Future UK Gas Security: The Future Role of Gas?

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About the UK Gas Security Forum

This briefing is informed by discussions at the third UK Gas Security Forum, which brought together a range of stakeholders from government, business, think-tanks and academia to consider the impact of Brexit on the UK gas industry. The aim of the Forum is to inform the Brexit negotiations and the formulation of a Post-Brexit UK Gas Security Strategy. The Forum builds on previous research funded by UKERC on: *The UK's Global Gas Challenge* (Bradshaw et al. 2014) and *The Future Role of Natural Gas in the UK* (McGlade et al. 2016). The approach adopted combines a supply chain analysis of energy security with a whole system approach, that places gas security within the wider context of the decarbonisation of the UK energy system. It is assumed that a future UK gas strategy must deliver secure, affordable and sustainable energy services to end users.

A Supply Chain Approach to Gas Security

A supply chain approach was adopted in our previous research to provide a holistic analysis of gas security that also links to wider energy system issues. The aim of the Forum is to aid in the updating of our earlier analysis which was aimed at assessing the challenges and opportunities that are now further complicated by Brexit, as well as the requirements for a post-Brexit UK Gas Security Strategy.

The first Forum focused on upstream security of supply, the second considered critical infrastructures in the midstream, and third focused on the future role of gas. A daylong conference, in February 2018, will consider the impact of Brexit and the key challenges that should be addressed in a future UK Gas Security Strategy (a final report will be published soon after).

Upstream Security of Supply

The majority of studies of energy security focus on upstream security of supply, while some consider the resilience of the midstream infrastructure to deliver sufficient gas to customers. But, more recently, as the low-carbon transition has gathered momentum, there has been increasing interest in security of future demand as a challenge to the integrity of the gas supply chain. As noted in the second briefing (Bradshaw 2018), investment in maintaining, let alone expanding, aging gas infrastructures is made all the more complicated by the possibility of significant future demand destruction leading to the stranding of assets. The UK's natural gas consumption peaked at 97.4 bcma in 2004—the year it became a net importer—and in the following decade average annual demand was around 94 bcm. After 2010 demand started to fall and reached a low of 66.7 bcm in 2014, 31% down on the 2004 peak, only to recover to 76.7 bcm by 2016 (BP 2017). Given the importance of winter weather conditions, it is natural to expect year-on-year variation in gas demand, but there are also other factors that explain the recent fall and recovery in demand. A combination of high gas prices and low carbon prices enabled coal to regain a share of the power generation market in 2013-14; but as gas prices themselves fell and the carbon floor price (explained below) remained in place, gas regained its share of the power market at the expense of coal. However, renewable generation—wind and solar—has also continued to grow faster than expected, changing the role of gas in the power generation mix and reducing the load on gas-fired power stations (with some being moth-balled).

Going forward, the decision to close all non-abated coal fired generation by 2025 may result in more robust gas demand, but much will depend on the growth of low-carbon generation, improvements in energy efficiency and demand reduction, and the pace of development of electricity storage technology all of which might depress demand for gas in power. One final key uncertainty is the rate of progress of nuclear new-build and the ability of existing nuclear power stations to remain in service. Further delays and early retirements might result in additional demand for baseload power generation that could favour gas. All this serves to highlight the importance of a whole systems approach to gas security. But, as we shall see, the future of gas is about a lot more than gas in power, and it should also be remembered that the responsibility for decarbonisation falls on the entire

