategy, it also provided a viable alternative strategy, which is to maintain the gas network, but to decarbonise it through the use of several, complementary measures. As Dr Alan Whitehead, a former Shadow Energy and Climate Change Minister argues in the Green Book: "*whilst there is no easy switch with which to wish away mineral gas, there are collectively, a number of what might be as '10% solutions' which between them, go quite a long way towards meeting much of the likely demand for gas as a fuel for domestic and commercial heating. And whilst all of these solutions have* *different advantages, limitations and drawbacks, it does look as if, collectively, they pose a few gentler and less disruptive challenge than ripping everything out and starting again with heat pumps."* [v]

Some of the contributory partial solutions can be summarised as follows:

- National Grid suggests that assuming continued improvements in the thermal efficiency of buildings, there could be a reduction of 30% of gas usage by domestic households by 2050; [vi], [vii]
- Bio-Substitute Natural Gas (bioSYN) has the potential to increase the amount of renewable gas produced in the UK to 100TWh per annum using gasification (the potential to satisfy 50% of that residual domestic gas demand by 2050). [viii], [ix]
- Biomethane produced by anaerobic digestion could contribute a further 35Twh.[x]
- The hydeploy project shows that up to 20% hydrogen can be introduced into the grid. [xi]
- The H21 project shows that it would be viable to have 100% hydrogen on perhaps a city wide basis. [xii]

it should be noted in addition that:

- Gasification plants are future proofed with only low risk of becoming stranded assets if the grid later converts to hydrogen, as the same waste and biomass supply chains, gasification, (and potentially, carbon capture and sequestration) processes can be used for both bioSYN and hydrogen production. [xiii]
- Producing bioSYN is the best performing option for reduction of greenhouse gas emissions from the treatment of municipal waste. [xiv]
- BioSYN provides the baseline potential to decarbonise the gas grid without replacing it by electric powered heating. It would be a lower cost option, and would meet the approval of domestic gas consumers. Domestic heat customers are very resistant to heat pumps or heat networks but would be happy to use biomethane because it does not require new heating equipment.

Therefore, a strategic commitment towards the development of bioSYN and hydrogen technology to decarbonise heating, while preserving the existing gas transmission and distribution infrastructure, would be a low regrets option, and would offer the best solution for making best use of the energy available from using the UK's waste as feedstock. [xv]

It can be confusing to non-specialists that there are two different technologies for producing biomethane:

- Biogas produced when organic matter decomposes without the presence of oxygen, known as anaerobic digestion (AD) can be upgraded to "biomethane" by removing impurities, such as carbon dioxide, hydrogen sulphide, moisture, and other gases. [xvi]
- Biomethane can also be produced by gasification and methanation, which is known as Bio-Substitute Natural Gas (bioSYN).

In the UK, support from the Non-Domestic Renewable Heating Initiative (NRDHI) scheme has kickstarted a domestic biomethane industry which has so far delivered over 10,000 GWh worth of low carbon gas into the gas grid, produced by AD. [xvii], [xviii] As of January 2020, the RHI had supported the deployment of 94 biomethane plants. [xix]

However, while AD can make a significant, secondary contribution to gas decarbonisation, it will never be able to produce enough biomethane on its own to solve the problem. Gasification to produce bioSYN is necessary. AD has a number of disadvantages, in particular:

- In the UK, some projects have failed, due to lack of capacity in the grid to receive the gas, for example, Grindley Farm, has been closed since 2018, having operated for only 1500 hours since opening in 2016. [xx]
- Uncertainty in the business model can represent significant capital risk. This is despite the technology being well established, and there being an established investment community happy to support projects. [xxi]
- Lack of grid capacity has led to approximately 30% of potentially viable biomethane projects in the UK either not proceeding at all, or the gas has gone instead to electricity generation through Combined Heat and Power (CHP), which is less effective for mitigation of greenhouse gases, and is a less efficient use of energy. [xxii]

The grid capacity issue does not occur with bioSYN. However, the bioSYN industry is in a transitional stage, where the commercial viability has been established on a demonstration stage, but government support, not all of it financial, is necessary to develop the fledgling sector into an economically sustainable sector.

- Although still in the development stage as a commercial process, BioSYN is produced by gasification and methanation, both of which are mature and well understood technologies. The gasification plant at Great Plains, Dakota, has been in commercial operation producing methane from a fossil fuel feedstock (lignite) since 1984. [xxiii]
- The Gobigas project in Sweden has established that bioSYN production on a commercial scale is viable, although further refinement of the technology is required. [xxiv], [xxv]
- Most technological options for gasification lead to a sufficiently pure carbon dioxide stream to be suitable for carbon capture. [xxvi], [xxvii] The BioSNG demonstration plant in Swindon produced liquid carbon dioxide that was sold to Air Liquide for use in industry. [xxviii] However, there is a glaring gap in government support because CCS (Carbon Capture and Storage) is currently not financially rewarded.

