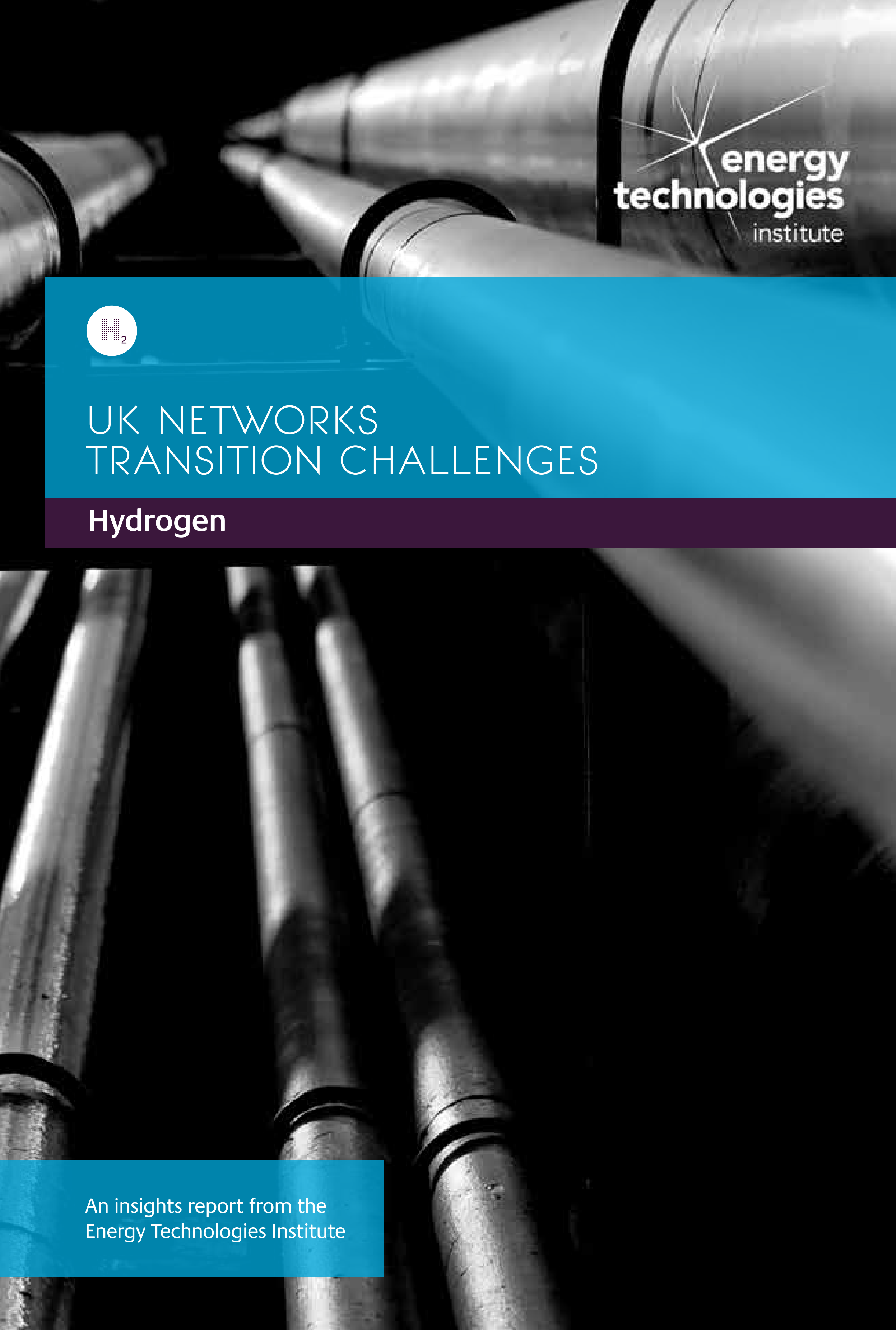

UK NETWORKS TRANSITION CHALLENGES

Hydrogen

An insights report from the Energy Technologies Institute

Contents

INTRODUCTION

Any move to a low carbon UK energy system that uses new and more varied sources of energy generation will require investment and an upgrade of the current energy network infrastructure.

At ETI we see there are three key challenges to transitioning UK networks for a wider adoption of low carbon sources. These are:

1. A need to adapt and enhance the existing network infrastructure to absorb new forms of energy generation.
2. The creation of efficient and effective new network infrastructure to deliver new forms of energy generation.
3. The integration of energy networks so the UK can optimise the use and performance of energy generated across a number of different energy vectors, effectively and efficiently.

Our analysis in this area has pointed to the fact that we see there is real value in the UK employing a multi-vector approach to its energy supply, both from the perspective of transitioning to a low carbon energy system, but also in a manner that is convenient and affordable to the end consumer.

To make this a reality whole energy system thinking is critical. Analysing the interactions between networks (as well as with the wider energy system) and how today's network infrastructure will influence the infrastructure that will be needed in the future is central to this because the challenge is one of knowing where, when and to what extent to enhance the network.

Today, current governance and regulatory frameworks are simply not designed to enable and incentivise the radical transformation that will be needed to move to a low carbon solution.

Against this backdrop, the ETI recommends the following actions should be taken to effectively transition to a low carbon energy system with a network infrastructure that delivers for future generations.

1. The UK should incentivise and target investment to allow it to adapt and enhance existing networks.
2. Alongside this the UK needs to make clear decisions upon what and where they want new networks to operate and invest in them accordingly.
3. The UK should design network infrastructures to ensure that they work together efficiently across multiple vectors in real time – providing an economic and consumer solution to the delivery of low carbon energy.

Whilst we advocate the systems-wide approach, this insight report looks in more detail at the challenges faced in the UK in establishing and developing a hydrogen supply infrastructure to provide a low carbon solution and form a strong component of a multi-vector approach to UK energy infrastructure.