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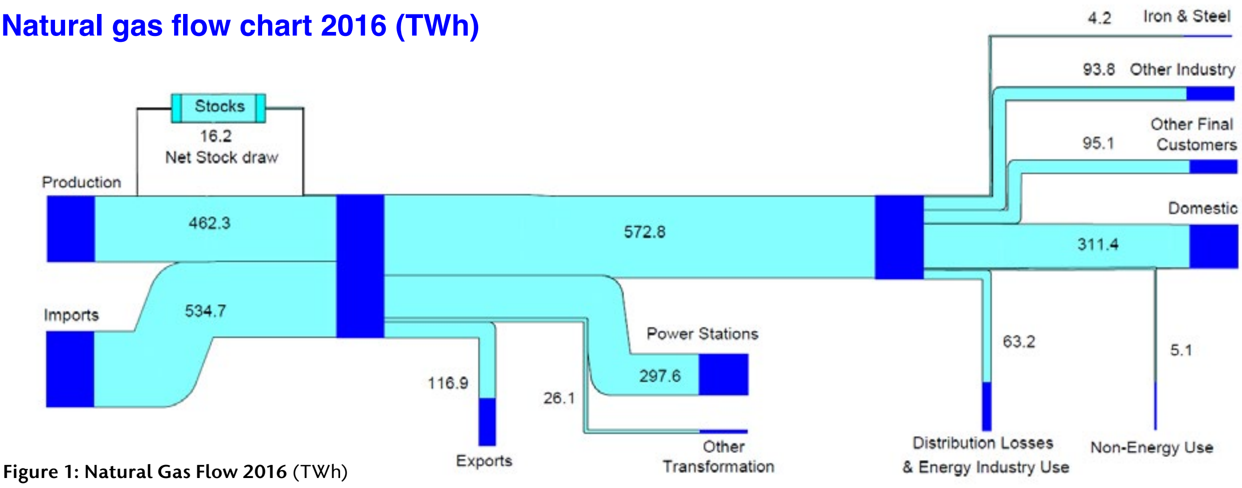

Figure 1: Natural Gas Flow 2016 (TWh)
Source: BEIS (2017a, 90)

economy, particularly heat and transport, and not just the power sector.

This briefing is divided into five sections. The first section examines the current role of natural gas in the UK energy mix, as well as recent trends in power generation. The second section reports on recent research by UKERC on the future role of gas in the UK. The third section examines what National Grid's (2017a) most recent *Future Energy Scenarios* have to say about the future role of gas. The fourth section reviews other industry analyses about the future role of gas. The fifth, and final section, examines the ways in which Brexit complicates the situation. The briefing concludes by highlighting the policy challenges in relation to future security of demand.

The Current Role of Natural Gas

At present, natural gas consumption in the UK is split roughly three ways with power stations consuming 29.8% of total gas flows in 2016 (see Figure 1), domestic consumers (for heating and cooking) consumed 31.2% of total gas flow, and the iron and steel, non-energy use (feedstock) and other industries account for 9.9%. Overall, in 2016, natural gas met nearly two-thirds of UK domestic energy demand, including providing just over half the fuel for electricity generation (BEIS 2017a, 89). Thus, natural gas security is also critical to electricity security of supply, but it is also important to remember that two-thirds of gas consumption lies outside the power sector.

Nevertheless, the greatest attention has been paid to the role of gas in power because this is where the impact of climate change and air pollution policies have been significant in constraining the use of coal, and where the rapid growth of renewable, low-carbon electricity has started to impact. Further decarbonisation of the power sector will be required if the UK is to meet its carbon reduction targets, but the decarbonisation of domestic heat represents the most significant challenge. While not all areas of the UK have access to pipeline gas, around 85% of UK households use natural gas for domestic heating. In the vast majority of instances this involves an individual household boiler that produces hot water for heating and bathing. Although there are some district heating systems, it seems the case that UK households like the autonomy of having their own boiler, which is an important factor in considering alternative low carbon heating solutions. In industry, natural gas is both a feedstock and a source of heat, with many industrial processes requiring a level of heating that is best delivered by gas. In this context, the decarbonisation of power generation can be seen as the easiest first option.

Figure 2 shows the changing power generation fuel mix since 1990, when natural gas was first allowed as a fuel for power generation. The so-called 'dash for gas' is clear to see, with the share of natural gas climbing from next to nothing in 1990 to just over 34% in 2000. Thereafter, we see the impact of fuel-switching between gas and coal, with coal having a last gasp, before gas regains its position. The question is what happens next?