In the UK the Renewable Heat Incentive (RHI) is the most obvious mechanism to provide support for bioSNG injection into the gas grid, however, BEIS is now proposing to only support AD. [xxix] This both undermines the certainty required for investors into BioSYN, and also removes the foundation of sustainable income required for the sector to move forward.

Currently the cost of producing bioSNG is substantially higher than the cost of producing natural gas. This implies that support will be needed whilst the technology comes down the cost curve to approach the cost of natural gas, however weak and market-based support policies can be a strong barrier to the development of additional plants and low natural gas prices can magnify this problem. [xxx], [xxxi] Industry sources have proposed [xxxii] the levels of support they believe necessary for the development of commercially viable bioSNG plants, but the tariff levels currently being proposed for the Green Gas Support Scheme would not be sufficient. [xxxiii]

Sadly, the UK government displays a very weak understanding of the strategic advantages of bioSYN from gasification, for example, the latest BEIS consultation commits only to the proposition that “*It may also be appropriate to extend green gas support in the longer-term to innovative green gas production technologies, such as advanced gasification.*” [xxxiv]

The economics of AD and bioSYN need to be considered separately, as AD is now a relatively mature technology, and is favoured by UK government support. Arguably, biomethane for heating produced from AD has received better levels of political support than other types of renewable energy such as solar, onshore wind and biogas for electricity generation, where tariffs and obligations have been reduced or withdrawn. [xxxv]

However, even with biomethane from AD, gas producers point to a confusing landscape of sustainability policies, with inconsistent criteria for transport (the renewable transport fuel obligation guidance from the Department of Transport); for heating (the RHI guidance from Ofgem); for electricity generation (the Contract of Difference sustainability criteria); and for meeting the renewables obligation sustainability criteria, (also administered by Ofgem). There are some significant differences. For example, transport biofuels made from waste are required to demonstrate that their greenhouse gas emissions are significantly lower than fossil fuels while electricity generated from waste does not have to carry out any greenhouse gas emissions assessment. [xxxvi] A coherent government sustainability policy across all sectors would be a zero cost boost to the sector.

The UK has also failed to develop a strategic plan for feedstock supply chains. Cadent has pointed out that the UK lacks a joined-up government approach to waste and energy. [xxxvii] At present there is also no clear policy on how land should be used, with competing demands between energy crops, food, leisure and wildlife, and this deters landowners in investing in crops for bioenergy. [xxxviii]

The UK government's vision is to *"focus on market-based mechanisms, which leverage competitive forces to drive down costs and ensure cost-effectiveness, as the basis for any ongoing policy support for the range of green gas options that might be commercially available"* [xxxix]

There is a paradox here, because any purely market-based approach will struggle to produce gas at a price competitive with natural gas from fossil sources. At a global level, the natural gas market continues to prosper and expand, including the huge expansion of non-conventional gas from shale sources in the USA, and the resulting price drop. [xl] It is therefore foreseeable that between now and the 2050 target for the UK to decarbonise its heating network, all options will be more expensive than retaining natural gas. Therefore, decarbonisation inevitably requires government intervention to distort market mechanisms.

For this reason, a clear strategic plan from government is required to address what the most effective decarbonisation options are; to support early stage development of technologies as they scale up for commercial viability; to plan for feedstock availability; and to provide subsidies and tariffs that achieve the objectives. To ensure competitive return on investment, producers need to be assured that they will continue to have a market for their gas over the lifetime of the project, where the greater competitiveness of natural gas prices is a long term risk.

While the fundamental technology is well understood, a range of potential improvements to today's bioSNG technologies could further reduce costs, improve efficiency, and reduce greenhouse gas emissions. [xli], [xlii], [xliii], [xliv]

To expand bioSYN production, the following steps are required.

- A clear commitment towards expanding the bioSYN sector as a strategic goal to improve investor confidence. The development of supply chains and gasification technology is future proofed, as these would also be applicable for hydrogen production.

- BioSYN needs to either be included in the remit of the Green Gas Support Scheme, or a separate scheme is required to specifically support bioSYN. Tariffs need to be set at a level that will support bioSYN until production costs come down the cost curve to levels similar to natural gas.
- There needs to be strategic commitment to building multiple bioSYN plants, to allow refinement of the technology, and to improve engineering, procurement and construction (EPC) experience.
- Government clarification is required that bioSYN investment is protected by the infrastructure loan guarantee programme.
- Direct government investment in the first plants would kick start this contribution to strategic national infrastructure
- The benefits of carbon capture and storage need to be monetised.
- Government support is needed to ensure supplies of waste as feedstock, as Municipally Sourced Waste (MSW) supplies may be limited by existing long-term contractual commitments for other disposal methods.