INTRODUCTION

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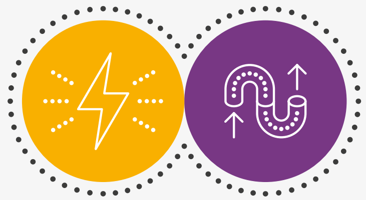
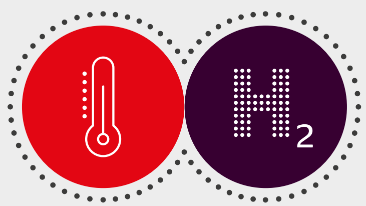
Challenge one

Adapting and enhancing existing network infrastructures



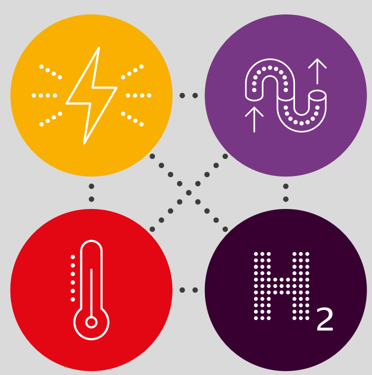
Challenge two

Enabling creation of efficient and effective new network infrastructures



Challenge three

Integrating new and existing networks to enable optimisation across vectors



HYDROGEN NETWORKS, WHERE ARE WE NOW?

Today hydrogen has very limited use as an energy carrier in the UK. The hydrogen supply chain that does exist is almost exclusively for the chemical industry, with the hydrogen predominantly transported by vehicle in liquid or compressed form. The pipelines that do exist are used to move hydrogen relatively short distances and at relatively low volumes within the confines of chemical plants. Hydrogen is stored in reasonably large quantities in salt caverns, helping to balance somewhat intermittent consumption with the much steadier output from production plants. At present, hydrogen is predominantly produced from natural gas using a process known as steam methane reforming (SMR) but can be produced in a number of ways and from a variety of sources.

The limited infrastructure is not a feature unique to the UK with hydrogen currently having limited application, globally, as an energy carrier. It is, however, flexible in terms of its end uses and has the potential to serve a number of sectors, if the technology for those different applications continues to develop and the overall economics of low carbon production, supply and consumption of hydrogen can compete with alternative low carbon solutions.

HOW MIGHT THINGS CHANGE?

In this report we have used the ETI's published scenarios, which illustrate how the wider energy system might evolve, as a basis for exploring how we might need to invest in hydrogen networks. The scenarios themselves have been developed from extensive analysis of the overall energy system and how it might have to develop out to 2050 in order to meet the UK's greenhouse gas emissions targets. The underlying analysis covers, amongst other things: how technologies might develop; how they would need to interact with each other as part of an overall energy system; practical roll-out timeframes for those technologies; potential constraints on energy resources; operational constraints and, not least, changes in energy demands and customer expectations.

Two scenarios are depicted which offer contrasting pictures of the UK energy system evolution to 2050. These are referred to as **clockwork** and **patchwork** and are plausible and self-consistent examples of how the energy system might evolve to meet the UK's 2050 greenhouse gas emissions targets. They are not forecasts but portray distinct (yet not exhaustive) ways in which hydrogen networks could need to be developed, offering a means to explore a range of challenges that they might face.

Clockwork
From the mid-2030s hydrogen networks are steadily developed to serve both the power and industry sectors.
For the power sector, the onus is on hydrogen storage infrastructure with the hydrogen fuelling flexible power generation[1].
The predominant source of hydrogen is CCS-equipped biomass, coal and plants located in the north-east and north-west of England.
As well as access to CCS these regions also offer geology well suited to large-scale hydrogen storage[2] – with over 30GWh built by 2050.
By 2050, this enables over 40TWh a year of hydrogen to be used by 4GW of power generation, primarily for mid-merit, seasonal and peak generation, where there is sufficient shorter duration flexibility elsewhere in the system.
For the industry sector, the earliest opportunities lie in the north-east of England. Subsequently, a means of moving hydrogen from points of production to industry sites further afield is put in place.
Annual consumption of hydrogen by industry reaches more than 80TWh by 2050.

Patchwork
Hydrogen networks, led by smaller initiatives, are developed to supply the transport, industry and power sectors.
Hydrogen use in the domestic sector is an option explored in certain regions as a means of utilising the existing gas network once a cost-effective hydrogen supply emerges.
Supply to the transport sector begins in the mid-2020s initially serving back-to-base fleets of cars and vans.
As confidence in the technology grows, a nationwide refuelling infrastructure is developed with annual hydrogen consumption in the transport sector reaching 40TWh by 2050.
Once the availability of CCS enables sufficiently low-cost hydrogen to be produced in the 2040s, the industry and power sectors become major markets.
By 2050 industry demand reaches over 50TWh a year requiring the infrastructure to rapidly increase both its capacity and the number of locations it serves.
In the power sector hydrogen is used as fuel for peaking generation with 3TWh consumed annually by 2050 in 17GW of power plants, utilising over 25GWh of storage capacity.
The power sector also delivers an alternative source of hydrogen with excess renewable output converted to hydrogen via electrolysis.

