Driving the growth of low-carbon hydrogen, and the role of hydrogen in achieving net zero.

1 Key messages

Scottish Carbon Capture & Storage (SCCS) is pleased to submit evidence to the Science and Technology Committee. Authors: stuart.haszeldine@ed.ac.uk katriona.edlmann@ed.ac.uk

Our key messages are:

There are very different visions for hydrogen, but none have started committing to investment and pathways.

The UK needs to continue laying the scientific and physical foundations of hydrogen generation and pipeline grid transport.

Storage of hydrogen can be constructed to meet seasonally variable UK demand. This scale of hydrogen demand will require storage which can only be provided by underground geological storage. Two types of storage can be envisaged: 1) caverns excavated in salt, 2) large deeply buried bodies of porous sandstone rock.

Development of large and interdependent projects has significant co-ordination risk for Government. The UK lags behind Norway and Netherlands in crucial CCS developments with long lead-in times.

The UK needs to account full emissions from hydrogen creation, and create a badging system

Understanding the options for hydrogen storage in salt around the UK and offshore is important

Global experience in storage of hydrogen in sandstone pores is limited, but the UK has good geological databases and understanding, and good assets in depleted gas fields. Planning allocation is needed.

Multiple sites exist onshore, which are potential local stores for hydrogen in porous sandstones.

The UK has immense possibilities for geological storage of hydrogen offshore, close to some of the largest wind farms in the world. This could become a European hydrogen hub. Pilot test developments are urgently needed, to progress opportunities before rival European developers.

Scientific investigations show that immense geological storage of hydrogen can exist around the UK. Pilot development sites are needed to provide practical confirmation before 2025.

These are explored in our responses overleaf to the questions in the request for submissions at: https://committees.parliament.uk/committee/135/science-and-technology-committee-commons/news/136965/how-can-hydrogen-contribute-to-net-zero-mps-launch-inquiry/.

1.1 The suitability of the Government's announced plans for "Driving the Growth of Low Carbon Hydrogen"

1.1.1 The focus, scale and timescales of the proposed measures

Hydrogen in the UK has for many decades been safely and securely used in the petrochemicals and refining industries. Since 2018, investigations have accelerated on diverse uses of hydrogen such as: surface transport, shipping, domestic heating and cooking, and industrial heat. This will require i) abundant generation of hydrogen by chemical reforming of methane into hydrogen and carbon dioxide (CO_2), with pre-combustion capture, transport and storage of CO_2 (CCS), ii) increasing quantities of "green" hydrogen generated from water by electrolysis supplied by renewable energy, and iii) transport of hydrogen at high and low pressures through an extensive pipe network.

How much hydrogen does the UK plan for? The Government's 10 Point Plan[1] predicts developing 5GW of low-carbon hydrogen production capacity by 2030 - capable of generating 40 TWh/yr. The EU FCH UK[2] 2020 analysed EU national plans, and indicated UK hydrogen scenarios (excluding export) in excess of 20TWh (2.5 GW) per year by 2030. The Committee on Climate Change[3] (2019, Fig 5.4) estimated 225TWh (28 GW) hydrogen / yr by 2050. In Scotland the hydrogen policy statement[4] also seeks to install 5GW of hydrogen capacity by 2030, seeking to become a supplier of low-cost hydrogen derived from abundant onshore and offshore wind power.

There are very different visions, but none have irreversably committed to investment paths.

Costs of hydrogen are hard to compare between technologies and need to be compared on similar assumptions - as a guide the USA Department of Energy[5] (2020 Fig 5) places coal gasification with CCS at $1.63/kg; biomass gasification $1.91; steam methane reforming (SMR) with CCS $2.27; and wind power electrolysis at $6.0/kg. These compare with untaxed prices of USA petrol from $0.43/litre to $1.58/litre. Substantial progress is needed - in building additional wind power to operate the electrolysers, in efficiency of electrolysis, and in efficiency of conversion - before hydrogen competes with petrol.