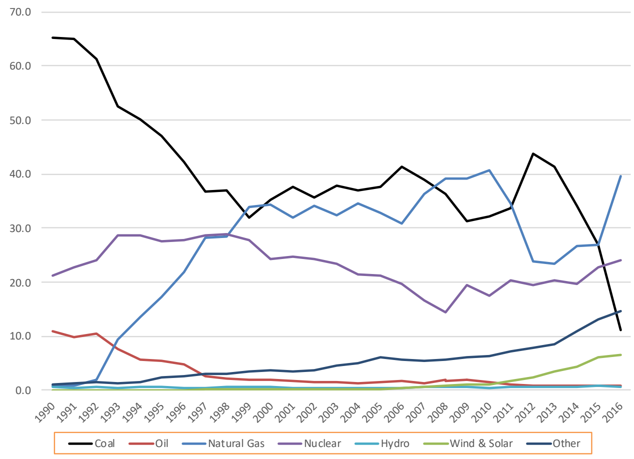

Figure 2: Fuel Input for Power Generation
Source: BEIS (2017a)

The Future Role of Natural Gas

In recent years there has been much talk of the role of natural gas as a 'bridge' to a future low carbon system. The rationale being that as natural gas emits about 40% the level of CO_2 that coal does per unit of energy produced when used to generate power, does not produce SO_2 and emits negligible fine particulate matter, switching from coal to gas can reduce greenhouse gases and, address the growing problem of urban air pollution. An earlier UKERC project (McGlade et al. 2014) explored the notion of the 'gas bridge' at a global scale and concluded that for certain regions—mainly those currently dominated by coal fired power generation—there was potential for gas to act as a bridge, but only for a limited period of time as deep decarbonisation would eventually require the removal of natural gas. It also demonstrated the importance of carbon capture and storage (CCS) in keeping gas in the mix.[2] The project did not explicitly consider the air pollution co-benefits of switching from coal to gas.

The global modelling approach was not appropriate for a detailed analysis of the UK situation and our more recent research uses two different models to investigate the sensitivities around GHG emissions reduction and future UK gas demand. The full details can be found in the UKERC report *The Future Role of Gas in the UK* (McGlade at al. 2016), while a more condensed version has recently been published in the journal *Energy Policy* (McGlade et al. 2018). Here I report on the key findings of one of the modelling exercises, the aim being to highlight the range of possible outcomes and the key drivers influencing future gas demand.

The UK TIMES model was used to explore a number of different scenarios. Here I report on three of those scenarios: *Maintain* that assumes the UK sticks with its current climate change policies and carbon budgets that call for an 80% reduction in GHG emissions by 2050, over 1990 levels; *Maintain (tech failure)* that assumes that the 80% reduction has to be achieved without access to carbon capture and storage (CCS) technology; and *Abandon* that assumes climate change policy is downgraded in the late 2010s—perhaps in response to the outcome of Brexit—meaning limits on emissions beyond the 3rd Carbon Budget (2018-22) are not implemented. Figure 3 shows the resulting levels of future gas consumption.

As one might expect, abandoning the 2050 target allows more gas to be consumed (83% of the 2010 level), but the maintain scenario also results in a significant amount of gas in the mix (46% of the 2010 level). However, without CCS gas consumption falls to around 12 bcm, a 90% reduction on 2010 levels. To understand these results, it is important to examine the role that natural gas is playing in the energy system under the different scenarios. Figure 4 shows the role of gas in 2016 and its predicted role under the two scenarios that meet the 2050 target.

The model results show a significant reduction in gas demand in power generation by 2030, and then between 2030 and 2050 the emphasis is upon reducing gas use in domestic heat (buildings). However, there is a significant difference between the two scenarios in 2050 and this is because under the *Maintain Scenario*, which has access to CCS, natural gas becomes the basis for hydrogen production to be used in domestic heating and transport. That option is absent in the *Maintain (tech fail)* scenario because of the absence of CCS, which is needed to store the carbon dioxide produced by the steam reforming of methane to produce hydrogen. In both scenarios there is still demand in industry and a modest amount of gas in power to provide back-up for renewable intermittency.