1 Gammer, D. (2015). The role of hydrogen storage in a clean responsive power system. [online]. Available at: http://ow.ly/euuq302IVsO
2 Day, G. (2014). Potential for CCS in the UK. [online]. Available at: http://ow.ly/VI8x302IUCY

HOW MIGHT THINGS CHANGE?
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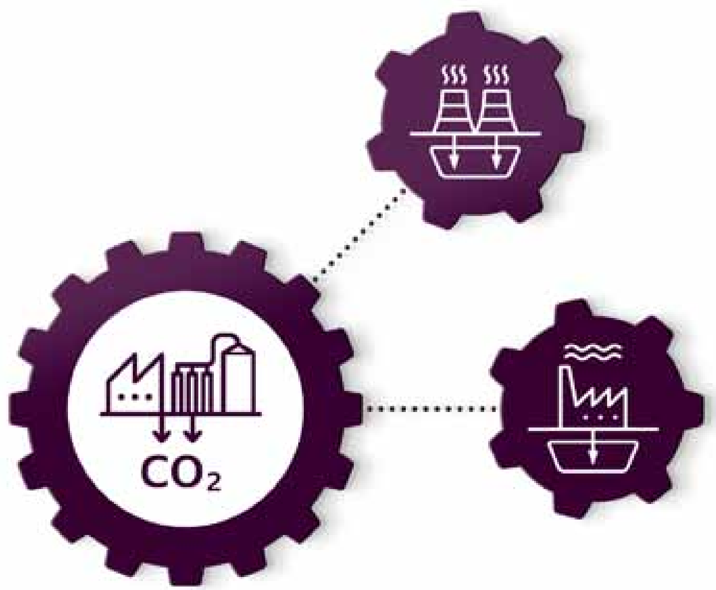
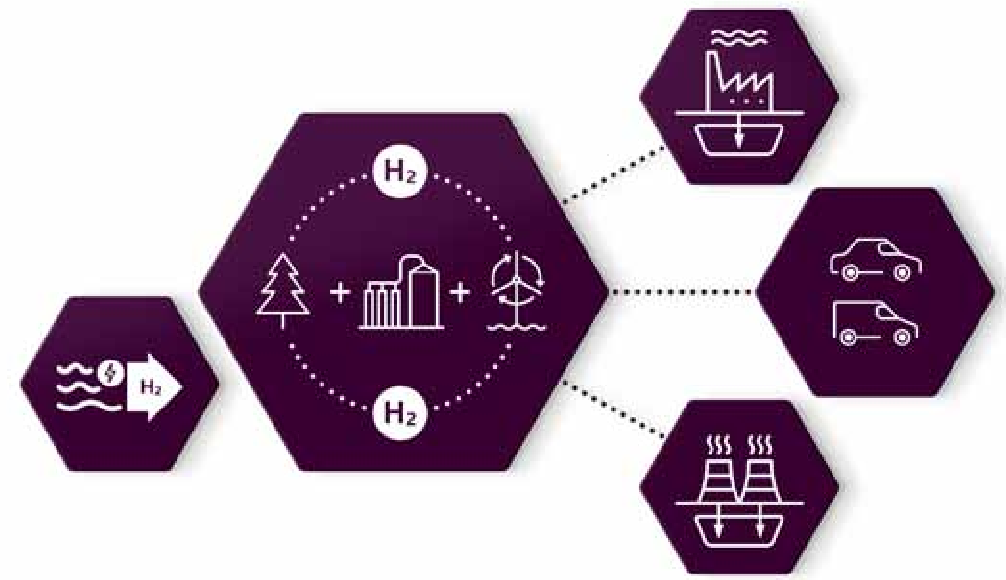




CLOCKWORK

From the mid-2030s onwards, the clockwork scenario sees hydrogen emerge as a prominent energy vector serving two sectors: power and industry.

In the case of power, this is for mid-merit seasonal and peak electricity generation expected to be located in the north-east and north-west of the country near to where the hydrogen is produced from CCS-connected production facilities, close to potential storage sites and also to industrial demand.

The associated infrastructure, including both pipelines and large-scale storage, will need to be developed to support this. Storage capacity reaches over 30GWh built by 2050 and contributes to over 40TWh of hydrogen being used for power generation every year.

Industry demand is less variable limiting storage requirements but the infrastructure needs to be able to supply to where the industry is located. In this scenario, annual consumption of hydrogen by industry reaches more than 80TWh by 2050.

PATCHWORK

In patchwork, hydrogen is needed by the power, industry, and transport sectors, and could be used for domestic heating also. To enable this there is a role for hydrogen networks (to predominantly connect centralised production facilities) and localised production (particularly electrolysis utilising excess renewable electricity production).

Supply to the transport sector begins in the mid-2020s initially serving back-to-base fleets of cars and vans, with the prospect that hydrogen buses could become more commonplace in some regions. This is centred around regional initiatives which are eventually connected to form a nationwide refuelling infrastructure as private use of hydrogen vehicles grows in the decades that follow. By 2050 annual hydrogen consumption in the sector reaches 40TWh.

Increased hydrogen consumption is partly driven by a reduction in the cost of hydrogen production in the 2040s, enabled by the availability of CCS, with production via electrolysis persisting alongside this. Consumption in the power sector also increases and industry emerges as a new demand, requiring the infrastructure to rapidly increase both its capacity and the number of locations it serves. By 2050 industry demand reaches over 50TWh a year. In the power sector hydrogen is used as fuel for peaking generation with just 3TWh consumed annually by 2050 in 17GW of power plants, whilst utilising over 25GWh of storage capacity. Hydrogen use in the domestic sector is an option explored in certain regions as a means of utilising the existing gas network once hydrogen supply becomes sufficiently cost-effective.

WHAT DOES THIS MEAN FOR HYDROGEN NETWORKS?

