HyStorPor

Industry Workshop: Hydrogen Infrastructure for a Decarbonised Energy System

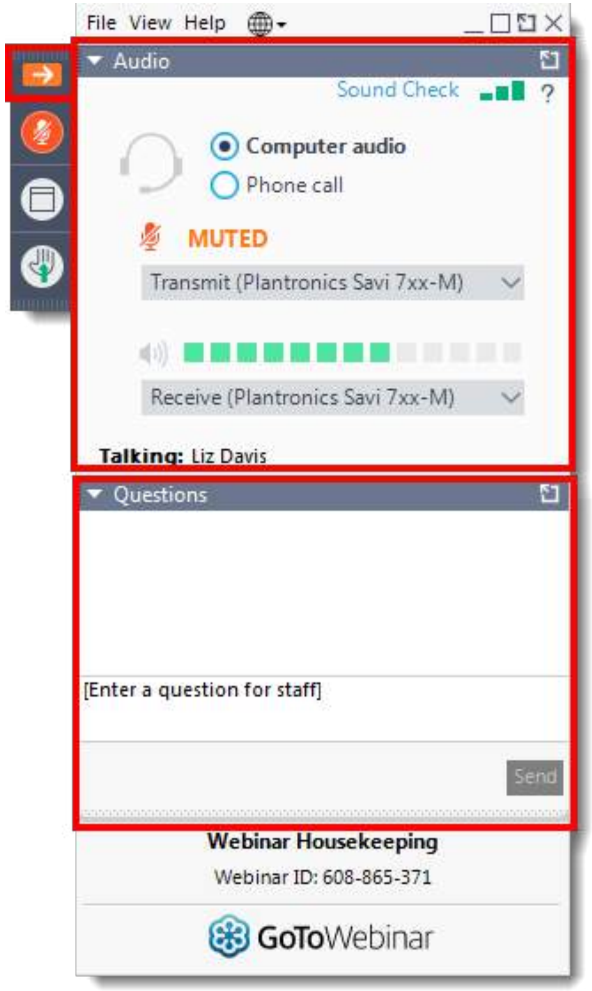
Nigel Holmes, SHFCA; **Stuart McKay**, Scottish Government

David Hogg, ARUP; **Mark Wheeldon**, SGN

Katriona Edlmann, **Stuart Haszeldine**, University of Edinburgh

Grégoire Hévin, Storengy; **Simonas Cerniauskas**, Jülich

Online 17/11/20



Your Participation

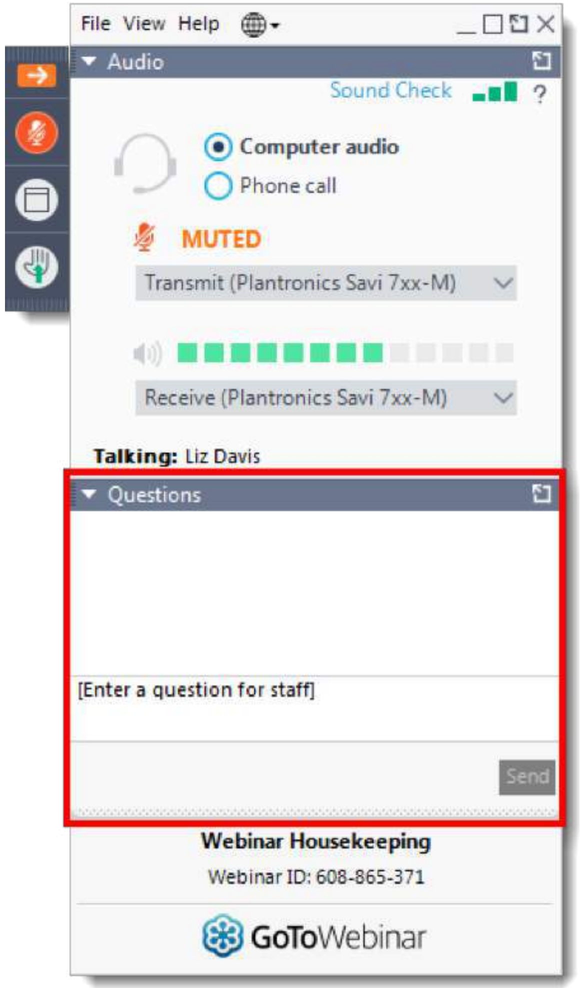
Open and close your control panel

Join audio:

- Choose **Mic & Speakers** to use VoIP
- Choose **Telephone (Phone Call)** and dial using the information provided

Submit questions and comments via the Questions panel

Note: Today's webinar is being recorded and will be available on the HyStorPor website soon.



