GEOSCIENCE AND THE HYDROGEN ECONOMY

A policy and technology explainer from the Geological Society

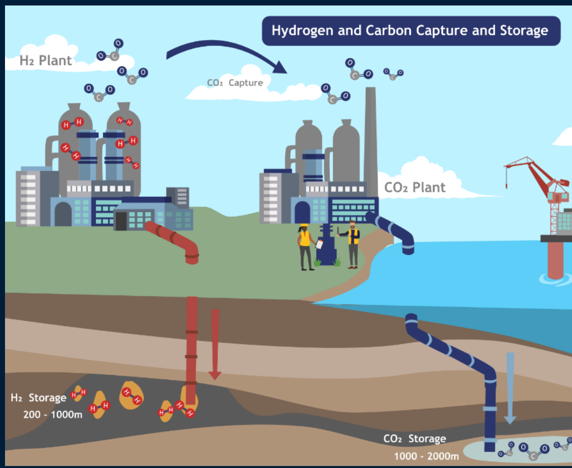
Hydrogen and decarbonisation

The decarbonisation of electricity production, industry, transport and heating to meet both UK and international climate change targets is a major challenge, and geoscience has an important role to play. Geological skills and knowledge are particularly relevant to the use of hydrogen, which offers an attractive alternative fuel to hydrocarbons, with the potential to reduce emissions from heavy industry (such as steel manufacturing), domestic heating, and transportation including freight.

The UK Government recognises the importance of hydrogen in achieving Net-Zero, and acknowledges its pivotal role in its Energy White Paper (November 2020). In particular, the Ten Point Plan (December 2020) sets out an intention to ensure there is capacity to generate 5GW of low-carbon energy from hydrogen by 2030, as well as developing a town that is heated entirely by hydrogen by the end of the decade.

Through the UKRI Industrial Decarbonisation Challenge Fund (March 2021), the Government has directed £171 million to research and development that supports the UK's drive for clean growth through technologies such as hydrogen fuel switching and carbon capture and storage.

Hydrogen is also integral to two of the four recommendations made by the Committee on Climate Change's 6th Carbon Budget (December 2020), which advises ministers on the volume of greenhouse gases the UK can emit under the Climate Change Act (2008).



Carbon capture and storage (CCS) separates carbon dioxide (CO_2) from industrial sources, transports it to a suitable storage location, and isolates it from the atmosphere through long-term storage. The CO_2 is stored in the subsurface within geological formations – deeper than 800m – that hold saline water (brine) or that previously held oil and gas, but have been depleted by production.

In the near-term, it is likely that CCS will be needed to store any CO_2 produced when hydrogen is derived through methane reforming. The ability to abate any CO_2 emissions generated enables hydrogen produced by methane reformation to support the transition to a low-carbon economy.

Many of the same geological skills, knowledge, data and infrastructure that have been developed within the oil and gas industry since the industrial revolution will be at the heart of finding, modelling, assessing and utilising geological storage sites for CO_2.

Hydrogen is an important part of the UK's decarbonisation strategy because it can deliver or store large amounts of energy. It can be used in fuel cells to generate electricity and it can be combusted to provide domestic and industrial heat. Whereas carbon-based fuels release carbon dioxide into the atmosphere when they are burned (contributing to anthropogenic global warming), hydrogen produces water and some nitrogen oxides. Hydrogen can replace carbon-based fuels (e.g. oil, gas and coal) to decarbonise parts of our economy such as transport, power generation, chemical production, refineries, and heat. In transport applications, hydrogen is currently best suited to road and rail. However, technological developments could mean it could be used in aviation and shipping commercially in the future.

Currently, most of the hydrogen used in industry is derived from coal or natural gas, and its production generates significant CO_2 emissions. To produce low-carbon hydrogen, we need to switch to alternative methods of production, either electrolysis powered by renewable energy (sometimes called green hydrogen) or methane reforming with carbon capture and storage (sometimes called blue hydrogen). Hydrogen produced by either low-carbon means could support the UK's transition to a decarbonised economy.