2. How do we support people who have lost employment during this crisis to move into environmental growth sectors? How can we ensure that such jobs are decently paid, with quality training, and offer representation by trade unions? What lessons can be learned from past programmes current support and international examples?

We have no view on this.

3. How should sector-specific support for business during this crisis be used to both protect and promote employment and to pursue our climate and nature objectives?

There are four sectors of employment that can benefit from expanding production of bioSYN.

- The development of each gasification plant would create up to 100 jobs during the construction phase,
- Each plant would provide jobs for up to 50 full-time, skilled engineers once operational, with further jobs created in the supply chain. [xlv]
- Processing municipal waste as a feedstock has a higher employment density than either incineration or landfill.
- If MSW is used as the feedstock of choice for bioSYN gasification, then it would make sense to increase the use of agriculturally sourced biomass for AD generation of biomethane, because this allows greater flexibility to locate AD plants where there is capacity in the grid to receive the gas. [xlvi] This would create additional agricultural and rural jobs.

In addition, maintenance of the gas transmission and distribution network will secure continued employment for the 120000 Gas Safe registered engineers, the staff of the 56000 businesses registered with Gas Safe, and the thousands of jobs in the supply chains for boilers, and other fittings.

To move the bioSYN sector from its current developmental phase to being an established and mature commercial industry would require some pump priming, of say twenty smaller plants. This would be expected to involve up to 2000 construction jobs, and 1000 operational jobs.

Currently, 52% of domestic waste goes to landfill, costing £65 per tonne to dispose of. A further 8% is exported to Europe. The availability and cost of domestic waste makes it commercially viable as alternative source of bioSYN.[xlvii] However, one of the obstacles is that municipal waste disposal is often locked into long term contracts, of up to 25 years. Currently, for the support of heat networks, the government provides practical support for projects through the Heat Network Delivery Unit (HNDU). A similar unit could be established to provide government support for establishing MSW supply chains for biomethane production, which would expand employment, as MSW is more labour intensive than either landfill or incineration, and in a higher value sector of the economy. [xlviii] This is a low-cost option, that would create jobs across the regions and nations.

At present there is no clear government policy on how land should be used, with competing demands between energy crops, food, leisure and wildlife, and this deters landowners in investing in crops for bioenergy. [xlix] Areas planted for energy crops are currently relatively low in the UK, but planned expansion of such crops could include such woody crops as short rotation coppice (SRC) and short rotation forestry (SRF), and grassy crops such as Miscanthus, which can be specifically grown for energy purposes, with high yields and relatively low inputs. [l] To expand this sector, government support is required for biomass supply chains, which would create employment across the regions and nations.

4. What is the scope for redeploying people from industries which are facing crisis? What are the models of retraining and support which should be examined? Do you know of examples of programmes which have been effective in enabling redeployment; and what can we learn from programmes that have not been effective?

We have no view on this.

5. Given the regional and area-based impacts of this crisis, what role can a green recovery play in mitigating these impacts? What are the lessons of past environmental interventions in terms of local and regional impacts?

We have no view on this.

6. How can we help existing businesses, including SMEs, to adapt as a result of the crisis, including through measures for a green recovery? How can these measures be allied to the improvement of productivity and viability for these companies?

We have no view on this.

7. How can measures you are proposing in this recovery and renewal period improve quality of life—for example around walking, cycling and public transport, and improving access to nature? What habitats are you especially concerned about and want to see more support for and focus on?

We have no view on this.

8. In providing responses to 1-7, please can you indicate to us what considerations of cost-benefit analysis are relevant (and, if such analysis has not been undertaken, what sources of information would be necessary to understand costs and benefits); and which institutions would be required to enable effective delivery? In particular what is the role of public and private investment and different ownership models?

The strategic opportunity provided by the gasification sector is that an established investment community already exists. It must therefore be stressed that the mature sector would rely upon private sector investment. However, the sector faces four challenges, which require public sector pump priming to rectify:

- Fragility of investor confidence to any sign of weakening of government support.
- Lack of government support in moving the sector from development to mature status.
- Incremental improvements to the technology require a number of commercial plants to be built, but investors are holding off because they want the technology to already be fully mature.
- Inadequate feed-in-tariff support (indeed BEIS is now proposing to completely exclude bioSYN from tariff support).