The findings of this analysis are clear, if the UK sticks with its current climate policy and carbon budgets this will constrain gas consumption, initially in the late 2020s in

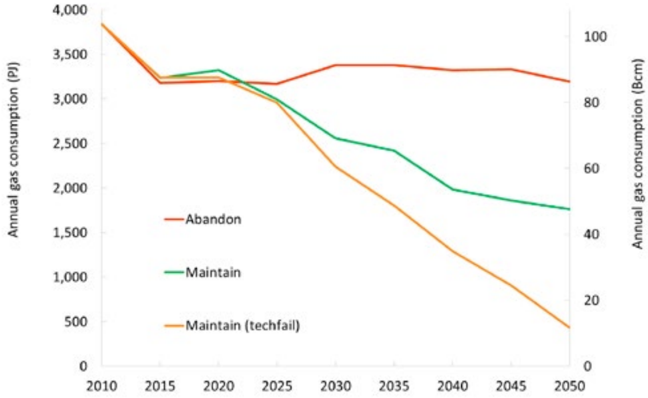

Figure 3: Gas consumption over time in Abandon, Maintain and Maintain (tech fail). Source: McGlade et al. (2018, 461)

power generation, and then in the 2030s and beyond in buildings. But, if CCS is available there is an alternative future that uses natural gas to fuel a hydrogen economy and to decarbonise gas-fired power generation to support renewable generation.

National Grid's Future Energy Scenarios

The National Grid's Future Energy Scenarios (FES) provide an alternative, industry view of possible futures for natural gas in the GB energy system.[3] As the owner and operator of the National Transmission System they have an obvious interest in how much gas is consumed in the UK. Their 2017 FES presented four scenarios: *Two Degrees*—where the UK's carbon reduction targets are achieved; *Slow Progression*—where low economic growth and affordability result in focus on cost efficient longer-term environmental policies; *Steady State*—a business as usual scenario with a focus on security of supply at a low cost for consumers; and, *Consumer Power*—a world with high economic growth where consumers have little inclination to become environmentally friendly. There is not the space here to explore the FES in detail, our major concern is what the various scenarios mean for future gas demand. It is noteworthy that only one of their scenarios—*Two Degrees*—meets the Government's 2050 target.

Two Scenarios—*Steady State* and *Consumer Power*—show a modest increase in gas demand in the 2020s and then plateau at a slightly lower level; gas remains relatively inexpensive and, with a limited decarbonisation agenda, it is not challenged. Both scenarios retain over 70% of 2010 gas demand in 2050. The other two scenarios show significant reductions in future demand: *Two Degrees* because climate policy promotes a reduction in gas usage across the economy, but particularly in power and heat (2050 demand is 46.6% of 2010). In the case of *Slow Progression*, where economic growth is low, gas is relatively expensive, which promotes decarbonisation of power generation (2050 demand is 46.4% of 2010). The key drivers would appear to be the level of commitment to decarbonise power generation and the success in decarbonising heat (heat pumps replacing gas boilers, combined with improvements in insulation), conditioned by the ability and/or willingness to make the necessary investments.

2 More recent policy discussion seems to talk in terms of carbon capture, utilisation and storage (CCUS), both terms are used in this briefing.

3 Bothe BEIS and National Grid make reference to the GB system as Northern Ireland is treated as part of a separate all-Ireland energy system.

The FES 2017 also considers a number of sensitivities, these are also part of their initiative on *The Future of Gas* (National Grid 2016, 2017b). Of particular interest is their 'Decarbonised Gas' analysis that explores using hydrogen for heating and transport, which parallels UKERC's *Maintain* scenario. In their sensitivity analysis hydrogen is produced from natural gas, in combination with CCS, providing heating for some cities. The analysis explores converting 17 cities, outside of those gas boilers would still be used for heating as the analysis is presented as an alternative to electric heating. The net result is that gas demand is comparable with the highest ever levels of demand in the early 2000s (130% of 2016 levels). Of this 55% is used for conversion to hydrogen, which provides 28% of total domestic heating demand by 2050. In addition, gas plus CCS provides backup for renewable intermittency, reducing the need for new nuclear capacity. This solution meets the 2050 carbon reduction goals, but the big problem is that the vast majority of gas demand needs to be met by imports. The current import infrastructure should be large enough to handle it; but, there would undoubtedly be increased concerns about upstream security of supply with such a high level of import dependence.

