HyStorPor Project
Hydrogen Storage in Porous Rocks

Katriona Edlmann, Niklas Heinemann,
Stuart Haszeldine, Mark Wilkinson, Ian Butler, Chris McDermott,
Eike Thaysen, Aliakbar Hassanpouryouzband,
Julien Mouli-Castillo, Jonathan Scafidi, John Low (UoE)

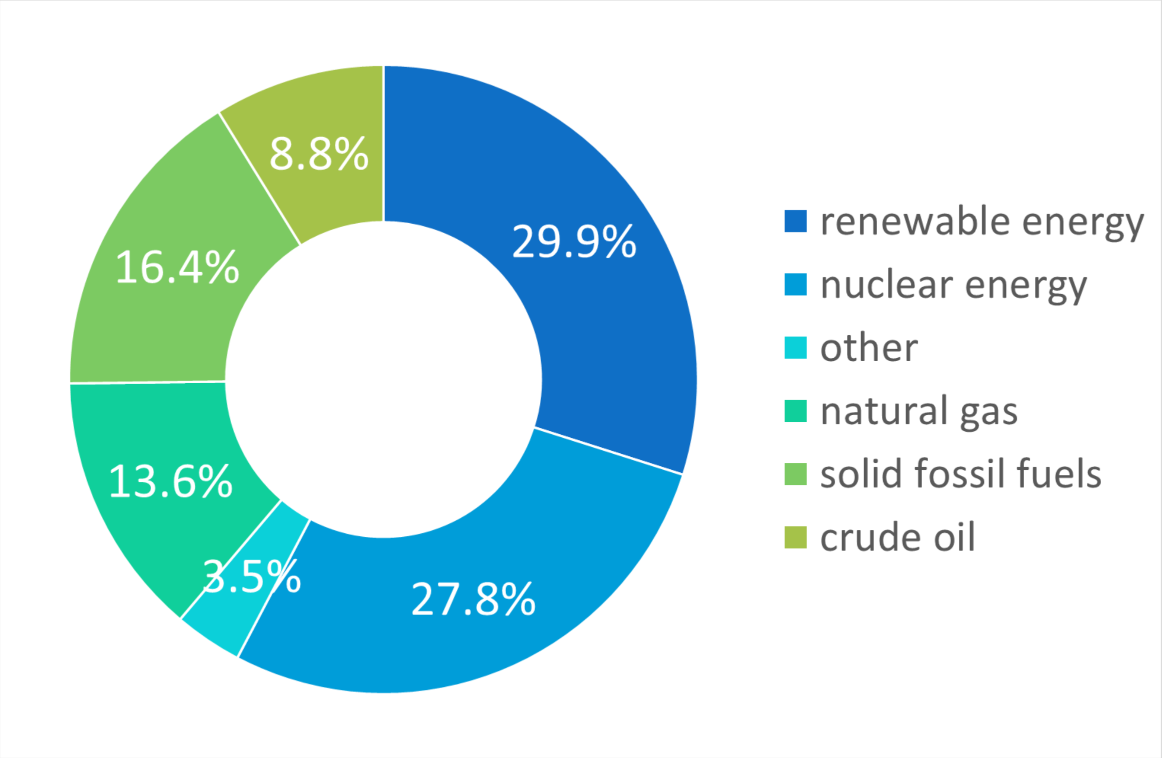
Leslie Mabon (SAMS), Romain Viguier (SCCS),
Gillian Pickup (HW), Sam Krevor (Imperial)

EPSRC
EP/S027815/1

HyStorPor

Energy sources in the EU

Production of primary energy, EU-28, 2017
(% of total based on tonnes of oil equivalent)



Progress had been made in reducing emissions from electricity by **increased renewables**

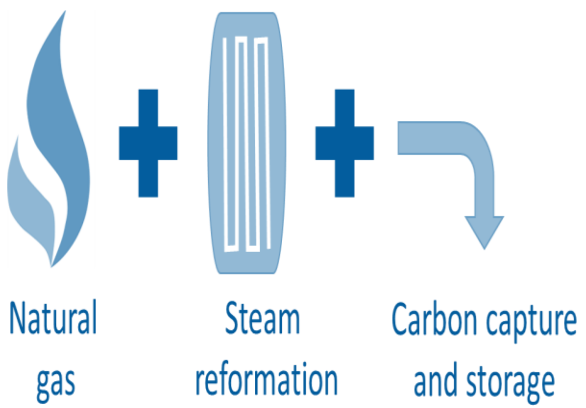
Only **57.7% of EU energy sources can be considered zero carbon**