Since the first commercial connection in 2012 the biomethane market from AD has developed rapidly in the UK due to the feed-in-tariff. However, tariff levels within the RHI reduced over time due to a so-called degression mechanism, which lowered entry point subsidies in response to market signals. [li] and when they fell below £58.70/MWh developers considered that new projects were not viable. [lii] In 2018 tariffs were reset to a higher level which triggered around 30 new projects, currently in various stages of development. [liii] This is evidence of a welcome willingness of BEIS to respond to support the sector, but also demonstrates the sensitivity of the sector to levels of subsidy support, and to the fragility of investor confidence where they sense any weakening of government support.

This sensitivity to signals from government can be seen in the paradox that the recent expansion of around 1000 new French registrations for proposed AD projects may be a response to perceived weakening support, with developers seeking to be accepted for Feed-in-Tariffs before the closing deadline. [liv] Government support is considered to be more stable in Germany, where the there is a clear understanding in the political debate over “Dialogprozess Gas 2030” that biomethane will play a significant role in the economy, especially against the background of the upcoming nuclear and coal phase out. This is a significant factor in providing business confidence for investors in Germany. [lv]

Capex costs for commercial-scale bioSYN plants are anticipated to be in the order of hundreds of millions of pounds. There is the perception that while UK funding for pilot and development-scale projects is available there is insufficient support for the capex costs of the first commercial-scale projects – either in terms of financial support or loan guarantees. As a result of the very broad definitions in the UK Infrastructure Act, it is not clear whether the UK's infrastructure loan guarantee programme would support an individual bioSNG project. [lvi] This is another area where strategic government support is required.

While the fundamental technology is well understood, a range of potential improvements to today's bioSNG technologies could further reduce costs, improve efficiency, and reduce greenhouse gas emissions. [lvii] As the industry moves towards a mature stage, [lviii] it is expected that deployment of multiple plants, combined with the scaling up of these plants would bring down plant capex by 30% and opex by 19%. [lix]

These reductions arise primarily from economies of scale in the major capital cost components (gasifier, methanation) and labour, and reduction of real and perceived risk leading to reduction in Engineering, Procurement and Construction (EPC) and construction management costs. High capital costs and technology risk also limit developers' access to capital, and the costs of methane produced will be higher than natural gas for the first plants. In addition, the value of negative emissions if bioSNG were combined with carbon capture and storage (CCS) cannot currently be monetised. [lx]

It is necessary to understand the "chicken and egg" dilemma that research into improved techniques, and the resulting economic benefits to cost and efficiency, relies upon commercial development of the bioSYN sector being undertaken before those process improvements have been perfected. Therefore, strategic government support is necessary for the first commercial scale plants in order to reduce project risk, reflecting the development status of bioSYN.

Larger-scale gasification plants will have lower costs through economies of scale. For example, on scale-up from 60MW to 200MW there is a 35% reduction in capex and a 36% reduction in opex, and on scale-up from 200MW to 400MW there is a 20% reduction in capex and an 18% reduction in opex. [lxi] However, this creates another "chicken and egg" dilemma that while bioSNG plants are only likely to be viable without subsidies at scales above 80 MW, investors are unlikely to risk the significant amounts of capital for such large-scale plants before they can see the technology operating reliably at smaller scale, and therefore a gradual scale-up is required in order to iron out any technology issues at smaller scales, to prevent these issues becoming a major challenge in a larger-scale plant. [lxii]

The deployment of multiple plants would also bring benefits, independent of the benefits that could be gained through scale-up. Industry data suggests that manufacture of multiple gasifiers, even if they were different designs, could bring down capex by 15%, and opex by 6.1%. Greater engineering, procurement and construction (EPC) experience in gasification would bring down costs. A lack of knowledge or experience with the construction of gasification plants means that EPC contractors perceive these projects as risky, and consequently charge more for project construction. It is estimated that EPC costs currently add 40% on top of plant capex, compared with the 15-20% commonly charged for established technologies. [lxiii]

The proposition for a future bioSYN plants once the sector matures, is summarised by Cadent: "*Commercial plant will be between ~300-600GWh per annum capacity. The long term price for gas is around £18-26/MWh without subsidy and depending on scale. In the shorter term, the first wave of commercial plants would depend on RHI support. …. A typical commercial waste-to-energy plant will process between 150,000 & 300,000 tonnes of feedstock to produce 0.3-0.6TWh per annum of gas. …. BioSNG plants will cost around £100m to build and would last 25 years. The majority of the investment is likely to be spent with UK companies, increasing economic activity and generating tax revenue for the Government*." [lxiv]

The strategic necessity is therefore for the government to commit to supporting the development of multiple, smaller plants, but that are still on a commercial scale.

As a model, the largest scale project to date producing biomethane by gasification was Gobigas in Sweden, run by Göteborg Energi. From a technical perspective the project made significant progress and demonstrated good results, with a capacity of 20 MW, and achieved production of 149 GWh per year. Phase 1 of the project was funded through a SKr222m (approximately £19m) grant from the Swedish Energy Agency (SEA).