Your Participation

- Please continue to submit your text questions and comments using the Questions panel

For more information, please contact Richard at r.l.stevenson@ed.ac.uk

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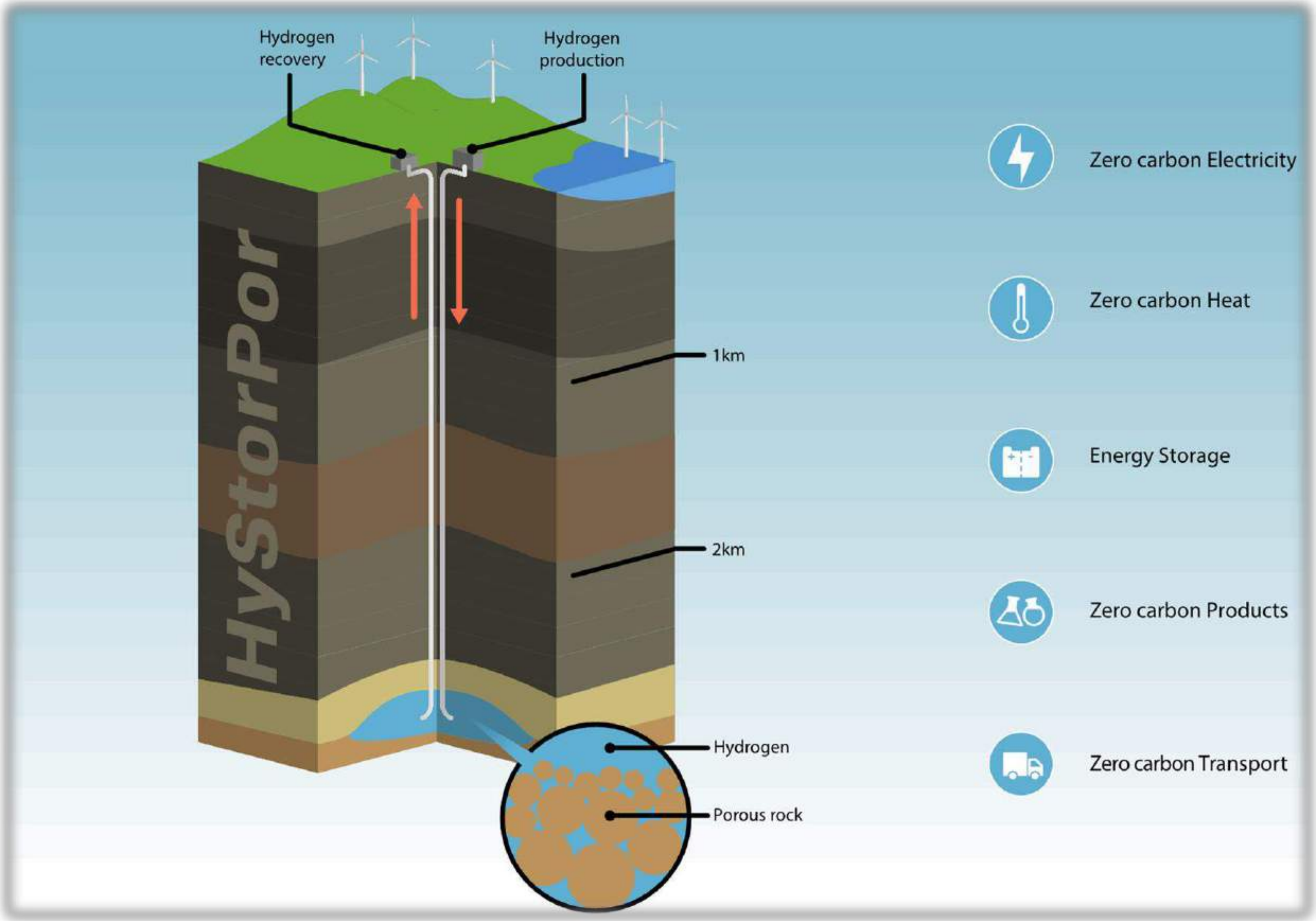
Industry Workshop: Hydrogen Infrastructure for a Decarbonised Energy System