Other Views of the Future of Gas

There are a number of other analyses that explore potential futures for natural gas. As the owner of the NTS, it is not surprising that National Grid should be exploring the sensitives around the future role of gas. The same is also true of those companies that own and operate the various gas distribution networks (GDNs) as they have an obvious interest in seeing gas remain part of the energy mix. They are the ones promoting the narrative around using the existing distribution network to transport hydrogen, made all the more possible by the replacement of iron pipes by polyurethane.

In 2016, KPMG (2016) produced a report entitled *2050 Energy Scenarios: The UK Gas Networks in a 2050 whole energy system.* The report was commissioned by the Energy Networks Association and KPMG worked in association with Kiwa Gastech, a company involved in the hydrogen sector. The study examined the cost effective and practical future alternatives for the decarbonisation of heat by 2050 with a particular focus on the future role of gas and its subsequent impact on gas networks. They developed four scenarios, all of which meet the 2050 decarbonisation target. They based their demand assumptions on the Gone Green scenario in National Grid's FES 2015. Their concern is not so much the level of future gas demand, but the consequences of the different scenarios for the GDNs.

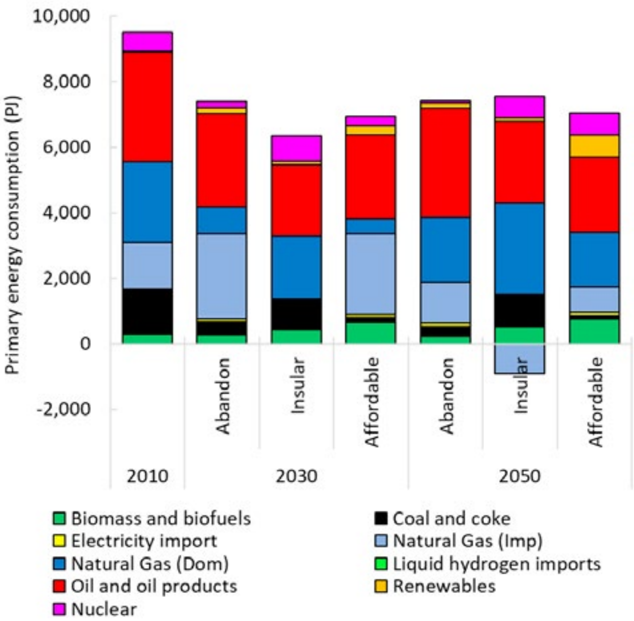

Figure 4: Sectoral Gas Use in Scenarios that meet the 2050 target.
Source: McGlade et al. (2018, 459)

The first scenario is *Evolution of Gas Networks* in which gas is still the main heating fuel, but the majority of customers convert to hydrogen produced from natural gas (with CCS), transport is also mostly partially decarbonised, and the GDNs are mostly used for hydrogen distribution across the country. The second scenario is *Prosumer* where heat is decarbonised with a mixture of self-generating heat and storage and electric heating, the majority of transport is decarbonised and the GDNs are not used. The third scenario is *Diversified Energy Sources* where a mixture of different technologies is used in different areas of the country, heat is partially decarbonised with a mixture of biomass sources, heat networks, gas and electric heating, transport is partially decarbonised and the GDNs are only used in half the country. The fourth, and final, scenario is *Electric Future* in which heat is electrified and power generation is completely decarbonised, the majority of transport is decarbonised and the GDNs are not used. The *Evolution of Gas Networks* scenario is presented as the most technically feasible and most cost effective, followed by the *Diversified Energy* scenario. For the purpose of the current discussion we can note that decarbonised gas can remain part of the energy mix, but it requires the availability of CCS and it will also require considerable policy support from Government (more on this below). The most immediate requirement is a demonstration project.

The *H21 Leeds City Gate project* is a feasibility study developed by Northern Gas Networks (2017) that aims to demonstrate the feasibility, from both a technical and economic viewpoint, of converting the existing natural gas network in Leeds to 100% hydrogen. The project participants have shown that: the gas network has the correct capacity for such a conversion; that it can be converted incrementally with minimal disruption to customers; that minimal new infrastructure will be required compared to alternatives; and, that existing heat demand for Leeds can be met via steam methane reforming and salt cavern storage (of CO_2) using technology in use around the world today.