Government support for commercial scale projects would provide leveraged benefits in improving investor confidence in the sector, particularly when combined with feed-in-tariff support, and support for feedstock supply chains.

Future commitment to providing monetisable incentives for CCS would further underpin the sector. Government incentives for CCS are already successfully operational in the North Sea, where since 1991 the Norwegian government has provided tax rebates to Statoil to sequestrate CO_2 from the Sleipner Field into a deep saline aquifer. [lxv]

Public sector partnership with private sector investment could be leveraged through a variety of mechanisms, such as SPVs, and it might be expected that £25 million of state support per project, for 20 projects would require £500 million of investment. There is precedent for such support, and the only UK plant using gasification has recently been revived by Advanced Biofuel Solutions following £10 million of funding being secured by the Department for Transport and Cadent. [lxvi] It needs to be understood that this investment would give a commercially valuable stake in profitable businesses, and the investment could be recovered.

To understand the level of feed in tariff required, under present commercial conditions, it would be advisable to talk to existing operators. Advanced Biofuel Solutions is working on reopening the plant in Swindon to produce bioSYN, but there are other operators using gasification from waste for other purposes, such as Energy Works in Hull, Amey in Milton Keynes and Air Products in Tees Valley. [lxvii]

9. What are the key institutions including business, local government, trade unions who should play a role in delivering a green recovery? Are there particular lessons that should be learnt about effective delivery? Local people know their communities better than Westminster. What steps do we need to introduce to empower local communities to be able to tailor the provision to suit their needs?

The most noticeable feature of current government policy towards decarbonisation is that it is taking place behind the backs of the general public, who remain unaware that there is a plan, however nebulous, and about which they have not been consulted, to electrify domestic heating and force gas customers onto heat pumps and heat networks.

The Labour Party has an opportunity to not only develop a coherent policy towards decarbonisation of heating, which the Party explored in 2016 in the Green Gas Book; but in so doing they will be adopting a policy that cuts with the grain of public opinion, who have high regard for the gas they use to heat their homes, and to cook with.

There is of course a well-developed gas industry business sector that the Labour Party can engage with, and professional institutions such as IGEM; but the party should also recognise the significant expertise of all the trade unions in the energy sector: GMB, Unison, Unite and Prospect. GMB is the lead union in the gas industry and has led the way in developing a comprehensive energy policy, and it is essential that the interests of the workforce are considered, as well as the interests of consumers, and the interests of Gas Safe registered businesses.

10. What other issues/points do you think are important? What are the Covid-19 challenges of delivering such a programme and how might they be overcome?

We have no view on this.

References

[i] "*Clean Growth - Transforming Heating Overview of Current Evidence*", Department of Business Energy and Industrial Strategy, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/766109/decarbonising-heating.pdf , 2018

[ii] "*Clean Growth - Transforming Heating Overview of Current Evidence*", pp 110 – 121, BEIS, ibid.

[iii] "*The Green Gas Book*", Parliamentary Labour Party Energy and Climate Change Committee, 2016.

[iv] "*The Future of the Gas Networks*" Glover T., The Green Gas Book, ibid, 2016.

[v] "*Decarbonising Heat - The Role of 'Green Gas'*", Whitehead A., The Green Gas Book, op cit, 2016.

[vi] "*Green Gas for an Affordable, Secure and Sustainable Future*", Foster M., The Green Gas Book, op cit, 2016

[vii] "*Future Energy Scenario 2015*", National Grid

[viii] "*The Future of Gas, Supply of Renewable Gas*", Cadent, p6, https://cadentgas.com/nggdwsdev/media/Downloads/Future%20of%20gas/The-future-of-gas-Feb-16.pdf, 2016.

[ix] "*The Future of Gas, Supply of Renewable Gas*", Cadent, p6, op cit.

[x] "*The Future of Gas, Supply of Renewable Gas*", Cadent, p9, op cit.

[xi] "*UK's first grid-injected hydrogen pilot gets underway*", Cadent, https://cadentgas.com/news-media/news/january-2020/hydeploy-hydrogen-project-reaching-20-blend, 2020.

[xii] "*About H21*", https://www.h21.green/about/, retrieved June 2020.

[xiii] "*Innovation and assessment for biomass heat*", p6, Ecofys and E4Tech for Department for Business, Energy and Industrial Strategy, www.gov.uk/government/publications/innovation-needs-assessment-for-biomass-heat., 2018.

[xiv] "*The Future of Gas, Supply of Renewable Gas*", Cadent, p5, 2016, op cit.

[xv] "*The Future of Gas, Supply of Renewable Gas*", Cadent, p5, 2016, op cit.