Session 1: Hydrogen Economy

Chair: Nigel Holmes, SHFCA


Hydrogen recovery
Hydrogen production
HyStorPor
1km
2km
Hydrogen
Porous rock
Zero carbon Electricity
Zero carbon Heat
Energy Storage
Zero carbon Products
Zero carbon Transport

Agenda

Session 1 – Hydrogen Economy
Chair: Nigel Holmes
13:00 – 13:05 Nigel Holmes, Scottish Hydrogen and Fuel Cell Association
13:05 – 13:15 Stuart McKay, Scottish Government
13:15 – 13:25 David Hogg, ARUP
13:25 – 13:35 Mark Wheeldon, SGN
13:35 – 13:45 Katriona Edlmann, University of Edinburgh
13:45 – 14:10 Panel Discussion

14:10 – 14:25 Break / Poster Session

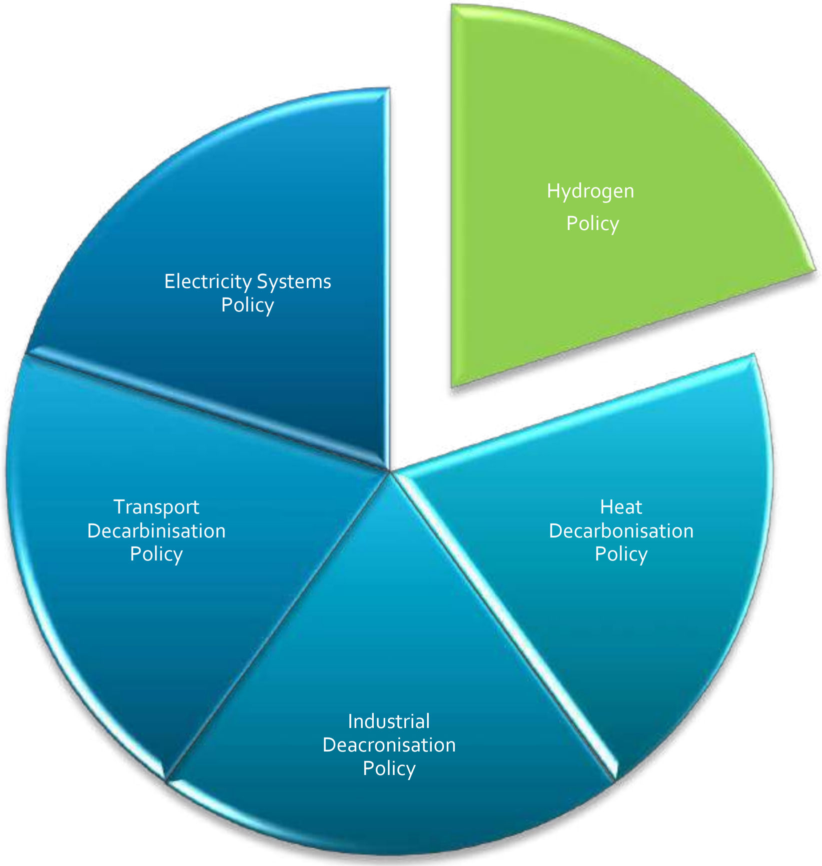
Session 2 – Hydrogen Storage
Chair: Stuart Haszeldine
14:25 – 14:35 Stuart Haszeldine, University of Edinburgh
14:35 – 14:50 Grégoire Hévin, Storengy
14:50 – 15:05 Simonas Cerniauskas, Jülich
15:05 – 15:20 Katriona Edlmann, HyStorPor
15:20 – 15:45 Panel Discussion