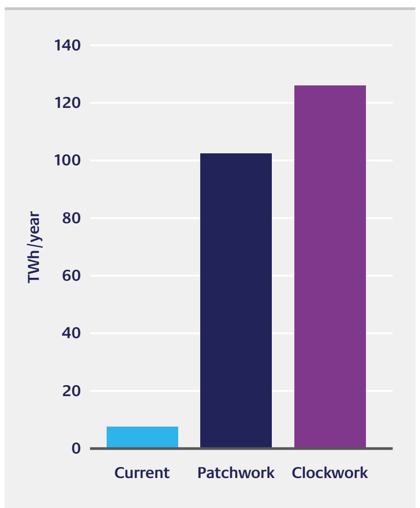
Both scenarios depict energy systems requiring large amounts of hydrogen and for that hydrogen to be moved from where it is produced to various demand locations. This will require the development of a hydrogen network, be that a pipeline or road transport based network. The volumes of hydrogen here far exceed current consumption of hydrogen, such as in the chemical industry (as illustrated in Figure 1). Building a network, or series of networks, able to deliver these quantities of hydrogen represents a considerable challenge in its own right.

A further challenge is the varying requirements the different sectors hydrogen could serve place on the hydrogen infrastructure. To enable the effective creation of hydrogen infrastructure, both of these challenges will need to be addressed.

Meeting power sector needs

The ETI has already outlined some of the major challenges and opportunities for supplying the power industry in its insights report[3]. With the UK having ample CCS and hydrogen storage potential, hydrogen could be generated in very low carbon ways, near to where it's stored and where it's converted into electricity, via hydrogen turbines[4]. This places less onus on the establishment of an extensive pipeline network. The requirement for the hydrogen to be used in peaking or seasonal mid-merit generation, though, makes the development of sufficient large-scale storage critical. As detailed in the analysis, salt caverns are a well-established and effective means of storing hydrogen in large quantities, with significant potential capacity in the north-west and north-east of England.

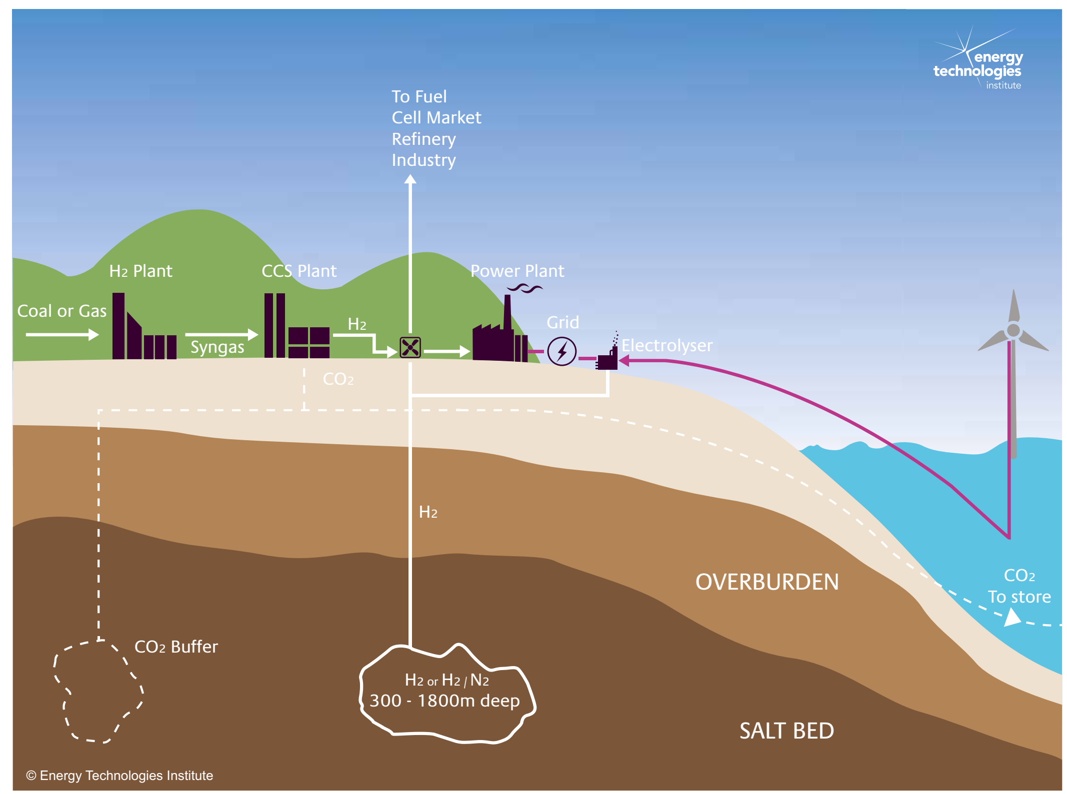
Figure 1
Current UK hydrogen production capacity compared with capacity required under the two scenarios



Whilst the pipelines that are constructed for moving hydrogen to and from the nearby stores would only need to be relatively short in length, they would have to have sufficient capacity to meet peak requirements. The pipelines taking hydrogen to the stores would need to be sized for peak hydrogen production, although this could be fairly steady, whereas those serving the hydrogen turbines would need to be large enough to carry the hydrogen needed to meet peak electricity requirements and could be several times larger.

There is a knock-on effect here for electricity network development. Under these circumstances there would need to be sufficient electrical network capacity to export the peak amount of electricity produced by the hydrogen turbines in these locations. There is an interdependence in terms of how the networks develop. The general principles of increased interdependence between networks are outlined in the accompanying overview publication[5].

Figure 2
Hydrogen storage as a part of a clean, responsive power system



3 Gammer, D. (2015). The role of hydrogen storage in a clean responsive power system. [online]. Available at: http://ow.ly/euuq302IVsO

4 Gas turbine vendors are already approving the use of their gas turbines with modest amounts of hydrogen (c. 25%) and are improving existing designs to cope with higher hydrogen content fuels[1]

5 Lidstone, L. (2016). UK Network Transition Challenges - A Systems View. [online] Available at: http://www.eti.co.uk/insights/network-transitions

WHAT DOES THIS MEAN FOR HYDROGEN NETWORKS?