Hydrogen can replace natural gas, crude oil and solid fuels for heat and power generation and decarbonising transport to decarbonise the remaining 42.3% energy sources

Hydrogen can increase uptake of renewables by providing energy storage, balancing supply and demand

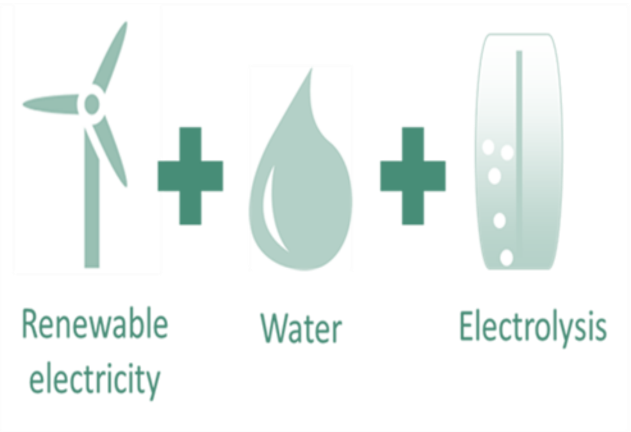
Data source: https://ec.europa.eu/eurostat

Hydrogen production



Blue hydrogen

- Methane steam reformation.
- 96% hydrogen currently produced this way.
- **7kg CO_2 for 1kg hydrogen.**
- Requires **Carbon Capture and Storage** (CCS) to be low-carbon blue hydrogen.

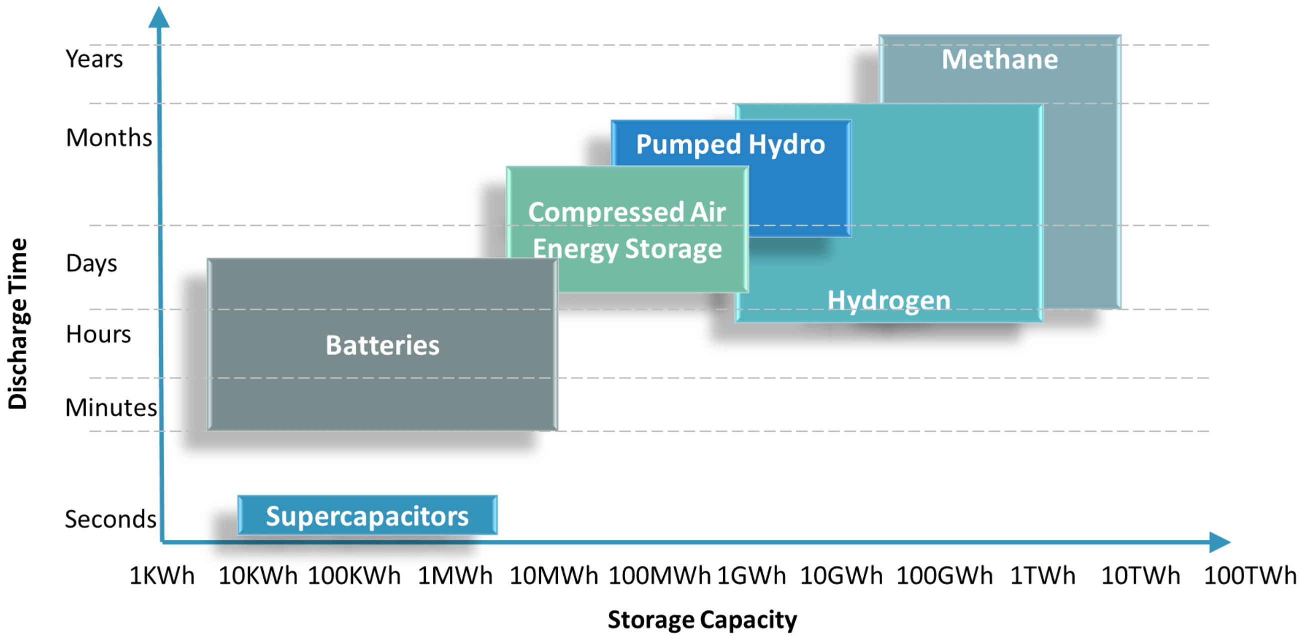


Green hydrogen

- Electrolysis and renewable electricity.
- Currently 70-80% energy efficiency.
- 1kg hydrogen (40kWh/kg) requires 50-55 kWh electricity.
- ~30% new renewable electricity for hydrogen = sufficient in green hydrogen by 2050.