But this hydrogen needs to be delivered - by road, rail or usually pipeline. By luck, the UK has nearly completed its pipeline replacement programme (IMRP) from iron mains to polythene low pressure distribution. Polythene has been shown as generally suitable for long term use with hydrogen, but incomplete progress has been made on evaluation to re-purpose high pressure transmission pipelines of steel. Some types of steel can be made brittle by carrying hydrogen.

The UK must continue laying the scientific and physical foundations of hydrogen pipe grids.

National grids will be essential to transmit hydrogen gas for the further upscaling of hydrogen to enable deep decarbonisation of energy, transport and manufacturing, and provide crucial energy security. This conversion will be a multi decade process. A full conversion of the UK gas grid occurred from town gas (hydrogen + carbon monoxide) to natural gas (methane) between 1966 and 1977, affecting 13 million homes (Elliott[6] 1980). The future task will be larger, with a greater number of homes and industries

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[1] HM Government (November 2020) The Ten Point Plan for a Green Industrial Revolution https://www.gov.uk/government/publications/the-ten-point-plan-for-a-green-industrial-revolution

[2] EU Fuel Cells Hydrogen UK (2020) Opportunities for hydrogen energy technologies https://www.fch.europa.eu/publications/opportunities-hydrogen-energy-technologies-considering-national-energy-climate-plans

[3] Committee on Climate Change (May 2019) Net Zero, the UK's contribution to stopping global warming https://www.theccc.org.uk/publication/net-zero-the-uks-contribution-to-stopping-global-warming/

[4] Scottish Government (December 2020) Hydrogen Policy Statement https://www.gov.scot/publications/scottish-government-hydrogen-policy-statement/

[5] US Dept Energy (July 2020) Hydrogen strategy: enabling a low carbon economy https://www.energy.gov/sites/prod/files/2020/07/f76/USDOE_FE_Hydrogen_Strategy_July2020.pdf

[6] Elliott C (1980) The history of natural gas conversion in Britain. Cambridge Information Services

In the recent 10 years, demand for methane has increased slowly per year. The total methane used in 2017 was 875 TWh, part of which was methane imports of 400 TWh. However, it is well established that methane use in winter (mostly for heating) is about 6x that of summer; and that the rate of daily demand change in winter can climb by 4-6x the entire electricity system within two hours (Wilson[7] 2018). It is not possible to meet these demands with electricity, unless there is an extension of the generation capacity by 4x plus rapid-response batteries or pumped storage at 2x present electricity system capacity.

Storage of hydrogen can be constructed to meet this demand. This scale of hydrogen demand will require storage which can only be provided by underground geological storage. Two types of storage can be envisaged: 1) caverns excavated in salt, 2) large deeply buried bodies of porous sandstone rock.

Gas storage at this scale has never been constructed in the UK, but comparable sites exist in Europe and the USA to store methane between seasons. This is discussed in detail below - including new research information containing the first published estimates of UK hydrogen storage capacity.

1.1.2 How the proposed measures—and recommended measures—could best be co-ordinated

For hydrogen the Government 10 Point Plan seeks milestones of a hydrogen strategy in 2021; first trials of 20% blends in pipelines by 2023; and 1GW hydrogen creation capacity by 2025. The speed of change anticipated is commendably aligned with the carbon budgets and pathway to Net Zero in Scotland by 2045, and the UK by 2050. That hydrogen needs to be clean and embedded carbon must be measurable.

The diversity of large activities does produce a large co-ordination risk for Government, because all parts of the energy system are interdependent. It is necessary to have abundant low carbon electricity - hence rapid wind development on- and offshore. Replacement of methane in heating and industrial processes requires large hydrogen tonnages by 2030 - with present-day costs strongly favouring SMR and autothermal reforming (ATR), which must have CCS to store CO_2. Thus CO_2 capture will be needed, along with CO_2 pipeline infrastructure, and large CO_2 storage sites. All components of this system need to be operating by the mid-2020s in the first UK industrial cluster, and several additional clusters need to be operating between 2025 and 2030. Government needs to explain that ambition more clearly.