Continued ›

The peaking operation of the hydrogen turbines is also relevant to the operation of the hydrogen stores[6]. The level of system balancing they need to provide (a function of the design of the rest of the energy system) will affect, for example, how full they need to be kept and how quickly they can be depleted to meet changes in demand. Equally this can impact on the architecture of the pipeline network if, say, it is necessary to incorporate a bypass system to supplement the extraction of hydrogen from the store in order to meet peak electricity demand. Figure 3 shows some power station configurations that use hydrogen storage.

The architecture of the network will also be influenced by the extent to which hydrogen will be needed in this peaking role over the longer term. Hydrogen turbines are capable of serving a role as peaking plant or mid-merit plant (examples of this are illustrated in Figure 4). Mid-merit plant are operated more often and for longer periods and as a result, produce more electricity and use far more fuel overall. There is the potential for hydrogen turbines to adopt a seasonal mid-merit role to support electrification of heat. All of this affects hydrogen supply and thus network requirements. The different roles also affect the number of turbines that are needed, which has knock-on effects for the electricity network, including network connections and capacity requirements.

ETI Project:
Salt Cavern Appraisal for Hydrogen and Gas Storage

This project will:

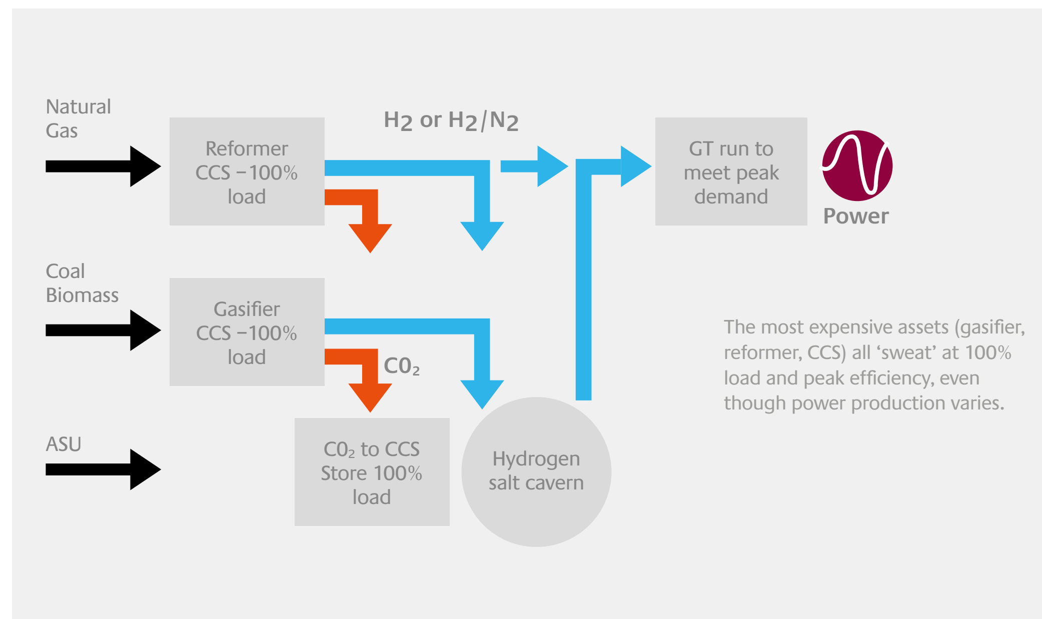
- Develop understanding of salt cavern flexibility, supporting ETI system level modelling activities, for 100% hydrogen and hydrogen/methane mixtures, with a focus on flexibility and cost
- Characterise key constraints and their causes when operating fast churn storage at selected sites, including those caused by integration with the hydrogen supply and the gas turbines.
- Identify a range of gas turbine offerings which match cavern capability or market needs.

Both the clockwork and patchwork scenarios utilise hydrogen turbines, yet the network requirements of each are quite distinct. In patchwork in 2050 they are operated as peaking plant, whilst in clockwork they are operated as mid-merit plant but only during the heating season. This results in over 10 times as much hydrogen being used in clockwork for power generation than in patchwork and in only a quarter of the power plants. Although the overall amount of hydrogen storage is similar between the two scenarios, the way in which storage would be operated in each is very different.

Even if hydrogen is used in peaking plant initially, this may change over time, depending on the cost of the hydrogen, the level of decarbonisation required in the power sector and the make-up of the rest of the power sector. The network will need flexibility to adapt over time.

This highlights the value of developing optionality. To be robust to potential future requirements, early designs and decisions need to incorporate flexibility to be able to expand capacity and production. For example, taking the two scenarios in Figure 4, it might be appropriate build turbine capacity at a slow rate from 2030 until it becomes more obvious which role is required towards the late 2030s.

Figure 3
Power station configurations using hydrogen storage



6 Gammer, D. (2015). The role of hydrogen storage in a clean responsive power system. [online]. Available at: http://ow.ly/euuq302IVsO

WHAT DOES THIS MEAN FOR HYDROGEN NETWORKS?