Renewable to hydrogen data courtesy of Julien Mouli-Castillo, University of Edinburgh

Hydrogen storage options



2,000,000 km 12" diameter pipe @70bar and 25C

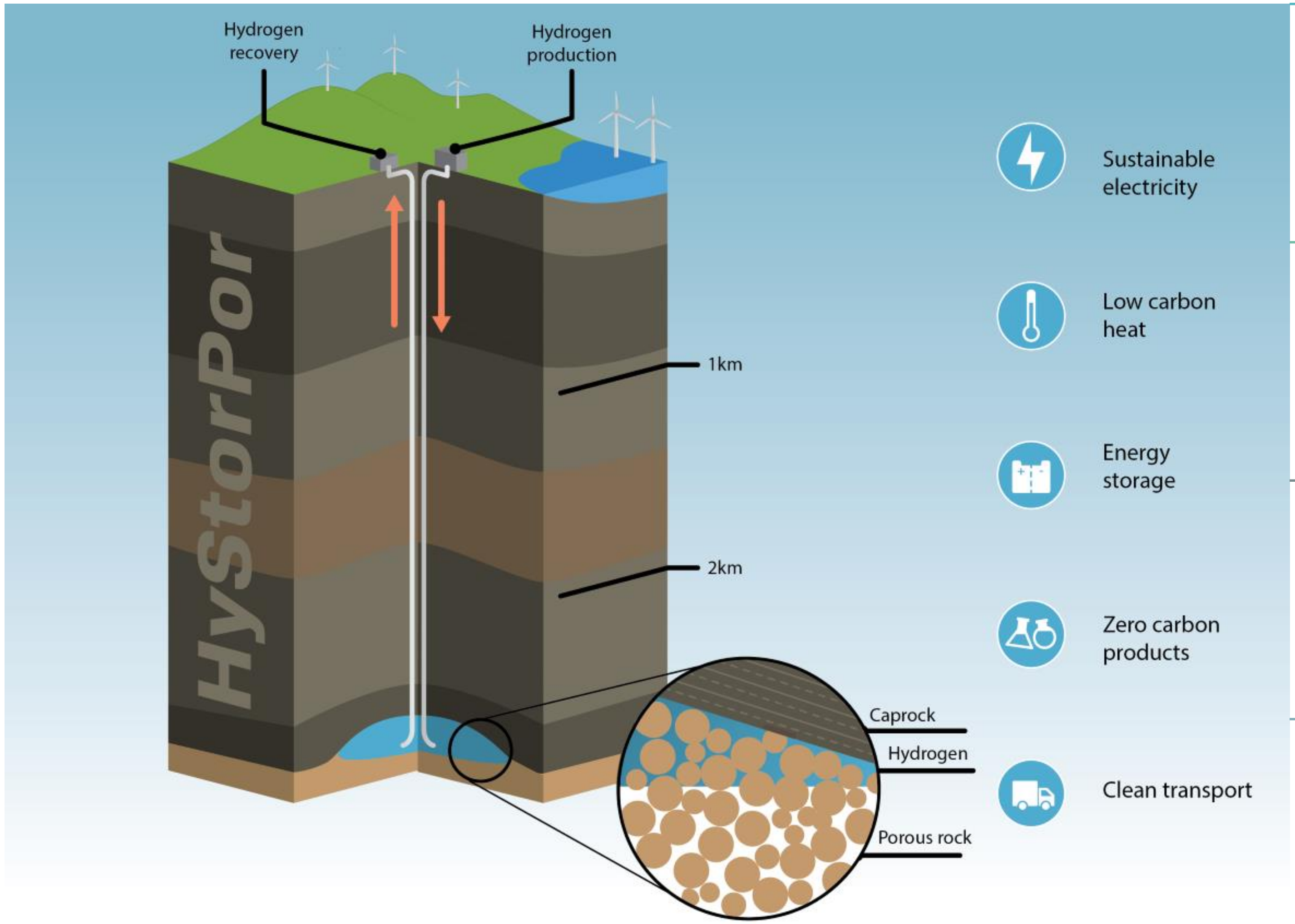
40,000 Olympic swimming pool sized tanks @100bar / 25C

230 salt caverns

~1 large offshore field (Rough)

[1] Data courtesy of Julien Mouli-Castillo, University of Edinburgh: Based on 2016 Scotland annual domestic gas demand (27,459 GWh), Using a Hydrogen mass equivalent conversion. Assuming no base load supply.