GEOSCIENCE AND THE HYDROGEN ECONOMY

Sources of hydrogen

Hydrogen can occur naturally as a pure gas. However, it bonds easily with other atoms, so is most commonly found within water (H_2O) and methane (CH_4) molecules.
There are two main ways to extract hydrogen from these sources: electrolysis – using electricity to separate the hydrogen and oxygen ions in water – and methane reforming, in which steam and methane and sometimes oxygen are reacted at high temperatures and pressures (Figure 1). Using renewable power for electrolysis offers a simple route to low-emissions hydrogen. However, in 2019, three quarters of global hydrogen production was by methane reformation, accounting for 6% of global methane use, while only 0.1% was produced by electrolysis.

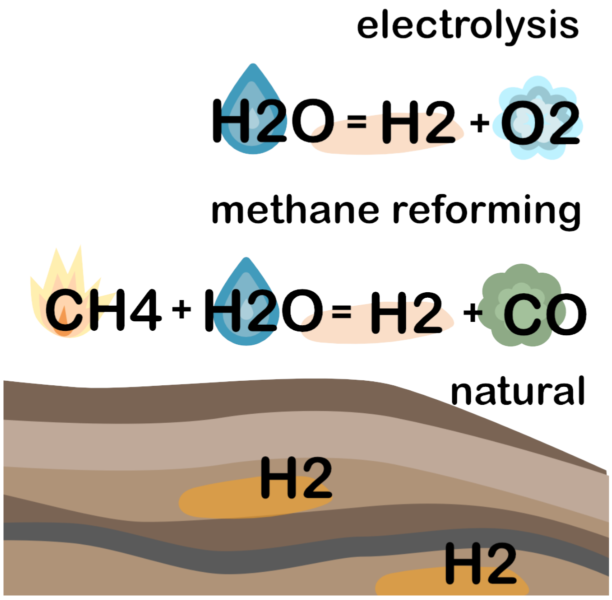


Figure 1 - Sources of hydrogen.
Hydrogen is a naturally occurring gas, but is also found bonded to other atoms in water and methane. It is separated from these molecules by electrolysis or methane reforming.
Note: this diagram illustrates simplified chemical reactions.

The need for carbon capture and storage

A low-emissions hydrogen economy will most likely require a mix of both routes to hydrogen production, depending on the availability and cost of renewable power or methane. The low cost of methane and its widespread availability, when compared to the current availability of renewable electricity, means that carbon capture and storage (CCS) will be needed to deliver a decarbonised hydrogen energy system until sufficient abundant and competitive renewable electricity sources are available. A move towards hydrogen generation using only renewable sources of energy will require abundant and competitive renewable electricity sources.

As more renewable energy sources come online over the coming decades, their use in hydrogen generation will comprise a greater share of the sector. Nevertheless, both technologies will be needed as a stepping stone towards a fully decarbonised hydrogen economy.

The need to store hydrogen

Storing hydrogen underground is critically important for decarbonisation because it offers storage of energy at very large scales and over long periods of time at reasonable cost. Until now, energy storage has been provided by hydrocarbon fuels but as we transition away from these in favour of energy from renewable sources, such as wind and the sun, we must find different ways to manage the mismatch between the availability of energy and the demand for electricity (Figure 2).

This mismatch arises for two reasons:

- Renewable energy resources such as wind, solar, wave and tidal are all intermittent – even when combined
- Demand for electricity is variable, and this variability is not in line with the variability of renewable electricity production

The mismatch between supply and demand occurs at many different timescales ranging from a few seconds to several years, and will require a combination of energy storage options at a number of scales. We are likely to need several TWh of grid-scale energy storage to decarbonise the UK's energy system, which can be delivered through the underground storage of hydrogen.

