Hydrogen Storage in Aquifers and Depleted Gas Fields[a]

Introduction and conclusions

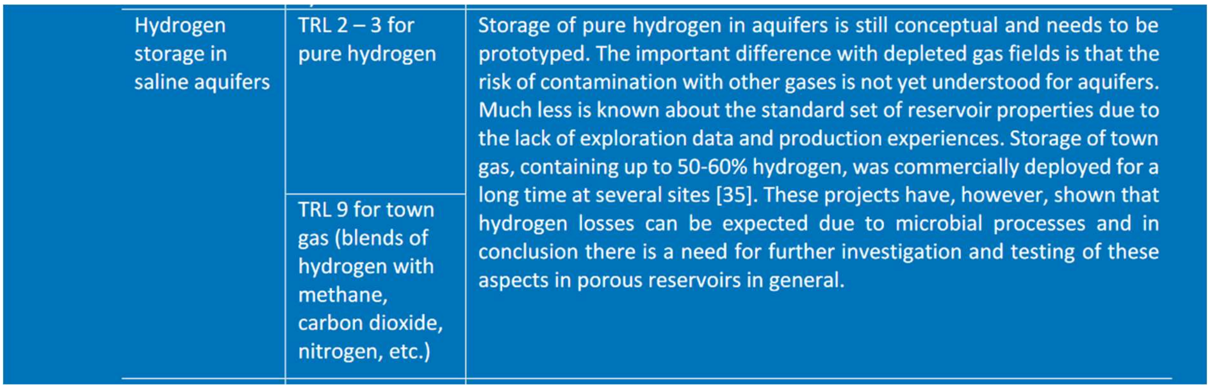
The possibility of storing hydrogen in aquifers was raised during the meeting on 8/9/23 when the Royal Society storage report was launched. According to a detailed IEA Technology Monitoring Report[i], hydrogen storage in aquifers is at TRL 2-3, and in depleted oil and gas fields is at TRL 3. The report therefore focussed on storage in solution-mined salt caverns, which is at TRL 9[b].

Using aquifers and/or depleted gas fields (and possibly oil fields depending on composition of residual hydrocarbons, which may react with hydrogen) would enable large-scale hydrogen storage in regions that are remote from salt deposits, which would provide important system benefits. There is therefore a compelling case for carrying out the additional work and trials that are needed to see if this is a real option. This note summarises some of the information about storage in aquifers and depleted gas fields that can be found in the literature, and information about the location of aquifers in Great Britain. As discussed in the IEA report, if aquifers and depleted gas fields are used the capital and operational cost of the surface facilities (compressors, coolers, dryers, purifiers) would be larger than if salt caverns are used (the H21 NE study of salt caverns that was used in the report found that surface facilities contribute well over half the capital cost). Site specific studies would be needed to determine and compare actual costs.

Some of the issues related to storing hydrogen in aquifers and depleted oil and gas fields are also relevant for the possibility of using them to store compressed air.

Issues

The IEA's report's summary of conclusions on storage in aquifers is:



Hydrogen storage in saline aquifers	TRL 2 – 3 for pure hydrogen	Storage of pure hydrogen in aquifers is still conceptual and needs to be prototyped. The important difference with depleted gas fields is that the risk of contamination with other gases is not yet understood for aquifers. Much less is known about the standard set of reservoir properties due to the lack of exploration data and production experiences. Storage of town gas, containing up to 50-60% hydrogen, was commercially deployed for a long time at several sites [35]. These projects have, however, shown that hydrogen losses can be expected due to microbial processes and in conclusion there is a need for further investigation and testing of these aspects in porous reservoirs in general.
	TRL 9 for town gas (blends of hydrogen with methane, carbon dioxide, nitrogen, etc.)	