15:45 – 15:55 Closing remarks

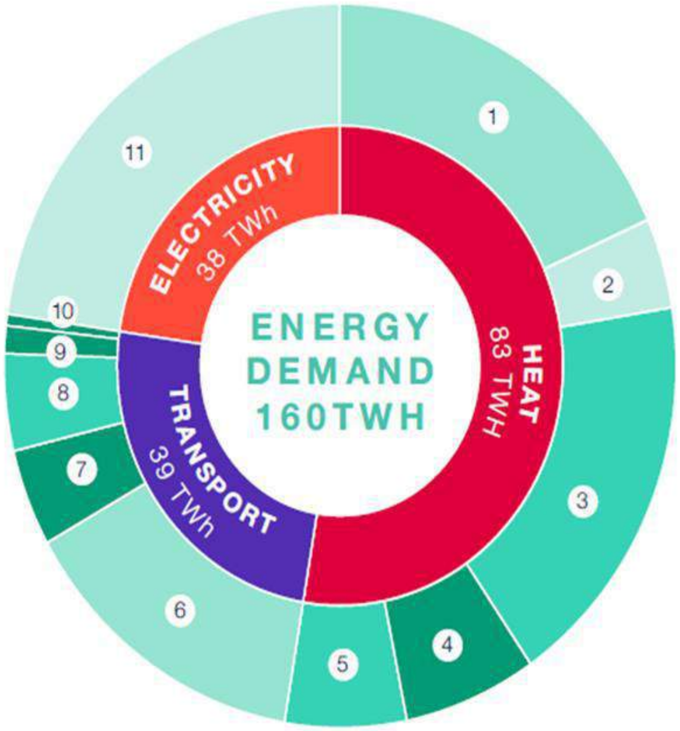
Hydrogen Assessment Project

Stuart McKay, Scottish Government

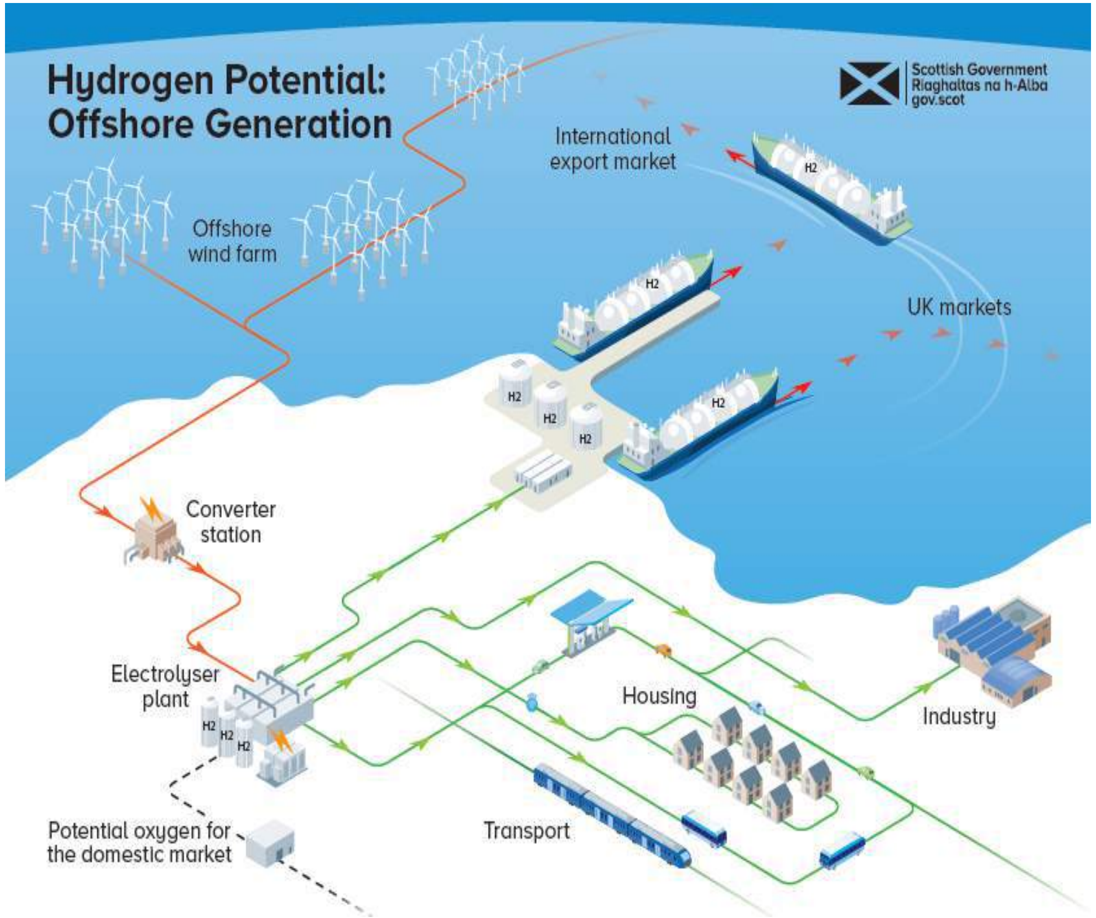
Hydrogen Assessment Project



Scotland’s Energy Demand by Sector and Integrating Green Hydrogen into the Energy System



1. Commercial and industrial non-gas
2. Domestic non-gas
3. Domestic gas
4. Industrial gas
5. Commercial gas
6. Cars
7. Heavy goods vehicles (HGV)
8. Light goods vehicles (LGV)
9. Buses
10. Rail
11. Electricity