The *Liverpool-Manchester Hydrogen Cluster* seeks to build on the H21 study by developing a deliverable project that is cost effective and provides meaningful emissions reductions (Progressive Energy 2017). This project is a regional scale solution that maps onto the GDN owned and operated by Cadent. It leverages the existing industrial capacity in the region and proposes to reduce the carbon intensity of the GDN by blending hydrogen at 10-20% volume in the natural gas supply. This solution does not require customers to change their appliances. At the same time, hydrogen would be supplied to 10-15 industrial sites via a new pipeline infrastructure to allow combustion on high hydrogen/natural gas mixtures. The availability

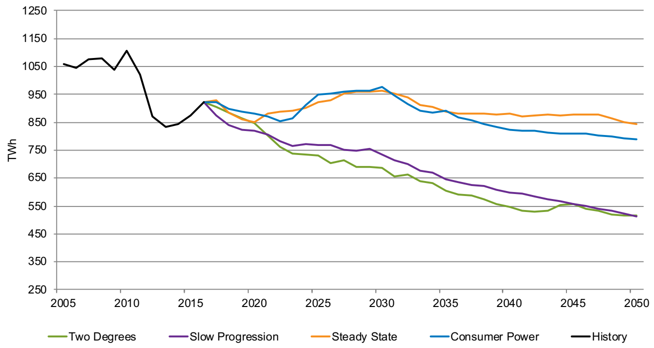

Figure 5: Future Gas Demand in FES 2017
Source: National Grid (2017)

of hydrogen in the region also contributes to the decarbonisation of the transport sector. Finally, a low-cost CCS infrastructure is developed using existing natural gas production facilities and depleted fields in the East Irish Sea off the coast of Merseyside. To progress this vision, Cadent is leading the *HyDeploy* project that is carrying out live trials of natural gas blended with hydrogen at Keele University. The University owns and operates its own gas network, independent of the national gas network.

All of these projects represent an initiative by the gas distribution industry to respond to the need to decarbonise gas. Their proposition is that repurposing the existing gas networks presents the least cost option to decarbonising heat, and potentially transport. The hydrogen option also results in the least disruption for consumers; however, it is dependent on the availability of CCS and requires strong government policy support. The final section considers the extent of that policy support and the potential complications presented by Brexit.

Decarbonised Gas and Brexit

The current transition is necessitated by the challenge of climate change and the need to decarbonise the energy system. Thus, the first factor to consider in the context of Brexit is the Government's continuing commitment to the Climate Change Act (2008) and the associated carbon budgets. These policies are not a consequence of EU policy, in fact the UK's climate change policy is more ambitious in terms of outcome, though less prescriptive in terms of the pathways to achieving its targets. There remains all party support for the Climate Change Act, but it may be that a bad economic outcome from Brexit might lead to a reconsideration of the costs associated with energy system transformation. The result being relaxation of the carbon budgets, akin to UKERC's Abandon scenario, resulting in more unabated gas in power generation, but, potentially reduced enthusiasm for decarbonised gas.

The EU's Emission Trading System (ETS) was introduced in 2005 and is the central pillar of the EU's climate change policy. However, the ETS, in which the UK makes up 10% of the market, has been plagued with problems and in 2013 the UK Government introduced its own Carbon Floor Price (CFP) to supplement the ETS-generated cost of carbon to set a more predictable lowest price for electricity generators thereby incentivising low carbon investment. In 2014 the CFP was frozen at £18/tCO_2 to limit the competitive disadvantage by business (vis-à-vis the rest of the EU where the ETS price was lower) and also to reduce energy bills for consumers. In 2016 this freeze was extended to 2021. However, as demonstrated earlier, in recent years the CFP has been effective in driving coal out of power generation, and this has supported gas demand.