[xvi] "*Biomethane, Production and Applications*", Koonaphapdeelert S. et al. p xiii, Springer, 2020.

[xvii] "*RHI deployment data*" table 1.5, Department of Business Energy and Industrial Strategy, https://www.gov.uk/government/statistics/rhi-monthly-deployment-data-january-2020 (2020)

[xviii] "*The Non-Domestic Renewable Heat Incentive: Ensuring a sustainable scheme*", p14, Department of Business Energy and Industrial Strategy, www.gov.uk/government/consultations/non-domestic-renewable-heat-incentive-ensuring-asustainable-scheme, 2020.

[xix] "*Future Support for Low Carbon Heat*", p12, Department of Business Energy and Industrial Strategy, https://www.gov.uk/government/consultations/future-support-for-low-carbon-heat, 2020.

[xx] Lambert Smith Hampton, agent for machinery and Business Assets. https://www.lsh.co.uk/mba/private-treaty/grindley-biogas-ltd , retrieved June 2020.

[xxi] "*The Future of Gas, Supply of Renewable Gas*", Cadent, p9, op cit.

[xxii] "*Biomethane and its role in decarbonising the gas network: Webinar with focus on within grid compression*", Baldwin J., IGEM, June 2020. https://vimeo.com/425144617/26769882dd, retrieved June 2020.

[xxiii] This is a huge plant with 14 gasifiers, that consume 18500 tonnes of lignite and produce 3.7 million m^3 of methane per day. It cost US$2.1 bn and was supported by the Federal Nonnuclear Energy Research and Development Act of 1974. See "*The Hidden Value of Lignite Coal*", Dittus M. et al, Proceedings of the 2001 Gasification Technologies Conference, https://www.globalsyngas.org/uploads/eventLibrary/GTC01010.pdf , 2001.

[xxiv] "*Innovation and assessment for biomass heat*", p8, Ecofys and E4Tech for Department for Business, Energy and Industrial Strategy, www.gov.uk/government/publications/innovation-needs-assessment-for-biomass-heat., 2018.

[xxv] Unfortunately, the municipally owned energy company failed to find a commercial operator following the Phase 1 development stage, (see "*Göteborg Energi winds down GoBIGas 1 project in advance*", Bioenergy International, https://bioenergyinternational.com/research-development/goteborg-energi-winds-gobigas-1-project-advance,) Phase 1 of the project was funded through a SKr222m (approximately £19m) grant from the Swedish Energy Agency (SEA). the commercial phase 2 of the project would have created a 80 MW to 100MW plant, that would have produced fuel for up to 100000 cars (See "*Gothenburg Biomass Gasification Project (GoBiGas)*", Chemicals Technology, https://www.chemicals-technology.com/projects/gothenburg-biomass-gasification-project-gobigas/ , Retrieved June 2020.). Academic studies show that the proposed process plan for Phase 2 of the project may have been overcomplicated, making required capex costs up to 30% higher than necessary. (See "*Improved syngas processing for enhanced Bio-SNG production: A techno-economic assessment*", Haro, P. et al. Energy, 101, 380-389, http://www.sciencedirect.com/science/article/pii/S0360544216300809 (2016).)
A contributory factor for the difficulty in finding a commercial operator may be because the Swedish subsidy pattern supports consumers and not producers. (REGATRACE, pp 46-51, op cit.). The cancelled Phase 2 was expected to receive €58.8m of funding under the European Union's (EU) NER 300 programme, which promotes the development of renewable energy and low-carbon technologies. cars (See "*Gothenburg Biomass Gasification Project (GoBiGas)*", Chemicals Technology, https://www.chemicals-technology.com/projects/gothenburg-biomass-gasification-project-gobigas/ , Retrieved June 2020.).

[xxvi] *"Returning Carbon to Nature – Coal, Carbon and Storage"*, Stephenson M., Elsevier, 2013.

[xxvii] *"Innovation and assessment for biomass heat"*, p10, op cit, 2018.

[xxviii] "*Bioenergy Review 2018, Call for evidence, Response from Advanced Plasma Power Ltd*", Committee for Climate Change, https://www.theccc.org.uk/wp-content/uploads/2018/12/Biomass-response-to-Call-for-Evidence-Advanced-Plasma-Power.pdf, 2018.

[xxix] "*Future Support for Low Carbon Heat*", p11, BEIS. op cit.

[xxx] A review by the Sustainable Gas Institute in 2017 estimated that the cost of producing bioSNG is between 3 and 6p/kWh, compared with an average EU wholesale gas price of approximately 1.5 p/kWh in 2015. This implies that support will be needed whilst the technology comes down the cost curve to approach the cost of natural gas, however weak market-based support policies can be a strong barrier to the development of additional plants and low natural gas prices can magnify this problem. See "*White Paper 3 -A Greener Gas Grid: What Are The Options?*", Sustainable Gas Institute, http://www.sustainablegasinstitute.org/agreener-gas-grid/, 2017.