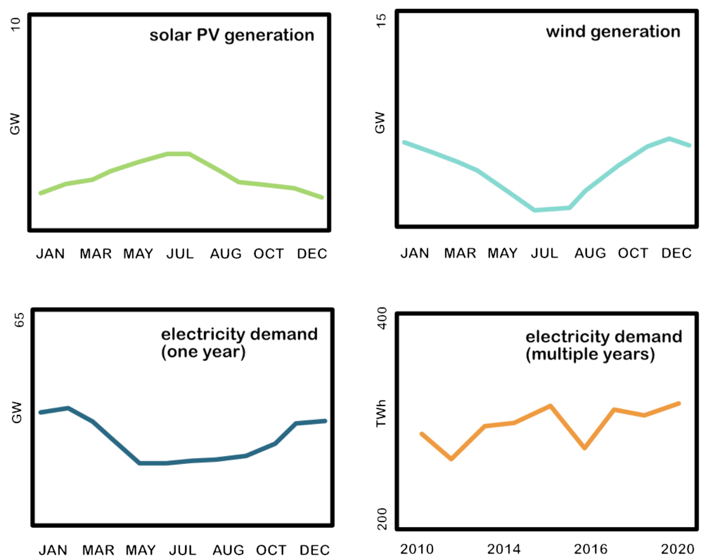


Figure 2 – Why store hydrogen?
Renewable energy varies both in-phase (wind) and out of phase (solar) with national energy demand. Surplus energy can be stored as hydrogen in the subsurface and used when demand necessitates.

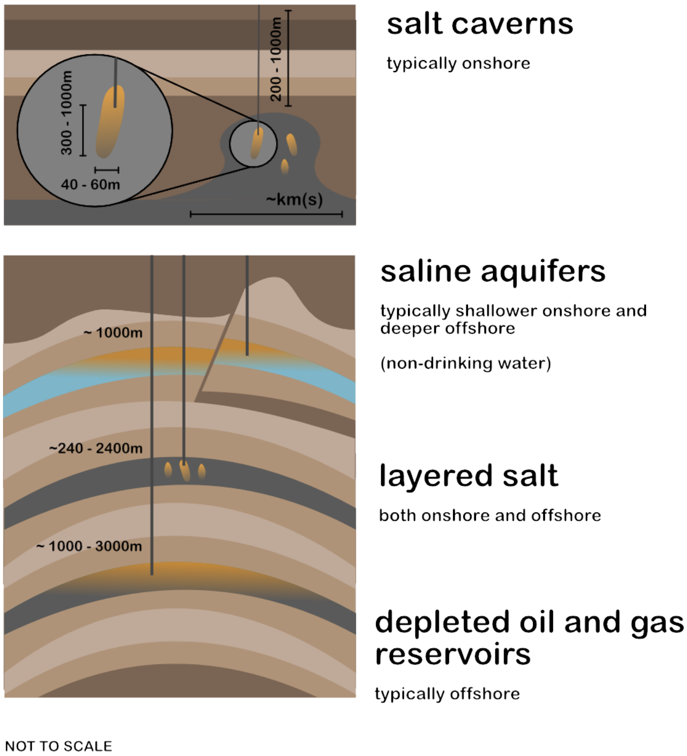


Figure 3 – Where can hydrogen be stored?
Hydrogen can be stored in the pore space within rocks, much like water can be stored within in a sponge. In contrast, salt caverns offer large open storage voids and are more commercially viable for storing hydrogen.

How and where can hydrogen be stored?

Hydrogen can be stored in rocks where there are large open voids (e.g. salt caverns) or in porous rock formations (such as sandstone aquifers or re-used oil and gas reservoirs) (Figure 3). Currently, solution-mined caverns (which have been used for many decades for gas storage) are the only commercially viable option. However, there is research into the viability of storage in reservoirs and aquifers, which will help enable hydrogen use across the UK. There is an abundance of depleted offshore oil and gas reservoirs in the UK, as well as a wealth of data on their properties and characteristics due to the legacy of the North Sea oil and gas industry. These reservoirs could be used for large scale storage if converted to enable the storage of hydrogen.

Hydrogen storage has been used by the petrochemical industry since the 1960s, with existing storage sites in both the UK (27 sites in 2009 located in Cheshire, Stafford, Yorkshire and on Teesside) and the USA – most in subsurface salt (halite) caverns. The cost of subsurface hydrogen storage is less than half than that of over ground storage, however subsurface storage is constrained by the frequency and distribution of available rock formations with suitable physical properties.

GEOLOGICAL SOURCES OF HYDROGEN

Naturally occurring hydrogen has two known geological sources:

the oxidation of iron-bearing minerals by water and the breakdown of water as a consequence of radioactive decay (radiolysis).

Geological conditions favourable to hydrogen production are commonly found in low-silica igneous rocks, iron-rich continental rocks, and in uranium-rich rocks.

