Creating a smaller footprint

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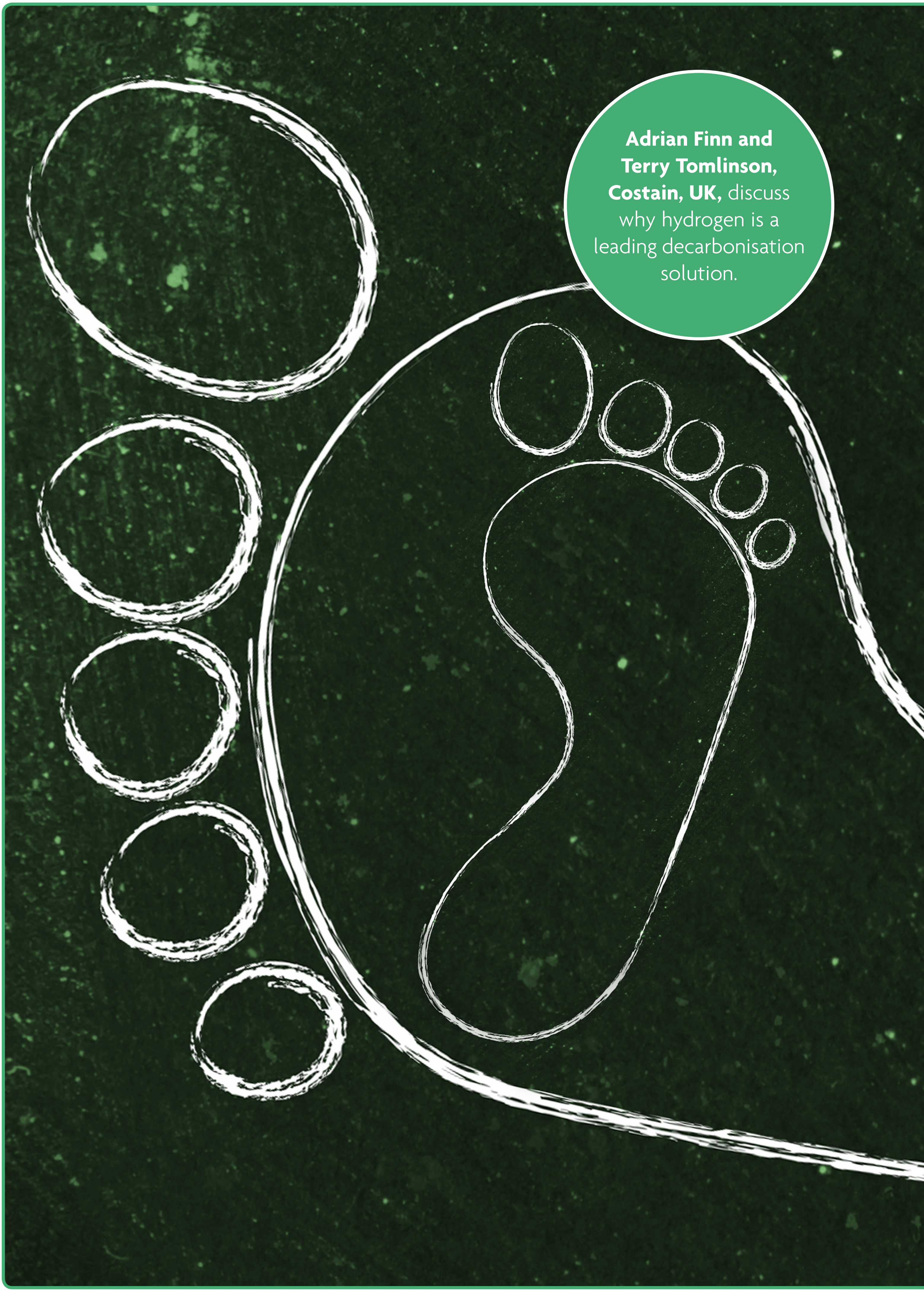

Adrian Finn and Terry Tomlinson, Costain, UK, discuss why hydrogen is a leading decarbonisation solution.

CREATING A SMALLER FOOTPRINT

Ensuring reliable energy supplies but with reduced carbon emissions is of global importance. Changing to less carbon-intensive energy sources is well under way in most nations, but there are considerable technical and economic challenges. Effective energy generation systems need to be evaluated with urgency (as investment cycles are long), developed and taken to 'technology ready' status to meet carbon emission targets. Focusing on the UK, this article will discuss why hydrogen is a leading decarbonisation solution.

Progress to decarbonisation

Reducing carbon emissions to the atmosphere is of paramount importance in avoiding the increased global temperatures and consequential effects of climate change due to escalating atmospheric carbon levels. For most developed nations this has meant reduced coal use for electricity generation and increased use of natural gas, nuclear and renewable energy for both industrial and domestic use.