Because the ETS falls under the jurisdiction of the European Court of Justice, the UK Government's current 'red lines' would suggest that after 2021—assuming a two-year transition period from 2019—full UK membership of the ETS is unlikely. However, the UK Government has recently reiterated its commitment to carbon pricing. Given that the UK's policy on carbon pricing is more effective than the ETS at promoting decarbonisation, although reforms of the latter are underway and its current phase ends in 2020, it is safe to assume that some form of carbon price will continue in the UK beyond 2021. However, its precise nature and its relationship to the EU's ETS remain unclear.

If we conclude that, whatever the outcome of Brexit, the UK government will remain committed to the Climate Change Act (2008) and will maintain policies that support a low-carbon energy transition, the question then remains what role might gas play in that future policy landscape? Previous UKERC research has criticised the various UK Governments of late for pursuing an implicit strategy of 'gas by default,' rather than 'gas by design.' The notion of 'gas by default' means that the gas sector is relied on to 'be there' when other elements of energy policy fail to deliver, without explicit policies to address the uncertainties facing the gas sector as a result of the low carbon transition. The net result has been a failure to encourage investment in new gas generation and gas storage. In contrast, a 'gas by design' approach would build on the situation presented above to ensure sufficient gas power generation and continued investment in the gas networks in the early 2020s, while putting in place a strategy to decarbonise the gas system and to retain those gas networks. Two recent Government Policy statements—*The Clean Growth Strategy* (BEIS 2017b) and *The Industrial Strategy* (BEIS2017c)—provide and assess the current Government's thinking in relation to the gas sector.

The *Clean Growth Strategy* considers three possible pathways beyond the Fifth Carbon Budget (2028-32): an electricity pathway (based on renewables and nuclear), a hydrogen pathway (using natural gas and CCUS), and an emissions removal pathway (sustainable biomass plus CCUS). Modest amounts of funding are identified to enable the gas networks to develop and demonstrate new technologies, as well as new operating and commercial arrangements. Given the importance of CCUS as an 'enabling technology' to two of these pathways, new funding is provided in this area. The UK Government has a chequered history in relation to CCS/CCUS, having cancelled a £ 1 billion CCS competition, at short notice, in 2015 (Oxburgh 2016). Now the Government plans to convene a CCUS Cost Challenge Taskforce that builds on the success of the Wind Cost Reduction Taskforce. They will also create a new Ministerial-led CCUS Council with industry to review progress and priorities. Finally, the Government will spend up to £100 million from the BEIS Energy Innovation Programme to support industry and CCUS innovation and deployment in the UK. While these

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measures are welcome, some would see it as 'too little, too late' and it is unlikely to regain the momentum lost by the cancellation of the 2015 Competition.

The *Industrial Strategy* picks up the narrative and promises to explore: 'the long-term options for clean heating and the many potential uses of low carbon technologies' (BEIS 2017c, 45). Later this is linked to CCUS and the hydrogen economy, but the numerous references to energy are preceded by terms such as 'clean', 'smart' and 'affordable.' This is understandable, but it leads to a 'mind the gap' problem as the future of the gas industry is tied to technology that is not yet available (CCS/CCUS) as a possible pathway to a hydrogen economy in the 2030s. The problem is that there is a policy gap in terms of sustaining the gas industry in the 2020s when unabated coal is scheduled to close, there is uncertainty over the status of nuclear power and renewables penetration is undermining the traditional business model for gas-in-power. One final factor to consider is that the use of hydrogen in heating could result in an increase in gas consumption, requiring investment in the midstream infrastructure and raising concerns about energy security.

Brexit and the Future Role of Gas

The current uncertainties around the future role of gas in the UK's energy mix pre-date the decision to leave the EU. The failure to deliver a 'gas by design' strategy is long-standing but is now complicated by uncertainties around issues like the future of carbon pricing and commitment to the Climate Change Act (2008). At the moment, the Government is committed to both, but a bad economic outcome from Brexit may change attitudes in the early 2020s. The Government's recent policy documents provide support for exploring a possible hydrogen pathway to decarbonising heat, and renewed support for CCUS; but these are not part of a comprehensive strategy that considers the challenges to the gas industry over the coming decade. This is strange when you consider that in 2016 natural gas provided 40% of the UK's primary energy! At present, the demands of Brexit are imposing a huge opportunity cost on the policy-making capacity of Government and the danger is that we will arrive at the end of the transition period in 2021 having missed opportunities to lay the foundations of a 'gas by design' approach that ensures the UK gas industry is able to respond to challenges in the 2020s and is then capable of playing a new role in the future low-carbon economy in the 2030s and beyond.