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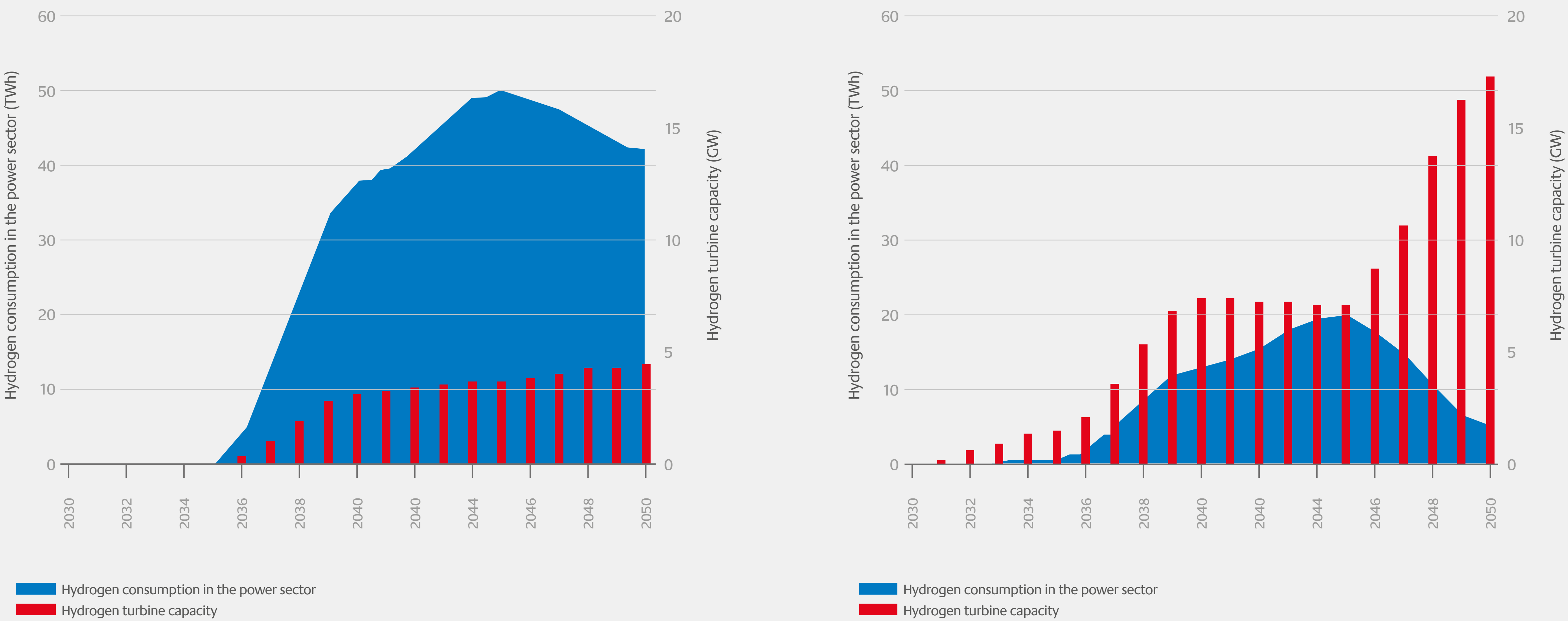
Figure 4

Illustrative examples, based on the ETI's clockwork and patchwork scenarios, of hydrogen turbine deployment and hydrogen consumption in the power sector when built to operate as: (a) mid-merit plant (only during the heating season); and (b) peaking plant.



WHAT DOES THIS MEAN FOR HYDROGEN NETWORKS?

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Meeting industry sector needs

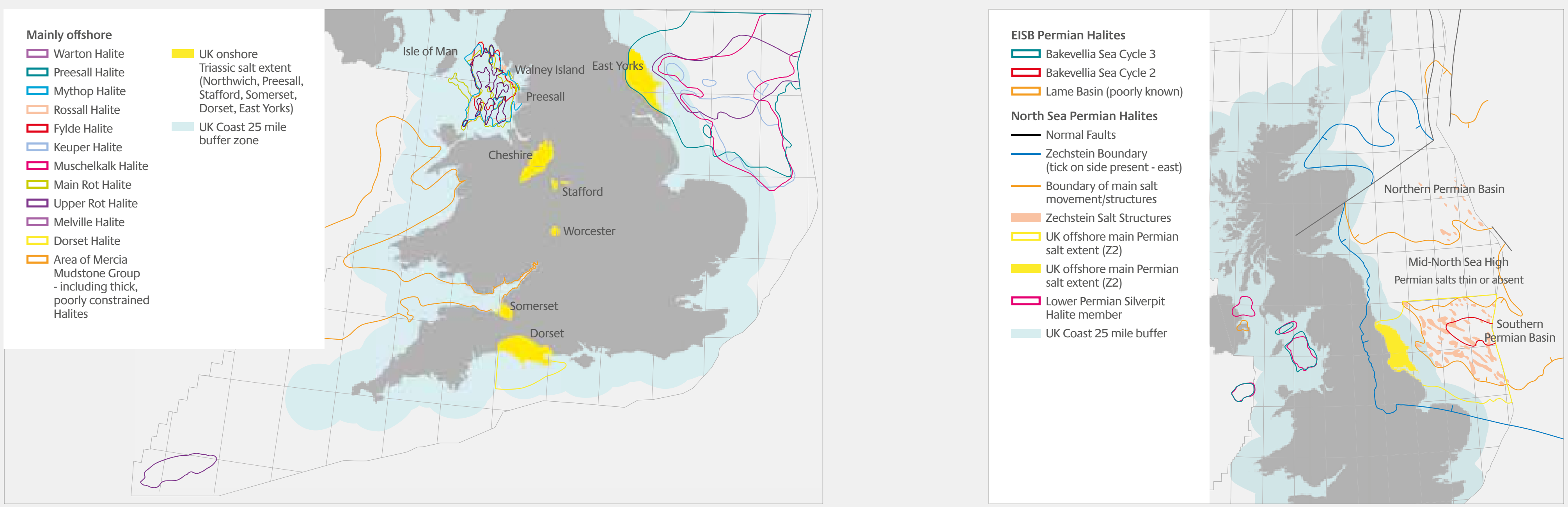
By contrast, pipelines would be a more substantial part of the picture for hydrogen use in industry. The large-scale centralised production of low carbon hydrogen is driven by access to CCS, which means hydrogen needs to be transported from these locations to where it is needed. For power, the UK's geology (see Figure 5) means it is likely that the hydrogen will only need to be transported relatively short distances, with the hydrogen both produced and consumed within the north-west and north-east of England. The location for industry demand, though, will be driven, as it is now, by other factors, albeit recognising that a significant amount of industrial activity is presently in the north-west and north-east of England. This will call for new pipelines or the use of other appropriate infrastructure, such as repurposed natural gas pipelines. Either will require substantial planning and investment to reach the required scale of supply to the locations that need it and to do so in time to deliver the benefits. The ability to finance these investments will be affected by the perceived longevity of the industrial sites. Alternatively, the availability of a cost effective hydrogen supply may come to influence the location of industrial sites.