[xxxi] *"Innovation and assessment for biomass heat"*, p18, Ecofys and E4Tech for Department for Business, Energy and Industrial Strategy, op cit.

[xxxii] Advanced Plasma Power (2016) The Renewable Heat Incentive: A reformed and refocused scheme Response to Consultation, see *"Innovation and assessment for biomass heat"*, p33, Ecofys and E4Tech for Department for Business, Energy and Industrial Strategy, op cit.

[xxxiii] BEIS are proposing Tier 1 tariffs in the range of 4.9-5.5 p/kWh, Tier 2 tariffs of 3.25-3.75 p/kWh and Tier 3 tariffs of 1.5-2.0 p/kWh. See "*Future Support for Low Carbon Heat*", p12, BEIS. op cit.

[xxxiv] "*Future Support for Low Carbon Heat*", p23, BEIS. op cit.

[xxxv] "*Mapping the State of Play of renewable gases in Europe, D6.1",* pp 55-57, REGATRACE, Renewable Gas Trade Centre in Europe, https://www.regatrace.eu/wp-content/uploads/2020/04/REGATRACE-D6.1.pdf 2020.

[xxxvi] "*Bioenergy Review 2018, Call for evidence, Response from Advanced Plasma Power Ltd*", Committee for Climate Change, https://www.theccc.org.uk/wp-content/uploads/2018/12/Biomass-response-to-Call-for-Evidence-Advanced-Plasma-Power.pdf, 2018.

[xxxvii] *"The Future of Gas, Supply of Renewable Gas"*, Cadent, p3, op cit.

[xxxviii] "*Bioenergy Review 2018, Call for evidence, Response from Advanced Plasma Power Ltd*", Committee for Climate Change, https://www.theccc.org.uk/wp-content/uploads/2018/12/Biomass-response-to-Call-for-Evidence-Advanced-Plasma-Power.pdf, 2018.

[xxxix] "*Future Support for Low Carbon Heat*", p23, BEIS. op cit.

[xl] "*Shale Gas and Fracking – The Science behind the Controversy*", Stephenson M. Elsevier, 2015.

[xli] These include high pressure gasification, sorption enhanced gasification, more efficient hot gas clean up, more robust methanation catalysts, alternative air separation technologies and coupling bioSNG with renewable hydrogen inputs. See *"Innovation and assessment for biomass heat"*, pp 7-38, Ecofys and E4Tech for Department for Business, Energy and Industrial Strategy, www.gov.uk/government/publications/innovation-needs-assessment-for-biomass-heat., 2018.

[xlii] "*Improved syngas processing for enhanced Bio-SNG production: A techno-economic assessment*", Haro, P. et al. Energy, 101, 380-389, http://www.sciencedirect.com/science/article/pii/S0360544216300809 (2016).

[xliii] These reductions arise primarily from economies of scale in the major capital cost components (gasifier, methanation) and labour, and reduction of real and perceived risk leading to reduction in Engineering, Procurement and Construction (EPC) and construction management costs. However, high capital costs and technology risk limit developers' access to capital, and the costs of methane produced will be higher than natural gas for the first plants. In addition, the value of negative emissions if bioSNG were combined with carbon capture and storage (CCS) cannot currently be monetised. (see "*First project progress report*", Gogreengas (2016), http://gogreengas.com/wp-content/uploads/2015/11/BioSNGDemonstration-Plant-June-2016-Project-Progress-Report.pdf) This shows the strategic need for government support to support the feed in tariff for early plants, to provide a long-term political commitment to provide certainty for investors, and to provide a financial framework to reward CCS.

[xliv] Industry data suggests that manufacture of multiple gasifiers, even if they were different designs, could bring down capex by 15%, and opex by 6.1%.These reductions would reduce the levelised cost of bioSNG production from a waste-based gasifier from £55/MWh to £39/MWh, see *"Innovation and assessment for biomass heat"*, p18, Ecofys and E4Tech for Department for Business, Energy and Industrial Strategy, op cit.

[xlv] "*The Future of Gas, Supply of Renewable Gas"*, Cadent, p13, 2016, op cit.

[xlvi] Most early AD projects in the UK used agriculturally sourced biomass (maize) as the fuel-stock, which has the advantage of greater flexibility, because a potential producer could find a spot on grid with capacity, where they could get planning permission, and then find local farmers to produce feedstock. The availability of feedstock is more geographically constrained when relying on waste, which means there may not be capacity in the grid local to where feedstock supply is. See "*Crops Grown for Bioenergy in the UK*", https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/775243/nonfood-statsnotice2017-31jan19i.pdf, Defra, 2017

[xlvii] *"Green Heat. Home Grown"*, Caroline Flint, p18, The Green Gas Book, op cit, 2016.