The UK is typical of many countries in having legislation to meet a 2050 target for carbon emissions (Climate Change Act 2008). The UK aims to achieve at least 80% reduction from 1990 levels. Deregulation of the gas market in the 1990s led to gas being used for power generation with resultant decarbonisation. The country now imports over half of its gas demand, and, for strategic reasons, has multiple methods of electricity generation. Renewables and nuclear power generation are important in a diversified mix of low-carbon energy supply. Of the 140 million toe consumed in 2016, 17% of primary energy came from low-carbon sources, with nearly half of that from nuclear and a third from bio-energy.[1] Changes in electricity generation, a decline in energy-intensive manufacturing and greater energy efficiency have helped reduce carbon emissions by 42% since 1990 (compared to the Climate Change Act target of 26% reduction by 2020), while GDP has risen by 67%.[2] The use of gas for electricity generation (instead of coal) has risen dramatically (Figure 1).[3] Other countries are applying similar principles to decarbonise. However, much more needs to be done to meet carbon emissions targets.[4]

Natural gas

Natural gas is a suitable 'bridging fuel' for decarbonisation from coal whilst other methods of large-scale energy generation are developed. With the recent opening of major LNG production terminals in Australia, the US and Russia, many nations can now access plentiful, low-cost natural gas without needing pipeline supply. For countries such as the UK, and others with pipeline supply and well-established natural gas infrastructure, gas should be an effective source of low-carbon electricity, as well as for industrial and domestic heating.

'New' energy generation technologies

To meet global climate change targets, alternative energy sources must be developed at competitive cost. Both wind and solar power are being used more for electricity generation as technology has progressed. It is likely that costs will continue to fall. However, both require some form of energy storage to ensure that generated electricity is obtainable on demand and large-scale solutions are currently not available. While renewables may support electricity generation, crucially they do not help in heating or act as a raw material to produce chemicals and petrochemicals as natural gas does.

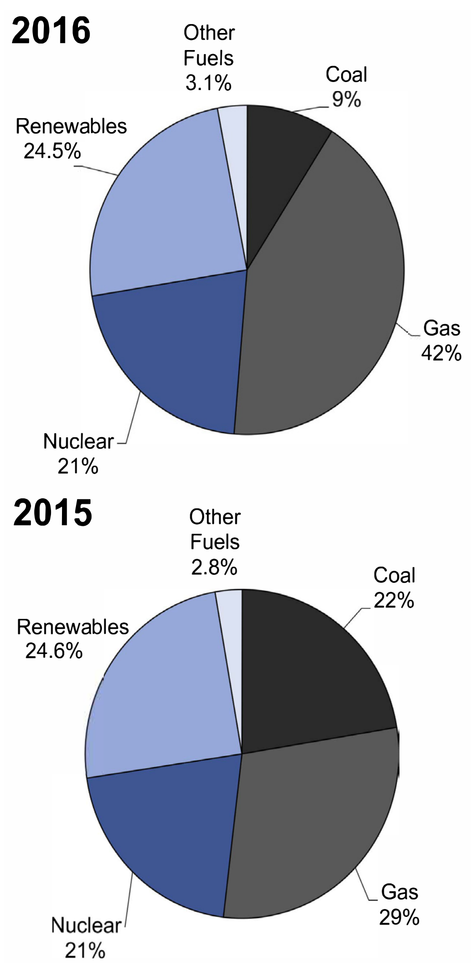

Figure 1. Share of electrical generation by fuel.

Hydrogen

The UK has an extensive gas distribution network but a decarbonised replacement is needed. This leads to the question of how to decarbonise whilst effectively utilising this countrywide network and existing gas reserves (and relatively low-cost imported gas)? This promotes the use of hydrogen, derived from natural gas, whilst alternative methods of providing low-carbon, low-cost industrial and domestic heating can be developed.[5] Hydrogen deserves detailed consideration as a replacement for natural gas and work must start now to meet 2050 emissions targets.[6] Reforming of natural gas to produce hydrogen for electricity generation is currently significantly cheaper than using wind or nuclear power and could save the UK £160 billion compared to other alternatives.[4]

A primary feature of pure hydrogen as a fuel is that when it burns, only water is produced and there is no direct carbon burden. However, reforming natural gas produces carbon dioxide. The effective capture and disposal (or usage) of this carbon dioxide is of key importance to the potential use of hydrogen as a fuel source.

There are major cost savings available by reforming natural gas to separate carbon dioxide from hydrogen, compared to capturing carbon dioxide that is highly diluted in flue gas from natural gas combustion, as has been the main focus of carbon capture schemes to date. Reforming makes it much easier to obtain pure carbon dioxide. Flue gas carbon capture has been evaluated extensively (mostly based on solvent) with little success in reducing cost, whereas carbon capture from hydrogen at an elevated pressure opens up a broad range of proven gas purification technologies.

