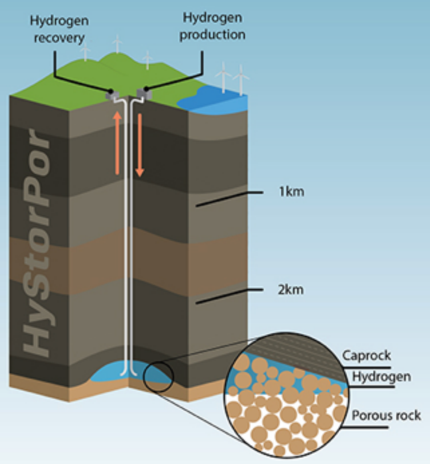

HyStorPor Shows Geological Storage of Hydrogen is Possible

Important Development for Deployment of Renewable Energy

September 2023

Introduction

The HyStorPor project has shown that subsurface geological storage of hydrogen is possible – an important development for the deployment of intermittent renewable energy.

The £1.4m three-and-a-half year project funded by the Engineering and Physical Sciences Research Council initiated a comprehensive, worldwide research effort on hydrogen storage, becoming a pioneer in systematically examining this field. Before HyStorPor there were limited research initiatives related to hydrogen storage. Being able to store large amounts of hydrogen is key to the energy transition and to the move to renewable sources. When demand for electricity is low, wind and solar power can be converted into hydrogen and stored, before being drawn down and turned back into energy when demand is high.

The team identified different challenges around storing hydrogen and then delved into different research questions.

How Much Hydrogen Storage Will Be Needed by 2050?

According to the estimates in our paper, https://doi.org/10.1016/j.apenergy.2020.116348, the hydrogen energy storage demand in the UK is put at ~77.9 terawatt-hour (TWh), which is approximately 25% of the total energy from natural gas used for domestic heating. The total estimated storage capacity of the gas fields included in our study is 2661.9 TWh. The study reveals that only a few offshore gas fields are required to store enough energy as hydrogen to balance the entire seasonal demand for UK domestic heating. It also demonstrates that, as so few fields are required, hydrogen storage will not compete for the subsurface space required for other low-carbon subsurface applications, such as carbon storage or compressed air energy storage. We also made global estimates, summarised in our paper: https://doi.org/10.1021/acsenergylett.1c00845.

The papers follow on from the first definitive review paper on the challenges of underground hydrogen storage (UHS) which we coordinated: https://doi.org/10.1039/D0EE03536J. This was supported by Katriona Edlmann's leading role in compiling the IEA TCP UHS storage technology monitoring report https://www.ieahydrogen.org/task/task-42-underground-hydrogen-storage/