[xlviii] *"Heat Networks, A Critical evaluation of customer experience, the market and technology, as background to the BEIS consultation, "Heat Networks: Building a Market Framework""*, Newman A. Gas Users Organisation, https://7e5be875-7791-4457-902a-cbf7a54e369c.filesusr.com/ugd/4bd1a6_7e40142487554d29957ad5252adec718.pdf, 2020.

[xlix] "*Bioenergy Review 2018, Call for evidence, Response from Advanced Plasma Power Ltd*", Committee for Climate Change, https://www.theccc.org.uk/wp-content/uploads/2018/12/Biomass-response-to-Call-for-Evidence-Advanced-Plasma-Power.pdf, 2018.

[l] *"Innovation and assessment for biomass heat"*, p58, Ecofys and E4Tech for Department for Business, Energy and Industrial Strategy, www.gov.uk/government/publications/innovation-needs-assessment-for-biomass-heat., 2018.

[li] "*Non-domestic RHI Factsheet March 2019*", BEIS, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/795580/Non-domestic-Factsheet-March-2019.pdf, 2019.

[lii] REGATRACE, p56, op cit.

[liii] "*The Future of Gas, Supply of Renewable Gas"*, Cadent, p18, op cit.

[liv] In January 2019, the French government, through its Pluriannual Energy Programme (PPE or Programmation Pluriannuelle de l'Energy), announced its intention end the feed in tariff for the biggest biomethane plants. Among the measures announced, the 2030 target for the share of renewables in gas in France's total gas consumption is to be lowered from 10 to 7%, sending mixed signals to the anaerobic digestion sector. See REGATRACE, pp 31-32, op cit.

[lv] REGATRACE, pp 34, op cit.

[lvi] *"Innovation and assessment for biomass heat"*, p18, Ecofys and E4Tech for Department for Business, Energy and Industrial Strategy, op cit.

[lvii] These include high pressure gasification, sorption enhanced gasification, more efficient hot gas clean up, more robust methanation catalysts, alternative air separation technologies and coupling bioSNG with renewable hydrogen inputs. See *"Innovation and assessment for biomass heat"*, pp 7-38, Ecofys and E4Tech for Department for Business, Energy and Industrial Strategy, www.gov.uk/government/publications/innovation-needs-assessment-for-biomass-heat., 2018.

[lviii] *"Innovation and assessment for biomass heat"*, p1, Ecofys and E4Tech for Department for Business, Energy and Industrial Strategy, www.gov.uk/government/publications/innovation-needs-assessment-for-biomass-heat., 2018.

[lix] "*Improved syngas processing for enhanced Bio-SNG production: A techno-economic assessment*", Haro, P. et al. Energy, 101, 380-389, http://www.sciencedirect.com/science/article/pii/S0360544216300809 (2016).

[lx] "*First project progress report*", Gogreengas (2016), http://gogreengas.com/wp-content/uploads/2015/11/BioSNGDemonstration-Plant-June-2016-Project-Progress-Report.pdf

[lxi] These reductions would reduce the levelised cost of bioSNG production from a waste-based gasifier from £39/MWh to £23/MW, see *"Innovation and assessment for biomass heat"*, p18, Ecofys and E4Tech for Department for Business, Energy and Industrial Strategy, op cit.

[lxii] Analysis by APP anticipates an 84 MW commercial-scale plant converting wastes. E.ON previously targeted projects at 200 MW and above.

[lxiii] *"Innovation and assessment for biomass heat"*, p17, Ecofys and E4Tech for Department for Business, Energy and Industrial Strategy, op cit.

[lxiv] These reductions would reduce the levelised cost of bioSNG production from a waste-based gasifier from £55/MWh to £39/MWh, see *"Innovation and assessment for biomass heat"*, p18, Ecofys and E4Tech for Department for Business, Energy and Industrial Strategy, op cit.

[lxv] "*Returning Carbon to Nature – Coal, Carbon and Storage"*, pp 48-49, Stephenson M., Elsevier, 2013.

[lxvi] "*Waste-to-gas plant revived after administration*", Doherty J., www.Letsrecycle.com , https://www.letsrecycle.com/news/latest-news/waste-to-gas-plant-revived-after-administration/ , November 2019. Retrieved June 2020.

[lxvii] *"Innovation and assessment for biomass heat"*, p14, Ecofys and E4Tech for Department for Business, Energy and Industrial Strategy, op cit.