The use of hydrogen will require long-term strategic planning as well as government support and subsidy, particularly for the incentivisation of carbon capture and storage.[7] A national benefit from greater availability of hydrogen could be the uptake of fuel-cell electric vehicles (FCEVs), which react stored hydrogen and oxygen from the air to produce electricity to power the vehicle. This opportunity to reduce carbon emissions from transport requires further assessment and incentivisation, and is supported by the UK government's Clean Growth Strategy.[2] Economic comparison with greater use of electric battery vehicles, with their need for regular charging, would be valuable. The latter will need electricity grid reinforcement.

Pure hydrogen can be sourced by using a direct current for the electrolysis of water. This also produces pure oxygen as a byproduct, which has several important industrial uses. Large-scale electrolysis is currently more expensive than natural gas reforming,[8] but deserves more evaluation and may be relevant to smaller applications. Costain is currently engaged in assessing the 'round trip efficiency' for a UK project to address the economics of hydrogen production by electrolysis for energy storage.

Although gasification of biomass or domestic waste is a source of hydrogen, it generates much more carbon dioxide than reforming natural gas.

Natural gas reforming

Hydrogen production through the high temperature reforming of natural gas with steam has been practiced for almost a century, to provide a synthesis of gas for the manufacture of chemicals such as methanol and ammonia, and produce high purity hydrogen for refinery operations including hydrotreating and hydrodesulfurisation. Over 90% of industrial hydrogen is produced in this way. Reformer technology is mature and well-proven.

The amount of hydrogen needed for large-scale heating is much more than that currently produced for chemicals manufacture and refinery use, which presents challenges on whether the maximum size of reformers can be scaled-up.

Reforming with steam is performed using a catalyst according to:

$$CH_4 + H_2O \leftrightharpoons 3H_2 + CO$$

The carbon monoxide is then converted into carbon dioxide by the water gas shift reaction:

$$CO + H_2O \leftrightharpoons CO_2 + H_2$$

Figure 2. SMRs for hydrogen production.

Figure 3. Synthesis gas processing plant for hydrogen recovery.

The reforming reaction is highly endothermic and needs a lot of heat. High temperature heat raising from hot exhaust gas increases energy efficiency to very high levels.

Steam methane reforming (SMR) gives (on a dry basis) approximately 70% hydrogen and up to 10% carbon dioxide (before carbon monoxide 'shift' to carbon dioxide and hydrogen). Autothermal reforming (ATR) uses oxygen in lieu of air to produce higher pressure hydrogen (up to 100 bar) at up to 1000˚C. This technology is economical at the large capacities of today's methanol, ammonia and gas to liquids (GTL) plants, but produces significantly more carbon dioxide. SMR is therefore preferred, but studies on optimal and lower cost carbon capture technology may mean that ATR will be favoured for some applications in the future. More work is needed on this.

The carbon dioxide can be removed from the hydrogen by several well-proven technologies – by solvent, pressure swing adsorption (PSA), semi-permeable membrane and cryogenic.[9] Costain has designed many hydrogen related facilities, including for synthesis gas purification and for hydrogen recovery. A hydrogen purity of 99+% can be economically achieved.

Large-scale carbon dioxide capture from hydrogen has been demonstrated industrially but there are opportunities for technology development and optimisation of the purification technologies such as chemical looping and hybrid process schemes of PSA, membrane and cryogenic technology.

Hydrogen projects

Due to the large scale of hydrogen deployment, it must be considered in a staged way by geographical area, with arising technical and financial know-how being made available for future use. This approach was employed in the UK for two front-end engineering and design (FEED) projects for carbon capture and storage, one at Peterhead in Scotland (post combustion capture downstream of an existing gas-fired power plant) and the White Rose project at Drax, North Yorkshire (carbon capture from new oxyfuel coal-fired power plant). Both intended to ultimately store carbon dioxide in North Sea reservoirs. In November 2015, the government's financial support was withdrawn and the projects were abandoned. However, the 2017 Clean Growth Strategy[2] is an opportunity for project developers, techno-economic consultants and engineering companies to develop a more compelling case for government funding for hydrogen use and for carbon capture, usage and storage.

Leeds, one of the UK's largest cities, has been proposed as the first area in the country to potentially use pure hydrogen as a fuel source for industrial and domestic heating.[10] Hydrogen would be supplied by pipeline from four SMRs on Teesside, with 1.5 million tpy of carbon dioxide piped to the North Sea for storage. Salt caverns would be used for hydrogen 'buffer' storage. This project could be used as a template for the wider implementation of hydrogen through the 2030s.