HyStorPor Project Goals



To identify if **chemical and microbial reactions** between the rock, fluids and hydrogen could compromise storage *(Work Package 1)*

To determine what **flow processes** will apply to hydrogen migration and trapping through the brine and gas filled reservoir and caprocks during injection and withdrawal *(Work Package 2)*

Undertake **reservoir simulations to estimate what volumes of hydrogen can be stored and recovered** from storage sites of varying scales *(Work Package 3)*

To **clarify what citizens and opinion shapers think about hydrogen storage** *(Work Package 4)*

Work Package 1: Chemical (and biological) reactions in the reservoir and seal

Review key microbial processes and impact on the reservoir

Reaction of hydrogen with rock and brine under reservoir temp and pressure

Geochemical modelling & Benchmarking standard geochemical software

Microbial Reactions involving hydrogen: Learnings from town gas / nuclear waste industry

Hydrogenotrophic methanogenesis (archaea that grow on H_2 and CO_2 = methane)
$\frac{1}{4}HCO_3^- + H_2 + \frac{1}{4}H^+ \rightarrow \frac{1}{4}CH_4 + \frac{3}{4}H_2O$

Iron(III) reduction by chemotrophic bacteria that oxidise dissolved ferrous iron
$2FeOOH + H_2 + 4H^+ \rightarrow 2Fe^{2+} + 4H_2O$

Sulphur / sulphate reduction by bacteria to form hydrogen sulphide
$H_2 + S \rightarrow H_2S$

Acetogenesis (anaerobic bacteria reduce CO2 to acetate using H)
$\frac{1}{2}HCO_3^- + H_2 + \frac{1}{4}H^+ \rightarrow \frac{1}{4}CH3COO^- + 2H_2O$

Aerobic hydrogen oxidation (Knallgas bacteria oxidise H with O2)
$H2 + \frac{1}{2}O2 \rightarrow H2O$

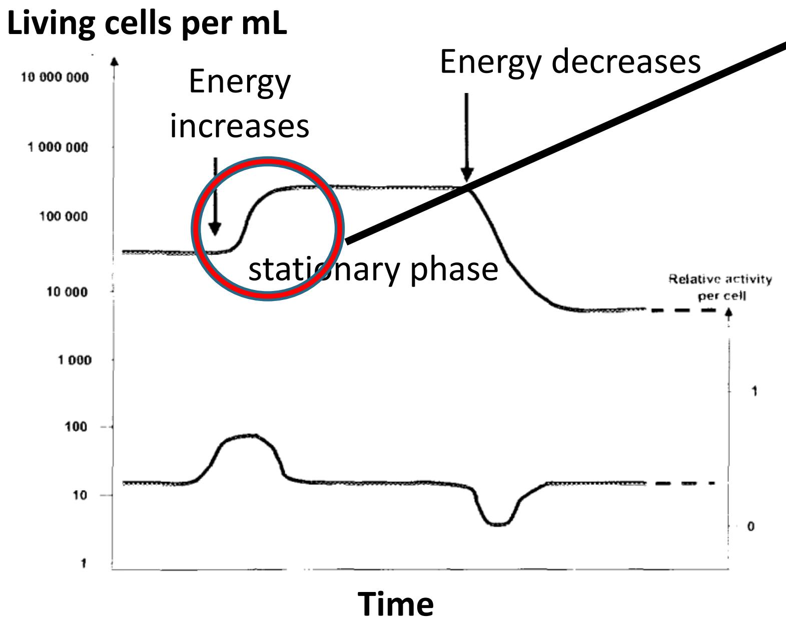
Dehalorespiration by bacteria using halogenated compounds
Halogenated compounds + H_2 → dehalogenated compounds + 2HCl

Fumarate Respiration by eukaryotic organisms
H_2 + fumarate → succinate

Denitrification (reduction of nitrate) by hydrogen oxidising bacteria
$\frac{2}{5}NO_3^- + H_2 + \frac{2}{5}H^+ \rightarrow \frac{1}{5}N_2 + 1\frac{1}{5}H_2O$

Results of biological reactions of hydrogen: Review of studies for model input

Major H_2-consuming processes in the subsurface where data are available
Methanogenesis
Sulphate reduction
Acetogenesis