The lead-in time to proving a CO_2 storage site in the UK from concept to commercially investable quality can be 5 years. Norway[8] has already designed such a system, and will be offering first in the world carbon capture from cement works, municipal waste carbon capture, and CO_2 storage as an international service - operating in 2024. Porthos[9] CCS project at Rotterdam will operate in 2023. Acorn Hydrogen and Acorn CCS[10] capture transport and storage from St Fergus plans 2024 operation.

Development of large and interdependent projects has significant co-ordination risk for Government. The UK lags behind Norway and Netherlands in crucial CCS developments with long lead-in times.

[7] Wilson, Taylor, Rowley (2018) '*Challenges for the decarbonisation of heat: local gas demand vs electricity supply Winter 2017/2018'* UKERC Briefing Note. https://ukerc.ac.uk/publications/local-gas-demand-vs-electricity-supply/
[8] CCS Norway website, https://ccsnorway.com
[9] Porthos CCS Rottderdam project website, https://www.porthosco2.nl/en/
[10] Acorn CCS and Acorn Hydrogen (2021). Project website. https://pale-blu.com/acorn/

1.1.3 the dependency of the Government's proposed plans on carbon capture and storage, any risks associated with this and how any risks should be mitigated

The creation of hydrogen from methane can be combined with carbon capture at the site of manufacture by SMR or other technologies - effectively a centralised pre-combustion capture, which can typically be configured to be 95% (90-99%) efficient. If undertaken as part of a decarbonised industry hub, that CO_2 can be pipelined offshore to storage.

However not all methane has the same source. A few percent of grid methane supply is now biomethane from anaerobic digesters - with a minimal embedded CO_2 cost of creation. The great majority of methane has been from UK domestic gasfields supplied by pipeline from the Irish Sea and southern North Sea, with a typical embedded emissions intensity of 22 kgCO_2/boe, that is well into terminal decline, and is being replaced by methane pipelined from Norwegian gas fields - with a lower intensity. However, the import of methane as liquified LNG is already at large scale, and will greatly increase. The energy used in cooling, compression to transport by ship, and in re-gasification on arrival into the UK is typically more than double that of domestic supplies[11] at 60 kgCO_2/boe -about 13% of the gas. That "upstream" emission is not mitigated or recaptured by any actions in the UK. But because of UN FCCC accounting rules, those emissions are assigned to the country of origin, such as Qatar or USA. Consequently, "blue" hydrogen can contain very variable full-life cycle emissions. An accounting system of hydrogen origin and emissions could quantify with numbers on an AAA+ to G scale like domestic appliances -rather than the present rainbow descriptions.

The UK needs to account full emissions from hydrogen creation, and create a badging system

1.2 The progress of recent and ongoing trials of hydrogen in the UK and abroad, and the next steps to most effectively build on this progress

Geological storage of methane has previously been constructed in salt caverns and in sandstone porespace. But it has never been constructed at this scale for hydrogen. We summarise recent research work for the first time, showing that massive storage of hydrogen is possible in depleted gasfields, and that technical criteria and offshore planning will be needed.

The UK has an exceptionally diverse geology so can access storage in salt caverns beneath Humberside, under Cheshire or Larne Loch[12]. An analysis of hydrogen storage in European and southern North Sea salt[13] (Caglayan et al 2020) found an unrisked technical potential totalling 85,000 TWh. Individual caverns may be 500,000 m^3 in volume, being 84m diameter and 120m high, separated by 4x cavern diameter, each storing 133 GWh of hydrogen. But many hundreds of caverns would be needed to reach 10,000 TWh as UK technical salt store capacity (ibid Fig 8). That compares favourably to existing grid-scale lithium batteries, individually 130MWh (0.13GWh) in Escondido California, or Horndale South Australia. Much larger storage in vertically extensive salt domes may be possible offshore of the UK. Those could be conceptually similar to Mitsubishi Advanced Clean Energy Storage[14] in Utah, of 1,500MWh (0.0015TWh).