References

BEIS (2017a) *Digest of UK Energy Statistics—Chapter 4 Statistics on supply and demand for natural gas*. London: BEIS. Available at: https://www.gov.uk/government/statistics/natural-gas-chapter-4-digest-of-united-kingdom-energy-statistics-dukes

BEIS (2017b) *The Clean Growth Strategy: Leading the way to a low carbon future*. London: BEIS. Available at: https://www.gov.uk/government/publications/clean-growth-strategy

BEIS (2017c) *Industrial Strategy: Building a Britain fit for the future*. London: BEIS. Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/664563/industrial-strategy-white-paper-web-ready-version.pdf

Bradshaw, M. (2018) *Future UK Gas Security: Midstream Infrastructure*. Warwick Business School/UKERC, forthcoming.

Bradshaw, M. (2017) *Future UK Gas Security: Upstream Security of Supply*. Warwick Business School/UKERC. Available at: http://www.ukerc.ac.uk/publications/future-uk-gas-security-upstream-security-of-supply.html

BP (2017) *BP Statistical Review of World Energy 2017*. London: BP. Available at: https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html

Cadent (2017) *HyDeploy: Future role of gas*. Coventry: Cadent. Available at: https://hydeploy.co.uk/about/

KPMG (2016) *2050 Energy Scenarios: The UK Gas Networks in a 2050 whole energy system*. London: KPMG. Available at: http://www.energynetworks.org/assets/files/gas/futures/KPMG%202050%20Energy%20Scenarios%20-%20The%20UK%20Gas%20Networks%20role%20in%20a%202050%20whole%20en...1.pdf

McGlade, C., Pye, S., Ekins, P., Bradshaw, M. and Watson, J. (2018) The future role of natural gas in the UK: A bridge to nowhere? *Energy Policy* 113: 454-465.

McGlade, C., Pye, S., Watson, J., Bradshaw, M. and Ekins, P. (2016) *The future role of natural gas in the UK*. London: UKERC. Available at: http://www.ukerc.ac.uk/publications/the-future-role-of-natural-gas-in-the-uk.html

McGlade, C.,Bradshaw, M, Anandarajah, G. Watson, J.and Ekins, P. (2014) *A Bridge to a Low Carbon Future? Modelling the Long-Term Global Potential of Natural Gas*. London: UKERC. Available at: http://www.ukerc.ac.uk/publications/gas-as-a-bridge.html

National Grid (2017a) *Future Energy Scenarios 2017*. Warwick: National Grid. Available at: http://fes.nationalgrid.com

National Grid (2017b) *The Future of Gas: Progress Report*. Warwick: National Grid. Available at: http://futureofgas.uk/news/future-of-gas-progress-report-2/

National Grid (2016) *The future of gas: a Transmission Perspective*. Warwick: National Grid. Available at: http://futureofgas.uk/documents/future-of-gas-transmission-perspective/

Northern Gas Networks (2017) *The H21 City Gate Project*. Leeds: Northern Gas Networks. Available at: https://www.northerngasnetworks.co.uk/wp-content/uploads/2017/04/H21-Report-Interactive-PDF-July-2016.compressed.pdf

Oxburgh, R. (2016) *Lowest Cost Decarbonisation for the UK: The Critical Role of CCS*. Report to the Secretary of State for Business, Energy and Industrial Strategy from the Parliamentary Advisory Group on Carbon Capture and Storage (CCS). Available: at http://www.ccsassociation.org/news-and-events/reports-and-publications/parliamentary-advisory-group-on-ccs-report/

Progressive Energy Ltd. (2017) *The Liverpool-Manchester Hydrogen Cluster: A Low Cost, Deliverable Project*. Coventry: Cadent. Available at: https://cadentgas.com/getattachment/About-us/Innovation/Projects/Liverpool-Manchester-Hydrogen-Cluster/Promo-LMHC-downloads/Technical-Report.pdf