H_2 consumption rates at excess H_2
(2-180 µM H_2 d^{-1} dm^{-3} aquifer brine)

Microbial growth per mole H_2 consumed
(0.2-1 g protein $mole^{-1}$)

Protein content of cells
(0.3-1*10^{-12} g protein $cell^{-1}$)

Daily protein production
(0.6-1*10^{-5} g protein day^{-1})

Daily cell increase
(6-30*10^{6} cells day^{-1})

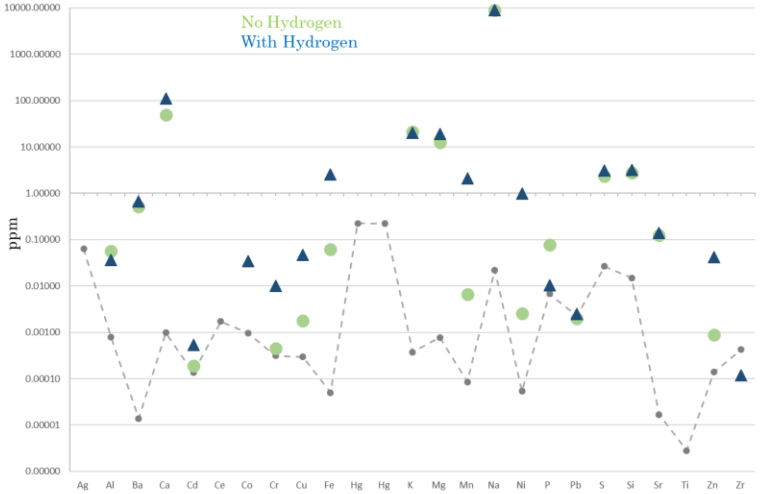
Cell volume
(0.9-1.8 µm^{3})

Volume increase in aquifer
(0.02-0.4 mm^{3} bacterial biomass d^{-1} dm^{-3} aquifer brine)

OpenGeoSys model

Ranges for model:
Temperature: 20-100°C
Pressure: 1-50 MPa
Salinity: ~0-120 g L^{-1} NaCl

Preliminary results of reactions of hydrogen with rock and brine



The effect of sand to water ratio	•Higher sand to water ratio→ more concentration of different component in water, and better repeatability.
Repeatability	•Optimum sand to water ratio should be chosen to have repeatability of experiments. It depends on grain size / heterogeneity. If heterogeneous (higher grain size in our samples) need higher sand to water ratio
Boiled water	•No effect was observed
The effect of sand size	•Generally, smaller sand sizes demonstrate lower measured concentrations of various components. Until we get to the powder where the concentrations are significantly higher than even the larger sand sizes.
Effect of Salinity	•Higher salinities show increased concentrations of the different component in water except for Si.
The effect of sand sterilization	•No effect has been observed so far
The effect of Hydrogen	•Different effects have been observed for different sand types in the limited experiments so far - However, all experiments so far have shown significantly increased Ni and Fe concentrations for both sands.

Work Package 2: Flow behaviour of hydrogen

Hydrogen flow properties

First time imaging of hydrogen flow hydrogen flow through porous rocks using X-ray CT.