It is also vital to identify the scale-up required to deliver green hydrogen from dispersed renewable energy capable of supplying the UK with hydrogen and deliver the route map to a cost effective and

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[11] Oil and Gas Authority (2020) *Emissions Intensity Comparison of UKCS Gas Production and imported LNG and Pipelined Gas*. https://www.ogauthority.co.uk/news-publications/publications/2020/ukcs-natural-gas-carbon-footprint-analysis/

[12] Geological Society (26 June 2020) Subsurface hydrogen storage https://committees.parliament.uk/writtenevidence/8170/html/

[13] Caglayan et al (2020) technical potential of salt caverns for hydrogen storage in Europe. Int J Hydrogen Energy https://doi.org/10.1016/j.ijhydene.2019.12.161

[14] CNBC (1 Nov 2020) A global hydrogen energy boom is coming. https://www.cnbc.com/2020/11/01/how-salt-caverns-may-trigger-11-trillion-hydrogen-energy-boom-.html

fair energy system transition across all energy vectors. Pilot projects such as Dolphyn[15] show that floating platforms of offshore wind 50-250km offshore can create "green" hydrogen by electrolysis at 4GW scale and £2-3/kg (ibid, Fig 3.6). Dogger region of the North Sea may by 2035 become an international scale hydrogen generation complex[16]. That can be pipelined to shore, where local storage can be connected to the hydrogen grid. So it is appropriate to consider storage at many locations around the UK not just in east coast salt.

Understanding the options for hydrogen storage in salt around the UK and offshore is important

The EPSRC funded HyStorPor[17] project at University of Edinburgh is the first UK practical project aiming to establish the feasibility of storing hydrogen in underground porous reservoirs. The HyStorPor project has developed fundamental understanding of hydrogen flow and reactivity in the subsurface, up scaled to the storage reservoir, coupled with public engagement to set the scientific foundations for hydrogen storage in porous rocks.

Defining the scientific and engineering knowns and unknowns is important. These are summarised by Heinemann[18] et al (2021).

Results generated by the HyStorPor project so far indicate that:

Globally, practical experience of hydrogen storage is so far limited to 1) Town gas (~50% hydrogen) storage in the 1960s and 70s in onshore saline aquifers at Ketzin, Germany; Beynes, France and Labodice, Czech Republic. 2) injecting green hydrogen into subsurface reservoirs to undergo bacterial conversion to methane, at Underground Sun Storage, Austria and Hychico, Argentina. 3) Salt cavern storage of 100% hydrogen at Teesside, UK since 1970 and at Spindletop, Clements Dome and Moss bluff in the USA since the 1980's onwards. Suitable UK storage sites should be planned and allocated for use as hydrogen stores.

Global experience in storage of hydrogen in sandstone pores is limited, but the UK has good geological databases and understanding, and good assets in depleted gas fields. Planning allocation is needed.

Growth of bacteria can prevent the storage of hydrogen. North Sea depleted gas fields have greater salinities and hotter temperatures that inhibit bacterial growth reducing the risk of biological hydrogen loss and contamination. These criteria identify suitable candidates for hydrogen stores as 7 from 42 fields examined (Thaysen[19] 2021). Not all sites are suitable for hydrogen storage, so government planning is needed to protect those most suitable sites allocated to hydrogen stores.

Retaining hydrogen within a porous sandstone requires a no-flow caprock layer above the hydrogen. Calculations indicate that sealing caprocks sealing methane into known gasfields will provide increased caprock sealing capacity to hydrogen.

Using these criteria, and conventional geological appraisal, we can identify potential sites for hydrogen storage onshore in the UK, which could integrate with demonstration projects[20] such as SGN H100 Levenmouth project for 100% hydrogen where this storage sites lies within 10km.