While for gas fields it is:

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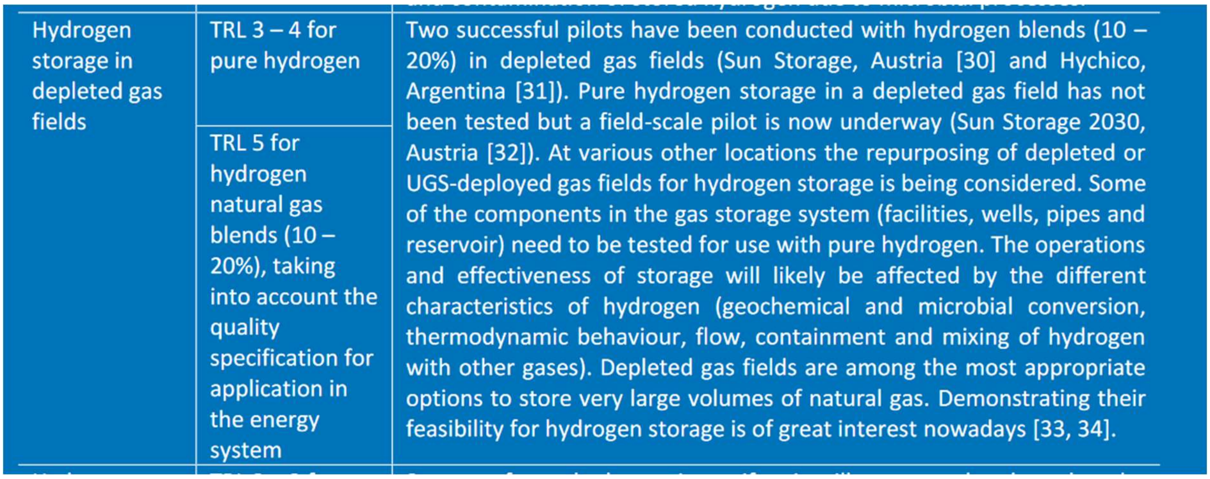
[a] This note, which was written by Chris Llewellyn Smith, incorporates comments and inputs from Stuart Haszeldine, Ed Hough,Andy Woods and Mike Muskett

[b] The IEA's definition of TRLs goes up to 11: TRL 2 - Application formulated, TRL3 - Concept Needs Validation, TRL 4 – Early Prototype, … TRL 9 - Commercial operation in relevant environment. The IEA report implies that hydrogen storage in salt caverns is rated at 9, rather than 10 or 11, because its commercial use (in large caverns in Texas and smaller caverns on Teesside) was 'for static or low-cyclic feedstock applications', but caverns used for the long-term storage described in the report will be cycled very slowly.



Hydrogen storage in depleted gas fields	TRL 3 – 4 for pure hydrogen TRL 5 for hydrogen natural gas blends (10 – 20%), taking into account the quality specification for application in the energy system	Two successful pilots have been conducted with hydrogen blends (10 – 20%) in depleted gas fields (Sun Storage, Austria [30] and Hychico, Argentina [31]). Pure hydrogen storage in a depleted gas field has not been tested but a field-scale pilot is now underway (Sun Storage 2030, Austria [32]). At various other locations the repurposing of depleted or UGS-deployed gas fields for hydrogen storage is being considered. Some of the components in the gas storage system (facilities, wells, pipes and reservoir) need to be tested for use with pure hydrogen. The operations and effectiveness of storage will likely be affected by the different characteristics of hydrogen (geochemical and microbial conversion, thermodynamic behaviour, flow, containment and mixing of hydrogen with other gases). Depleted gas fields are among the most appropriate options to store very large volumes of natural gas. Demonstrating their feasibility for hydrogen storage is of great interest nowadays [33, 34].

The brief summary above[c] does not do justice to the range and depth of the report, which is supported by 287 refences. Other issues that it discusses include: the possibility of hydrogen leakage from 'decommissioned or unmapped boreholes and wells that have not been properly completed or abandoned'; the potential for losses in the aquifer (caused by capillary trapping and/or hysteresis effects between injection and extraction); flow rates in porous rocks: the influence of cushion gas (porous rocks will typically be at greater depth than salt caverns so more cushion gas will be needed: the cost could be reduced by using alternative cushion gasses, but this would increase the requirement for post-storage processing); safety; and costs.