Naturally occurring hydrogen deposits are found in geological settings that are not typically drilled or monitored for gases at present due to the relatively recent interest in hydrogen as a commodity.

Consequently, the global geological abundance is not yet accurately known.

Hydrogen storage: the current state of play

The major benefit of hydrogen is its flexibility. It can be used both as a replacement fuel in transport but also as a battery to store energy produced by other sources (such as renewable energy). Both require substantial storage capacity, and there are a number of different initiatives exploring at-scale production and storage of hydrogen linked to CCS:

- **HyNet North West**

A project that focuses on the production of hydrogen from natural gas in North West England. It includes the development of a new hydrogen pipeline and the creation of the UK's first CCS infrastructure. The area's concentration of industry, existing technical skill base and unique geology means the region is a good opportunity for a project of this kind. The new infrastructure built by HyNet is readily extendable beyond the initial project, and provides a replicable model for similar programmes across the UK. HyNet aims to be the UK's first net-zero carbon industrial cluster with the aim of saving 100m tonnes of CO_2 per year.

- **ZeroCarbonHumber**

Based in the Humber Estuary and surrounding region, this project is located in the most carbon intensive industrial cluster in the country: 12.4 million tonnes of CO_2 are emitted here each year. The project proposes production of low carbon hydrogen at scale at the H_2H Saltend site among others. In addition to enabling a hydrogen economy, the project will also develop large-scale carbon capture across the region and bioenergy with carbon capture and storage to create the world's first negative emissions power station.

- **The Acorn Project**

This project has a dual goal to generate hydrogen from North Sea methane (Acorn Hydrogen), and then to capture and store any carbon emissions in geological formations offshore (Acorn CCS). Acorn's strategic location near the existing oil and gas industry in the northeast of Scotland offers access to legacy infrastructure, existing skilled geoscientists and industrial knowledge, as well as prime geological storage for CO_2 – 30% of the storage is located within 50km of the Acorn pipeline. Acorn Hydrogen will initially consist of a 200 MW hydrogen production plant, capable of generating ~1.6TWh of hydrogen per year from 2025, working towards to Scotland's potential to produce 121 TWh of hydrogen by 2050. Acorn CCS aims to eliminate 300,000 tonnes of existing CO_2 emissions from the St Fergus gas terminal by 2024, using 420km of existing offshore pipeline to enable CCS in the North Sea.

Figure 4 – The Acorn Project Infrastructure Map
The St Fergus gas terminal in North East Scotland, where the Acorn Project is being built, is the first landing point for around a third of all the natural gas used across the UK. The Acorn Project can take North Sea natural gas and reform it into clean-burning hydrogen, with the CO_2 emissions created from generating the hydrogen safely removed and stored.

Geoscience skills for a hydrogen economy

In order to safely and securely store hydrogen in the subsurface, geoscientists will need to study the properties and characteristics of proposed storage rocks. It is important that any storage site is well characterised, so that geoscientists can accurately predict how the rocks will behave when pores or caverns are filled with hydrogen. Scientists will especially need to predict the effects that rapid pressure cycling will have on site stability over very long periods of operation. Understanding how fluids behave in the subsurface is something geoscientists have extensive experience in from the study of resources such as groundwater and oil and gas, which exist naturally in underground in rocks. There are many skills, datasets, and lessons learned from the UK's oil and gas industry that will be essential for the development of both hydrogen and carbon dioxide storage underground.

There is also still much to be learned about the occurrence, abundance, and extraction potential of natural hydrogen. As was the case with the oil and gas industry, geoscientists will be central to advances in locating and extracting natural hydrogen.

About The Geological Society

The Geological Society of London is the UK's national society for geoscience, providing support to over 12,000 members in the UK and overseas. Founded in 1807, we are the oldest geological society in the world. We provide professional support to our members, as well as impartial scientific information and evidence to policy makers and the public.

Geoscience and policy

As the national forum for the debate and development of cutting-edge Earth science, the Geological Society has a special responsibility to communicate this science and its importance to society, the Government, the media, other scientific communities and the general public.

Our Policy Team engages with Parliament, Government, industry and academia to fulfil this purpose. Find out more at www.geolsoc.org.uk/decarbonisation.

This document has been reviewed for content and scientific accuracy by our Decarbonisation Working Group.