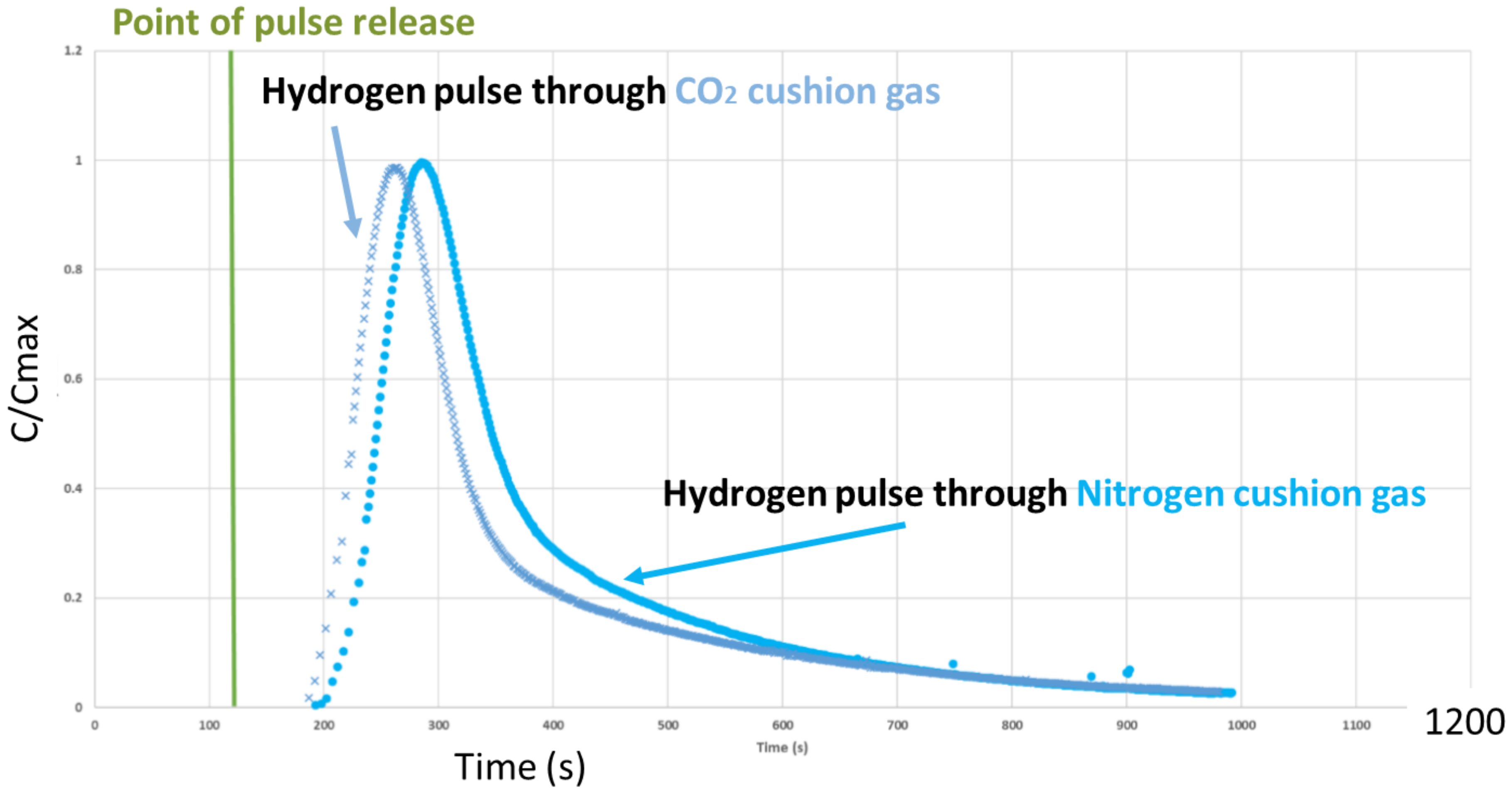
Characterising mass transport through porous rocks

Recovery efficiency over multiple cycles of injection and withdrawal?

Sealing of caprocks to hydrogen?

Benchmarking for numerical modelling

Preliminary results of Hydrogen flow through different cushion gases



Work Package 3: Numerical Simulation of Hydrogen Injection, Storage and Withdrawal

Benchmarked simulations to experiments – calibrating numerical simulators to Hydrogen

Understanding of the impact of different cushion gasses

Assessment of optimal geological trapping structures

Sensitivity of caprock integrity to injection and withdrawal conditions

Storage development plans for two potential storage sites – **small onshore / large offshore**

Work Package 4: Public and Stakeholder Understandings

Clarify existing societal views towards energy-related subsurface storage in the UK, through baseline review of extant research;

Evaluate community and opinion-shaper visions of a low carbon society, and the role of hydrogen storage in porous media within these;

Elaborate pathways to the governance and deployment of hydrogen storage in porous media within UK society.

HyStorPor Project Set-up

EPSRC and Advisory Board

EPSRC
Pale Blue Dot.
SGN
ATKINS
Environment Agency
EMEC
THE EUROPEAN MARINE ENERGY CENTRE LTD
ORKNEY
CGG
Passion for Geoscience
HYDRENOR
CLEANER ENERGY TODAY
Quintessa
SCOTTISH Hydrogen & Fuel Cell ASSOCIATION
equinor

WP4: Public and Stakeholder Understandings

Social Science and Public Interest

WP2: Fluid Flow

WP1: Chemistry & Biology

WP3: Reservoir Simulation

Sites & Samples

WP5 Dissemination Pathways to Impact

Industry
Government
researchers

Papers
Workshops
Conferences

Public
NGO
Policy