Hydrogen use in industry is one of the only credible means of producing low carbon high temperature heat. As such it provides a means for industry to combat its emissions whilst maintaining output. The majority of industrial uses require steady high temperatures during hours of operation. This points to a much smoother profile than would be seen for power and places less emphasis on storage of hydrogen, although some buffer storage may still be required.

For both the power and industry sectors the transport of hydrogen over meaningful distances raises a number of practical safety considerations. The small size of hydrogen molecules makes them more prone to escape than natural gas, so pipework, seals, compressor equipment, etc. will need to be sufficiently leak-tight to minimise this. Whilst the escape of hydrogen is less damaging from a global warming perspective than the escape of natural gas it is slightly more combustible. Hydrogen can also cause a weakening of some metals typically used in pipelines, a process called embrittlement, which can lead to cracking. Appropriate grades of steel and non-metals do not suffer from this and material selection for these pipelines will thus be important. These factors may prove particularly problematic for repurposing steel natural gas lines. The cost of repurposing (even where the routes are favourable) may make new-build pipelines more appropriate. Whichever approach is used, steps are likely to need to be taken to implement appropriate "odorisation" and "colourisation" to aid leak detection and spot otherwise colourless flames.

Figure 5

Location of UK salt fields (shown in yellow) Triassic (left) and Permian (right). Courtesy of BGS



WHAT DOES THIS MEAN FOR HYDROGEN NETWORKS?

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Meeting transport sector needs

Catering to the transport sector raises a further set of issues. The most likely way in which hydrogen would be used in the transport sector is through fuel cells. As it stands, the most promising fuel cell technologies require very high purity hydrogen to function without degrading.

It will be challenging to produce hydrogen of the required purity for fuel cells from the gasification of biomass (and, where appropriate, coal) with CCS without additional purification. Biomass with CCS does, however, represent the lowest carbon way of producing hydrogen and, without radical advances elsewhere, would be the most cost-effective way of producing it at scale. There are options for purifying the hydrogen produced. Decisions will need to be taken about which to use and where in the network to deploy them. The chosen approach will affect how the rest of the pipeline network should be designed.

The design will also be affected by the roll-out strategy that is adopted. There are two principal starting points here. One is the supply of depots for return-to-base fleets. The other option is to supply refuelling sites around major population centres and along major routes to provide a strong backbone ahead of wider expansion (as outlined in UK H2 Mobility's phase 1 results[7]). For hydrogen vehicles to be anything more than a niche solution the second option will need to be a part of the solution and a nationwide refuelling infrastructure will need to be established. The development of any hydrogen pipeline network infrastructure would need to reflect this.

Under this approach it may not be necessary to build pipelines for all refuelling sites. Delivery by road transport (in liquid form) could be suitable for some sites. This would, however, require liquefaction facilities to be integrated somewhere into the supply chain, to fill the tube trailers that would be used. Whilst liquefaction would add cost it would remove the need for separate purification, as the liquefaction process itself would purify the hydrogen. There is the possibility that the transport of liquefied hydrogen by road transport would negate the need for a pipeline infrastructure, though there is likely to be an emissions impact associated with doing so. Another approach would be to use road transport as the initial means of supplying refuelling stations to reduce the risk of investment in pipelines before sufficient sustained demand for hydrogen transport is assured.

Localised production of hydrogen through electrolysis is a further option. This then becomes an electricity network rather than a hydrogen network issue but is an important alternative. The costs of such an approach are expected to be much higher, particularly when requirements across the energy system, including the availability of sufficient low carbon electrical generation, are taken into account. In a world where a hydrogen network is needed to serve the transport sector, there are a number of ways in which electrolysis could support this. It could function as a means to seed a hydrogen supply chain; complement a growing and mature hydrogen supply chain; and/or support areas beyond the range that can be economically reached by pipeline or road transport.

Decisions will need to be taken about which of these hydrogen supply approaches to adopt. This will need to consider how demand for hydrogen transport may emerge and how the rest of the energy system might develop.

7 Lidstone, L. (2016). Gas Network Transition Challenges. [online] Available at: http://www.eti.co.uk/insights/network-gas

WHAT DOES THIS MEAN FOR HYDROGEN NETWORKS?

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Meeting building sector needs

Hydrogen use for buildings in the domestic and commercial sectors centres on replacement of gas (for heating and cooking), in part or fully. One of the potential benefits for using hydrogen to decarbonise this sector is the prospect of being able to use the existing gas distribution infrastructure. The implications of this are covered more fully in the accompanying Gas Transition Challenges Insights publication[8].

This may prove to be a viable solution for decarbonising heating in certain regions. How appropriate it is to adapt the gas grid to carry larger amounts of hydrogen will depend on the degree of physical adaptation needed and public acceptance, as well as the availability a sustainable source of hydrogen.

Scale-up

Whilst each of the end-use sectors have specific requirements, it is unlikely that the development of supply infrastructures to serve each of them will be mutually exclusive. For example, both the power and industry sectors offer the prospect for hydrogen to be produced and consumed in or near the north-east and north-west of England. This may create the opportunity to share production and/or pipeline capacity (were routes to be compatible with this). Serving a diverse set of markets can also lower the investment risk for the infrastructure. This also has the potential to influence the most cost-effective design and siting of the infrastructure. For example, the amount of storage that is needed and where it should be located may differ if two sectors are being served rather than one.