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[15] ERM (9 Oct 2019) Dolphyn hydrogen Phase 1 final report. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/866375/Phase_1_-_ERM_-_Dolphyn.pdf

[16] Dogger Bank Wind Farm (2021) Equinor and SSE https://doggerbank.com/

[17] HyStorPor (2021) project website, University of Edinburgh https://blogs.ed.ac.uk/hystorpor/

[18] Heinemann N et al (2021) Enabling large-scale hydrogen storage in porous media https://pubs.rsc.org/en/content/articlepdf/2021/EE/D0EE03536J

19 Thaysen etal (2021) Microbial hydrogen consumption in hydrogen storage as a basis for site selection https://eartharxiv.org/repository/view/1799/

20 Heinemann et al (2018) Hydrogen storage in porous geological formations onshore play opportunities in the midland valley. Int J Hydrogen Energy, 43, 20861-20874.

Multiple sites exist onshore, which are potential local stores for hydrogen in porous sandstones.

Using criteria for hydrogen storage and data derived from CO_2 storage databases, Scafidi[21] et al (2021) have mapped the offshore North Sea and Irish Sea opportunities for interseasonal geological hydrogen storage in porous gasfields. A similar calculation was made by Mouli-Castillo[22] et al (2020), but using original gas-in-place volumes derived from field histories - hence are more risked working gas volumes. These both show similar results: that the UK and North Sea has an unrisked 6,900 TWh (2,660 TWh) of hydrogen storage working capacity, which could be some of the world's largest. The annual storage requirement for the UK is 150 TWh (Scafidi, ibid) which would require at least 1,000 large salt caverns. Alternatively, that capacity can be supplied from just one or two depleted gasfields in the southern North Sea - close to the projected Dogger Bank offshore windfarm. This could become a European hydrogen hub.

The next steps to build on this progress are field tests to drive the technology to TRL 9 and turn theoretical storage capacity estimates to matched storage capacity estimates. This can be achieved through the implementation of a pilot site for the storage of hydrogen in an underground porous reservoir, ensuring the UK takes a world leading position.

The UK has immense possibilities for geological storage of hydrogen offshore, close to some of the largest wind farms in the world. This could become a European hydrogen hub. Pilot test developments are urgently needed, to progress opportunities before rival European developers.

1.3 The engineering and commercial challenges associated with using hydrogen as a fuel, including production, storage, distribution and metrology, and how the Government could best address these

Storage interseasonally is a vital part of the hydrogen system. About 15% of annual energy use is held as stores by advanced European countries, but the UK holds just 1-2% and will become much less resilient to weather and more vulnerable to supply shocks as domestic methane production inevitably decreases, and hydrogen has to be manufactured and stored in anticipation of demand.

Geological storage of hydrogen can occur deep underground at local small sites around the UK. National-scale storage can occur at multiple salt caverns deep below Tees and Humber, Larne or Cheshire. These can provide many hundreds of skilled jobs in Northern, Scottish and Irish regions and offshore.

Scientific investigations show that immense geological storage of hydrogen can exist around the UK. Pilot development sites are needed to provide practical confirmation before 2025.

21 Scafidi et al (2021) quantitative assessment of the hydrogen storage capacity of the UK continental shelf. Int J Hydrogen Energy https://doi.org/10.1016/j.ijhydene.2020.12.106
22 Mouli Castillo et al (2021) Mapping geological hydrogen storage capacity and regional heating demands, Applied Energy https://doi.org/10.1016/j.apenergy.2020.116348

2 SCCS

Founded in 2005, Scottish Carbon Capture and Storage (SCCS) is a partnership of the British Geological Survey, Heriot-Watt University, the University of Aberdeen, the University of Edinburgh, the University of Glasgow, and the University of Strathclyde working together with universities across Scotland. Our current funding has been provided by the Scottish Government, Scottish Funding Council, Scottish Enterprise and several research projects on Carbon Capture and Storage and Hydrogen funded by Horizon 2020 and ACT-3 programmes of the European Union.

SCCS provides a single point of coordination for CCS research, from capture engineering and geoscience to social perceptions and environmental impact through to law and economics. This work supports CO_2 capture and storage (CCS) for deep emission reductions from energy-intensive process industries. When used with sustainable biomass (BECCS) or air capture (DACCS), CCS can provide "negative emissions" and it has a role in producing clean hydrogen for heat and transport.

3 About the authors

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