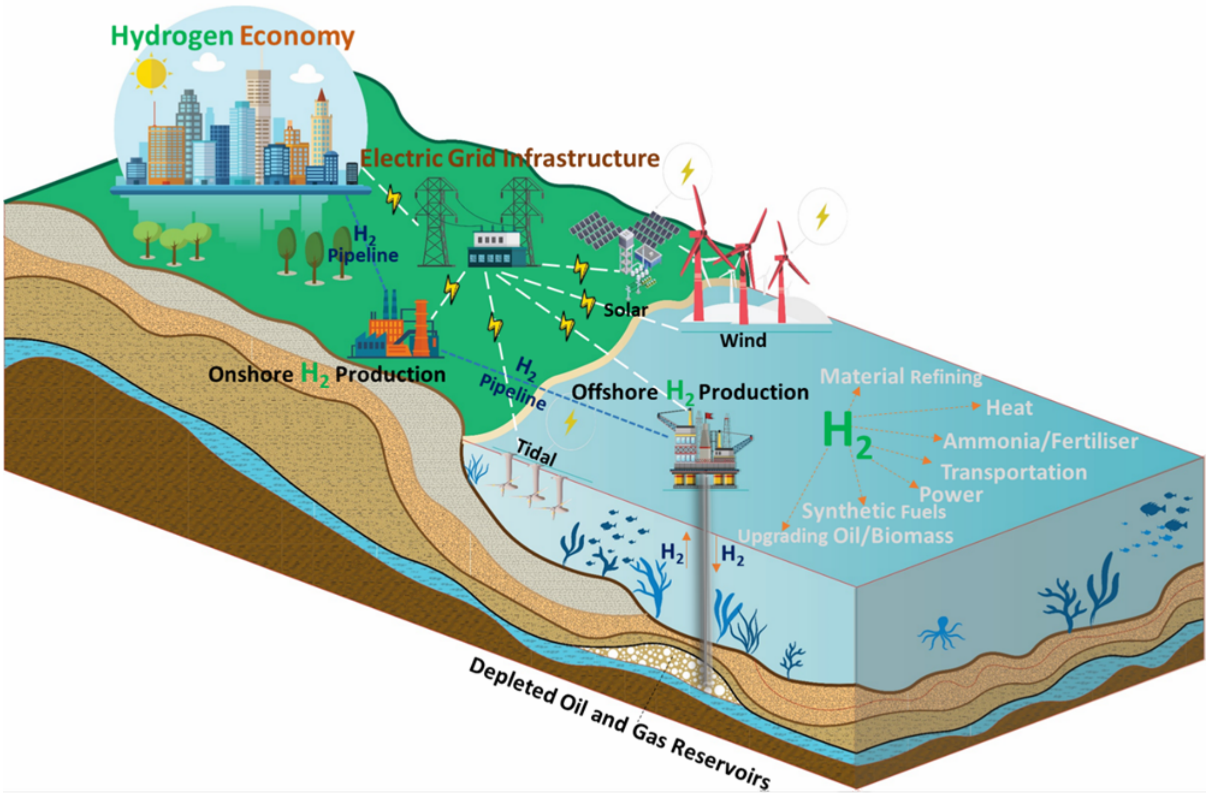

Figure 1 credit: Dr Aliakbar Hassanpouryouzband

Biological or Geochemical Reactions

This initial work was followed by research to identify if any biological or geochemical reactions would happen between the hydrogen, reservoir and cap rocks, existing fluids (brine, methane etc.) and well cements that could compromise the storage site in terms of reservoir integrity (security) or result in hydrogen loss or contamination. We found no issues:

- The caprock sealing of hydrogen using a newly developed column height conversion from methane to hydrogen is above 1. Therefore, a caprock can hold a higher column height of hydrogen than methane and this improves with depth. This is described in: https://doi.org/10.1021/acsenergylett.1c00845
- Diffusive losses are negligible (0.1%) so we will not lose hydrogen as it diffuses into the caprock. This is described in: https://doi.org/10.1016/j.ijhydene.2016.02.036
- Microbes thrive on hydrogen and can consume and contaminate the hydrogen; as long as we store hydrogen in reservoirs that are above 122 C, there are no issues as no microbes are active at that temperature. This is described in: https://doi.org/10.1016/j.rser.2021.111481. We then applied this as a site screening process to show that most North Sea reservoirs are at low risk of microbial consumption of hydrogen in this paper: https://doi.org/10.1016/j.fuel.2023.128852
- There is negligible geochemical reactivity between the stored hydrogen and the reservoir rocks and fluids for sites that are under 90 C. This is described in: https://doi.org/10.1021/acsenergylett.2c01024.
- We also looked at the geochemical integrity of well cements to check hydrogen would not degrade well cements – it does not, as described in: https://doi.org/10.1021/acs.estlett.3c00303

Flow Processes

We then researched flow processes which may impact hydrogen storage as we need to know where the hydrogen will migrate within a storage site and that it does not get trapped or stuck in pores during repeated injection and withdrawal cycles; this ensures that we can get out all the hydrogen we put in, to ensure excellent recovery efficiencies. There are a few positive points on this from our research:

- We have proof from Xray CT imaging experiments that hydrogen behaves as a wetting fluid, so will have a highly mobile flow and will not stick to the rock surfaces – it also means it flows in a similar manner to methane so our reservoir simulators and process understanding remains intact. This is described in: https://doi.org/10.1016/j.ijhydene.2022.10.153
- During injection and withdrawal cycles bubbles of hydrogen may be isolated and trapped within the residual water in the pores. So, we need to know if this happens? How much hydrogen can be residually trapped? And does it get worse with every injection and withdrawal cycle?. The answer is it does get trapped at a maximum of around 10% during the first withdrawal cycle, but the good news is that after that first loss it does not get worse with subsequent injection and withdrawal cycles – so essentially there will be an initial hydrogen loss which will have to be considered a capex. This is described in: https://doi.org/10.1016/j.ijhydene.2022.10.153
- We know the amount initially trapped depends on the geometry of pore network, which is dependant on the reservoir rock itself. Work is ongoing to establish these controls to help with site selection to minimise these initial trapping losses.
- We also established the first hydrogen relative permeability curves. This is described in https://doi.org/10.1029/2022GL099433
- We also looked at natural hydrogen seeps to understand leakage mechanisms. This is described in: https://doi.org/10.3390/hydrogen3040035

Dynamic Storage Capacity and Cushion Gas

Then we moved onto the reservoir simulations to look at cushion gas, well placement optimisation, influence of reservoir geometry and more.