Adding in transport or supply to the domestic sector brings further factors into play for developing a hydrogen supply infrastructure. The higher purity requirements of the transport sector may, however, keep this separate, at least in the earlier stages of any infrastructure deployment. As sectors mature, the need to produce much higher quantities of hydrogen may bring economies of scale that override other costs such as purification and lead to greater shared infrastructure.

The scenarios do not depict hydrogen being used in significant quantities until the 2030s. In patchwork, where hydrogen starts to be used in the transport sector prior to this, this is to serve back-to-base fleets and in sufficiently small quantities that it places less emphasis on a hydrogen supply infrastructure.

To achieve the longer term scale-up of hydrogen supply in all cases, decisions need to be made around the role of hydrogen and initial steps taken (such as the development of hydrogen turbines and implementing back-to-base hydrogen vehicle refuelling) by the mid-2020s.

In terms of the infrastructure itself there is the potential that road tanker transportation, new pipelines, repurposed natural gas pipelines, hydrogen storage and electrolysis could play a part. There are both practical and economic reasons for the use or not of each of these (see Figure 6).

8 Lidstone, L. (2016). Electricity Network Transition Challenges. [online] Available at: http://www.eti.co.uk/insights/network-electricity

WHAT DOES THIS MEAN FOR HYDROGEN NETWORKS?

Continued ›

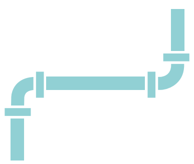
For any of the above options there would need to be a sufficient scale-up of an industry supply chain to deliver the roll-out required. Most of the above are at a level of maturity where cost improvements would predominantly arise from economies of scale and continued advances in manufacture and installation. For electrolysis there is also the opportunity to further reduce the cost and improve the performance and reliability of the technology itself.

As the role of hydrogen grows there is a strong chance that multiple forms of infrastructure are deployed; for example, road tanker transportation being used initially until, and if, sufficient quantities of hydrogen are used to warrant a pipeline system. It is also plausible that a mixture of infrastructure types may eventually persist, as the needs of different regions and different sectors vary.

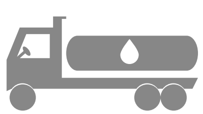
Until it is proven that low carbon hydrogen can be produced in meaningful quantities (e.g. via CCS or fully decarbonised electricity), there is a risk in developing wide-scale infrastructure. However, certain deployment options offer the chance to learn about implementation without the risk of building up stranded assets. These include: small scale testing and development of hydrogen in homes; hydrogen turbines in proximity to salt cavern stores and CCS sites; refuelling for back-to-base fleets of hydrogen vehicles (such as hydrogen buses).

Figure 6

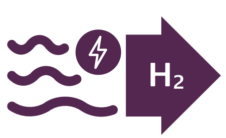
Infrastructure options for supplying hydrogen



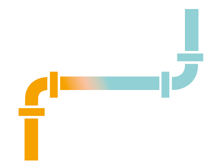
New pipelines are capital intensive, so there needs to be confidence that both the supply and demand for the hydrogen are there in sufficient quantities and for the long term, to make them viable.



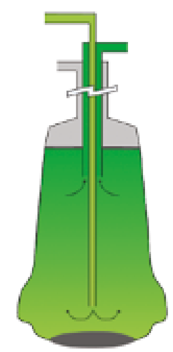
Road tanker transportation, carrying either compressed or liquefied hydrogen, offers more flexibility in terms of routes but is more appropriate for lower quantities of hydrogen than pipelines. It may also have a role in facilitating a scale-up of a hydrogen supply or as a means of distribution alongside a dedicated pipeline system.



Electrolysis, whilst another means of producing hydrogen, affects the electricity network more than a hydrogen network. It could be used to support a hydrogen supply infrastructure although its long-term cost effectiveness is unclear.



Repurposing exisiting gas pipelines to carry hydrogen may be less expensive, if materials are suitable, the degree of physical adaptation required is not too great and the existing routes and capacities are appropriate.

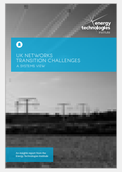


Hydrogen storage options are varied, from large-scale salt cavern storage to smaller tank-based storage. Salt cavern storage, whilst cost-effective, does have high upfront costs and can be time consuming to construct, so like pipelines, require sufficient confidence that they will be needed for the long term to be viable. They can also only be deployed where there is the appropriate geology, though the UK is fortunate in this instance. Tank-based storage can be deployed in many more locations although it is more expensive per unit of hydrogen stored than large-scale storage.

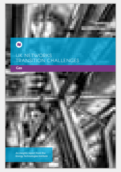
SUMMARY

The ability to supply hydrogen from low carbon sources and the infrastructure to move it to demand locations are crucial to delivering hydrogen to any sector. Building an infrastructure to move hydrogen for use as an energy carrier would be starting from virtually nothing. Major investment will be needed to make this a reality, both in equipment and in the growth of a supply chain to deliver it. This will take time to establish. Commitments around future demand for hydrogen, and the ability to produce it from low carbon sources, inevitably dictate an incremental approach which limits major infrastructure investment until demand and low carbon supply are further established.

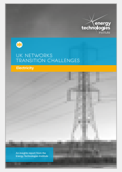
FURTHER READING



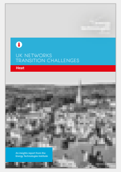
UK Networks Transition Challenges – A systems view
http://www.eti.co.uk/insights/network-transitions



UK Networks Transition Challenges – Gas
http://www.eti.co.uk/insights/network-gas



UK Networks Transition Challenges – Electricity
http://www.eti.co.uk/insights/network-electricity



UK Networks Transition Challenges – Heat
http://www.eti.co.uk/insights/network-heat

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