Figure 4. Leeds is proposed for a hydrogen network.

carbon capture from hydrogen; worked on hydrogen injection into the national gas grid; identified optimal locations for carbon capture and storage in offshore UK depleted gas fields; and defined optimal carbon dioxide transportation schemes.

An alternative approach has been proposed by Cadent[11] for the North West England conurbation. Three 260 MW SMRs will provide a reliable source of hydrogen to local chemical manufacturers and industrial heat consumers (which together consume over 5% of the UK's energy) through a new hydrogen pipeline system and by supplementing the existing natural gas network to a hydrogen content of 10%. This content is significantly more than current limits for UK natural gas and the effects of such a change are being assessed. A concurrent evaluation, termed 'HyDeploy', is assessing the viability of natural gas containing 20% hydrogen.[12] Carbon dioxide from the North West 'Cluster' is intended to be piped to the soon to be depleted Hamilton gas field in Liverpool Bay to store about 1.5 million tpy of carbon dioxide (including some industrial emissions currently sent to atmosphere).

The proposed North West 'Cluster' would have an advantage over the proposed Leeds scheme in not requiring modification to existing gas systems. It only provides partial decarbonisation of the gas network but would demonstrate some key elements of a fully decarbonised scheme. The economic feasibility of changing industrial and particularly domestic systems and burners from natural gas to suit hydrogen, which is important to the Leeds scheme, is currently being evaluated.

Technical issues with hydrogen use

The advantages of large-scale production and utilisation of hydrogen (over other proposed carbon reduction technologies) include:

- Most of the key technology elements and equipment are well established and understood by the leading process engineering consultants with reliable design methods and engineering procedures in place.
- Leading engineering companies already have corporate strengths in gas processing and transportation, design safety capability, understanding of key legislation, economic modelling capability, and the ability to deliver large scale technology intensive projects.
- Established supply chain for critical equipment.

As an example of necessary skills now being in place, Costain has worked extensively on the national gas grid and on underground gas storage; undertaken plant design and supply projects for hydrogen and for carbon dioxide capture; has intellectual property to reduce the cost of carbon capture from hydrogen; worked on hydrogen injection into the national gas grid; identified optimal locations for carbon capture and storage in offshore UK depleted gas fields; and defined optimal carbon dioxide transportation schemes.

Some technical concerns with hydrogen include:

- It is volatile and highly flammable and has inherent safety concerns that require key management and mitigation, including prediction of dispersion.
- As hydrogen has such low density, pipelines and infrastructure for hydrogen transport are more likely to leak than with natural gas.
- It can lead to pipeline embrittlement (though the UK low pressure gas distribution system should be 100% polyethylene pipe by 2032).
- The characteristics of hydrogen in terms of its combustion characteristics (such as flame speed) are different to natural gas (though Wobbe Index is within 10% that of natural gas).
- High flame temperatures with hydrogen promote NO_x formation.

The technical and engineering issues associated with high-pressure transportation and hydrogen use need detailed evaluation to provide confidence.

Conclusion

Technology consulting and engineering capabilities exist to progress hydrogen deployment. Today's challenge is organising and managing the key techno-economic studies and evaluations that are required to optimise hydrogen-based energy supply on a local and national level. There is an urgent need for this to happen to ensure critical targets for carbon dioxide emissions can be met.

References

1. 'UK Energy in Brief 2017', Department of Business, Energy & Industrial Strategy, (July 2017).
2. 'The Clean Growth Strategy', Department of Business, Energy & Industrial Strategy, (12 October 2017).
3. 'Digest of United Kingdom Statistics 2017', Department of Business, Energy & Industrial Strategy, (July 2017).
4. '2050 Energy Scenarios, The UK Gas Networks role in a 2050 whole energy system', KPMG, (July 2016).
5. 'Net-Zero North, Delivering the Decarbonisation Mission in the North of England', Institute for Public Policy Research, (December 2017).
6. 'Potential Role of Hydrogen in the UK Energy System', Energy Research Partnership, (October 2016).
7. 'The Transition to Low-Carbon Heat', Energy Research Partnership, (October 2017).
8. 'Clean Hydrogen and CCS', IEA GHG Information Paper 2017-IP23, IEA GHG, (April 2017).
9. VOLDSUND, M., JORDAL, K. and ANANTHARAMAN, R., 'Hydrogen production with CO_2 capture', International Journal of Hydrogen Energy XXX, pp. 1 – 24, (2016).
10. 'H21 – Leeds City Gate', Northern Gas Networks, (July 2016).
11. 'Liverpool – Manchester Hydrogen Hub, Energy to Fuel the Northern Power House', Aqua Consultants, (September 2017).
12. 'The Future of Gas, Progress Report', National Grid, (July 2017).