Table 7.1 in the IEA report compares the capital and operational costs of storing hydrogen in salt caverns and porous rocks. The subsurface capital costs, which are given per working gas capacity, are about 40% lower in porous rocks (within a large range of uncertainty). The surface capital costs, which are given per the maximum withdrawal flow rate capacity rate (they also depend on the maximum injection rate which must be assumed to be proportional to the maximum extraction rate in the model that was uses used), are a factor of more than three times higher for porous rocks than salt caverns (again with a large uncertainty). This is because in the latter case there is a greater need for drying and purification of the hydrogen to meet the demands of the transmission system, and more compression power may be needed, depending on the depth. The variable and operation costs are also higher for storage in porous rocks. Actual costs would be site specific and would depend on the injection and withdrawal rates, and if a depleted gas field were used on whatever modifications of the existing piping and valves would be needed to cope with possible embrittlement caused by hydrogen and the larger possibility of leakage.

Recent UK studies

Recent, generally upbeat, studies include:

- The EPSRC funded HyStorPor project, which has examined biological and chemical reactions, flow processes, dynamic storage and cushion gas, has concluded that 'subsurface geological storage of hydrogen is possible'[ii]

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[c] On 27/4/23 (after the IEA's report was written), Underground Sun Storage opened the world's first facility that stores pure hydrogen in a depleted gas field, at Gampern, Upper Austria. According to Underground Sun Storage (https://www.uss-2030.at/en/) *solar energy is converted into green hydrogen by water electrolysis and stored in pure form in an underground natural gas reservoir. The scale of the storage corresponds to the summer surplus of about 1,000 photovoltaic systems on family homes.*

- The British Geological Survey has performed laboratory experiments that targeted the two principal aquifers in the UK (shown in the map below) that found *no major changes to rock structure or composition following exposure to hydrogen at elevated temperatures and pressure*[iii].
- Amid et al.[iv] reach the strong conclusion that *There appears to be no insurmountable technical barrier to the storage of hydrogen in a depleted gas reservoir.*
- Heinmann et al.[v] [vi] have studied the role of cushion gas for injection and production in hydrogen storage in saline aquifers.

Potential Storage Capacity

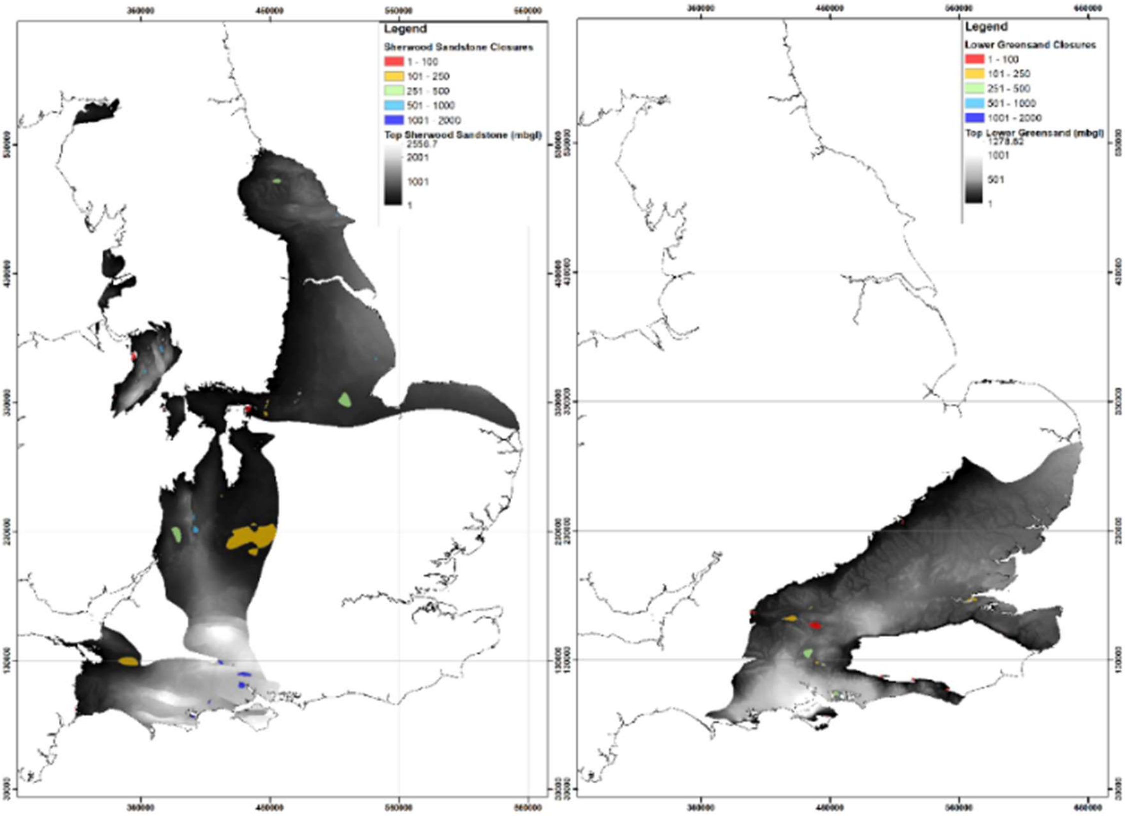
Sambo et al. have published a comprehensive review of potential and operating underground hydrogen storage facilities and locations world-wide[vii]. In the UK:

Gas and oil fields

Maps of the UK's offshore and (almost all very small) onshore oil and gas field can be found on the web[viii]. The potential for storing hydrogen in depleted gas fields in the North Sea far exceeds the potential need[ix] [x].

Aquifers

The Triassic Sherwood Sandstone and the Cretaceous Lower Greensand aquifers, whose locations are shown in the map below, 'have favourable properties' for storing hydrogen' according to the BGS[iii]. However, it seems that no estimates of the potential storage capacity are available.



Assessment of areas that may be suitable for hydrogen stoge in porous rocks[iii].

In Scotland

A detailed study has been made of porous geological formations in the midland valley[xi], but it seems that no estimates of the potential hydrogen storage capacity are available. See also Szebasztian Csernik-Tihn et al.[xii] for a dicussion of opportunities for hydrogen storage in Scotland.

Conclusions

Storage in aquifers (which is at TRL 2-3) and depleted gas fields (which is at TRL3) have the potential to allow underground storage of hydrogen to be distributed across the UK in areas that are distant from the potential sites for salt-caverns. This would provide important system benefits. There is therefore a compelling case for carrying out the additional work and trials that are needed to see if they are real options.

References

[i] Van Gessel & Hajibeygi, 2023 https://d2k0ddhflgrk1i.cloudfront.net/Websections/H2%20platform/Task42_UHS_TechnologyMonitoringReport.pdf)

[ii] Hystorpor https://blogs.ed.ac.uk/hystorpor/2023/09/19/hystorpor-final-results-brochure/

[iii] BGS, 2023 https://idric.org/wp-content/uploads/7.4-final-report.pdf

[iv] Amid et al. International Journal International Journal of Hydrogen Energy 41 (2016) 5548

[v] Heinmann et al. International Journal of Hydrogen Energy 46 (2021) 9284

[vi] Heinmann et al. Hydrogen 2022, 3*(*4), 550; https://doi.org/10.3390/hydrogen3040035

[vii] Sambo et al, 2022. International Journal International Journal of Hydrogen Energy 47 (2022) 22840

[viii] https://nstauthority.co.uk/data-centre/interactive-maps-and-tools/

[ix] Mouli-Castillo et al. 2021. Applied Energy 283 (2021) 116348

[x] Scafali et al. 2021. International Journal International Journal of Hydrogen Energy 46 (2021) 8629

[xi] Heinemann et al. 2018. International Journal of Hydrogen Energy 43 (2018) 20861

[xii] Szebasztian Csernik-Tihn et al. https://www.climatexchange.org.uk/media/5877/cxc-hydrogen-as-storage-medium-august-2023.pdf