- We demonstrated that the optimisation of cushion gas and working gas is essential in porous media. This is described in: https://doi.org/10.1016/j.ijhydene.2021.09.174
- We introduced a dynamic storage capacity estimation for seasonal hydrogen storage, taking into account cushion gas requirements and injection and production schedules. This is described in: https://doi.org/10.1016/j.ijhydene.2021.09.174
- We investigated what controls dynamic capacity, both geologically and scenario focused, for site selection purposes and technical optimisation strategies. This is described in: https://doi.org/10.3390/hydrogen3040035 and https://doi.org/10.1016/j.ijhydene.2021.09.174
- We considered hydrogen cushion gas as a capex as well as an emergency backup for upcoming energy crises, as a part of a zero-carbon national gas reserve. This is described in: https://doi.org/10.3390/hydrogen3040035

Public and Stakeholder Perception

We also ran a programme of research into the societal aspects of hydrogen storage. This is important because the effective deployment of hydrogen storage depends on support from people in sectors such as policy, industry and non-governmental organisations, as well as the wider public who will rely on the net-zero energy mix that hydrogen and its storage are embedded within. We found some clear action points that governments and developers of hydrogen storage can take to ensure hydrogen benefits society:

- Looking to lessons learned for successful public engagement from other uses of the subsurface, such as underground gas storage and carbon dioxide capture and storage (CCS), can help hydrogen storage developers and regulators to understand what stakeholders in host communities are likely to want to know. In particular, the experience of CCS shows the importance of communicating not only safety concerns, but also about who will benefit and how hydrogen storage can help the least well-off in society as part of the climate change response: https://doi.org/10.3389/fenrg.2022.869264;

- Social media platforms have an important role in shaping how the public think about new technologies like hydrogen. However, social media does not always lend itself to nuanced or complex issues like the role of hydrogen in the energy system. The most influential voices, and the pieces of scientific evidence that get amplified on social media, are not always the most rigorous or informed. Governments, hydrogen developers and researchers can engage with opinion-shapers and journalists to ensure that online dialogue is informed by a good understanding of how the geological storage of hydrogen fits into this debate;

- Stakeholders across a breadth of sectors do acknowledge the role that hydrogen and its storage can play in the net-zero energy mix, both in the UK and globally. However, there is a preference for transportation and industrial applications over domestic heat, and concern about the costs of hydrogen compared to electrification. It is thus important that the rationale for hydrogen and its storage is clearly articulated, and supported with feasible timelines for deployment;

- Linking hydrogen to CCS and to industrial clusters can help to build a case for how hydrogen can support a just transition and create green jobs for high-emitting regions under a just transition. However, association of hydrogen with fossil fuel industries can create suspicion among those who are not so familiar with the technology. A clear case for how hydrogen as part of regional clusters will first and foremost support emissions reduction and enable a long-term transition for high emitting regions and the people working within them is crucial: https://doi.org/10.1016/j.ijggc.2021.103288

Integration of Storage (and Hydrogen Transport) within the Wider Energy System

We compiled all of the findings described above, collated them into site selection criteria and mapped porous rock storage locations, capacities and storage integrity factors. This was then integrated with data on existing energy system assets, oil and gas infrastructure, renewable energy developments and wider considerations such as demand centres, land use, conservation areas etc. to produce the UK hydrogen storage database: www.edin.ac/uk-hydrogen-storage-database. We did some modelling of the thermodynamics of gas mixtures which is important for hydrogen storage and transport through pipelines: https://doi.org/10.3390/hydrogen3040035. We also looked at the integration of underground hydrogen storage with offshore wind which is described in: https://doi.org/10.1144/SP528-2022-40.

HyStorPor Published Papers

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