Scottish Government
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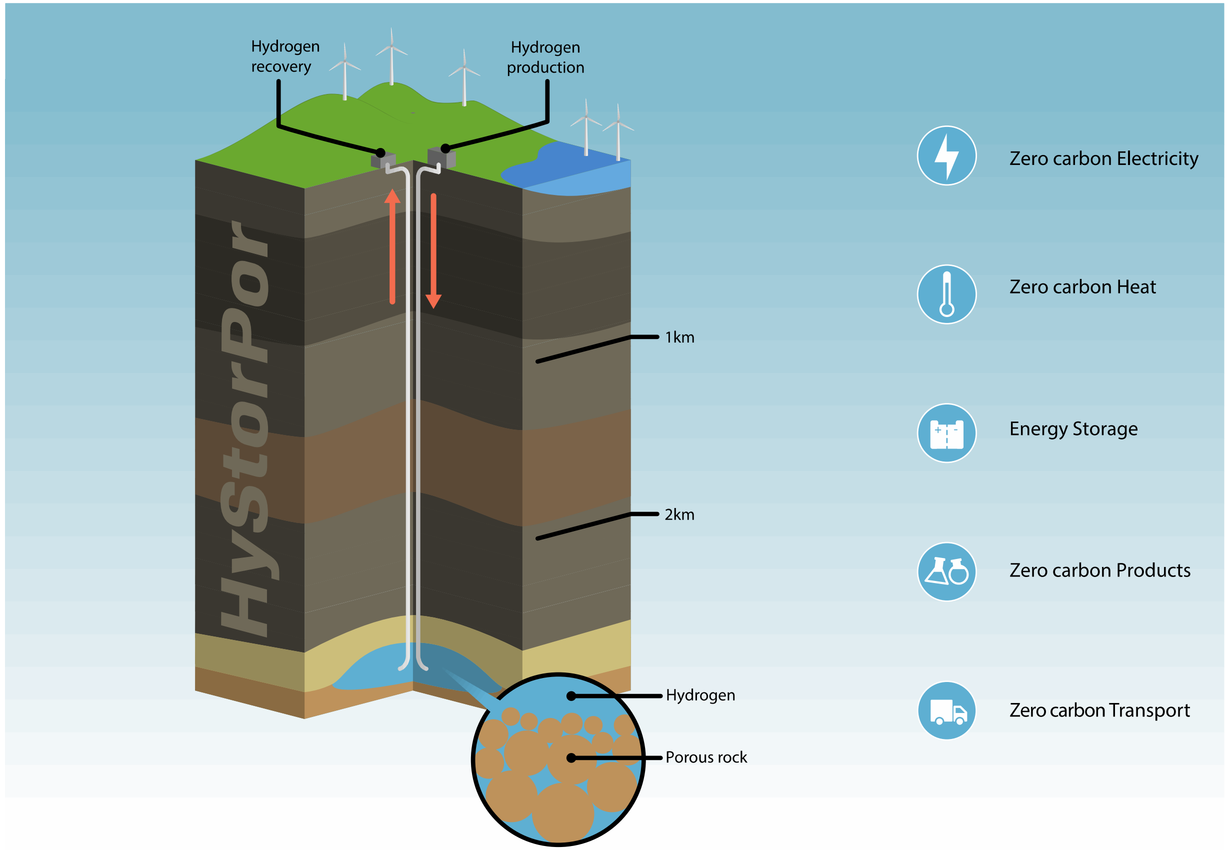
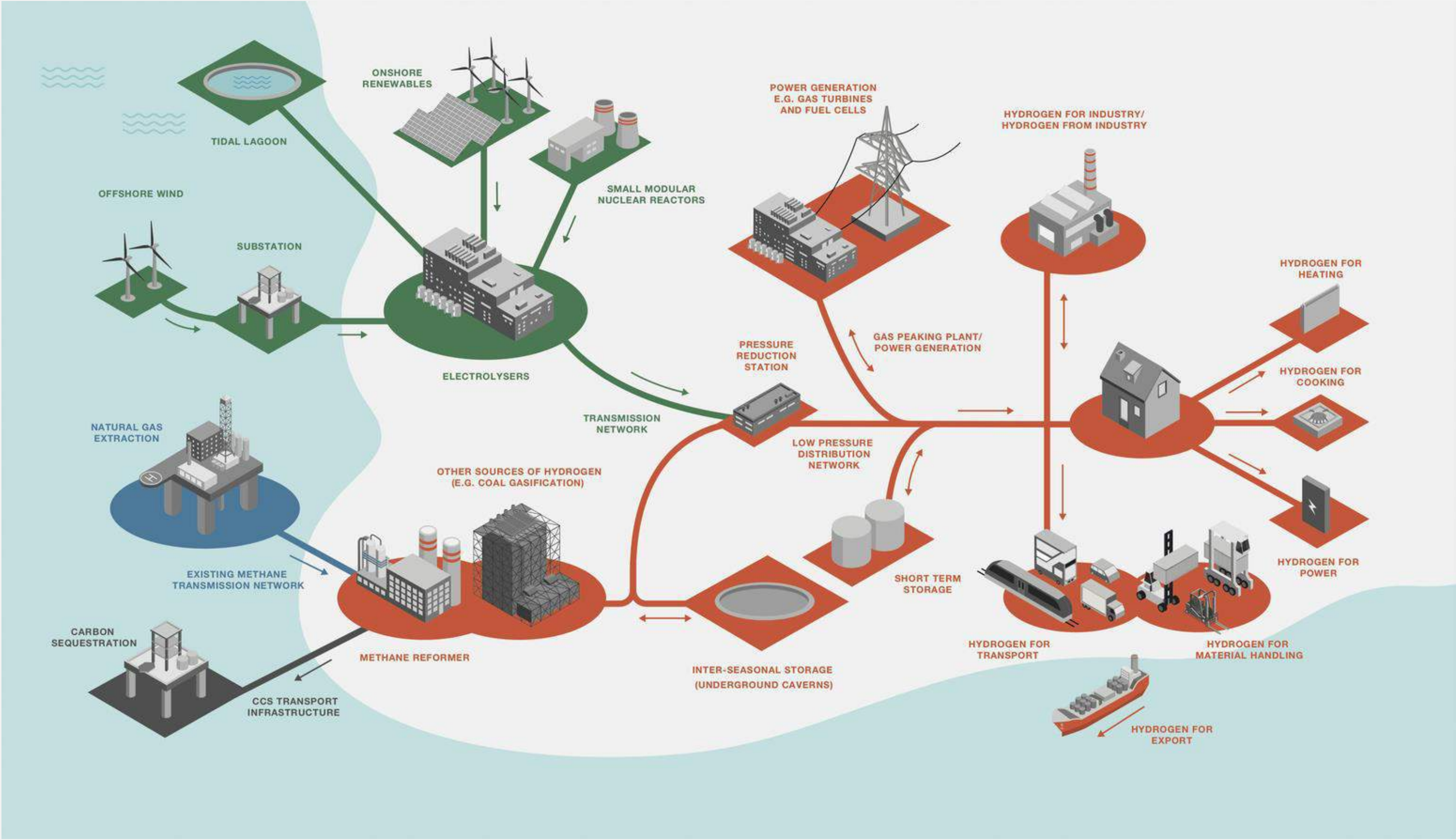


ARUP

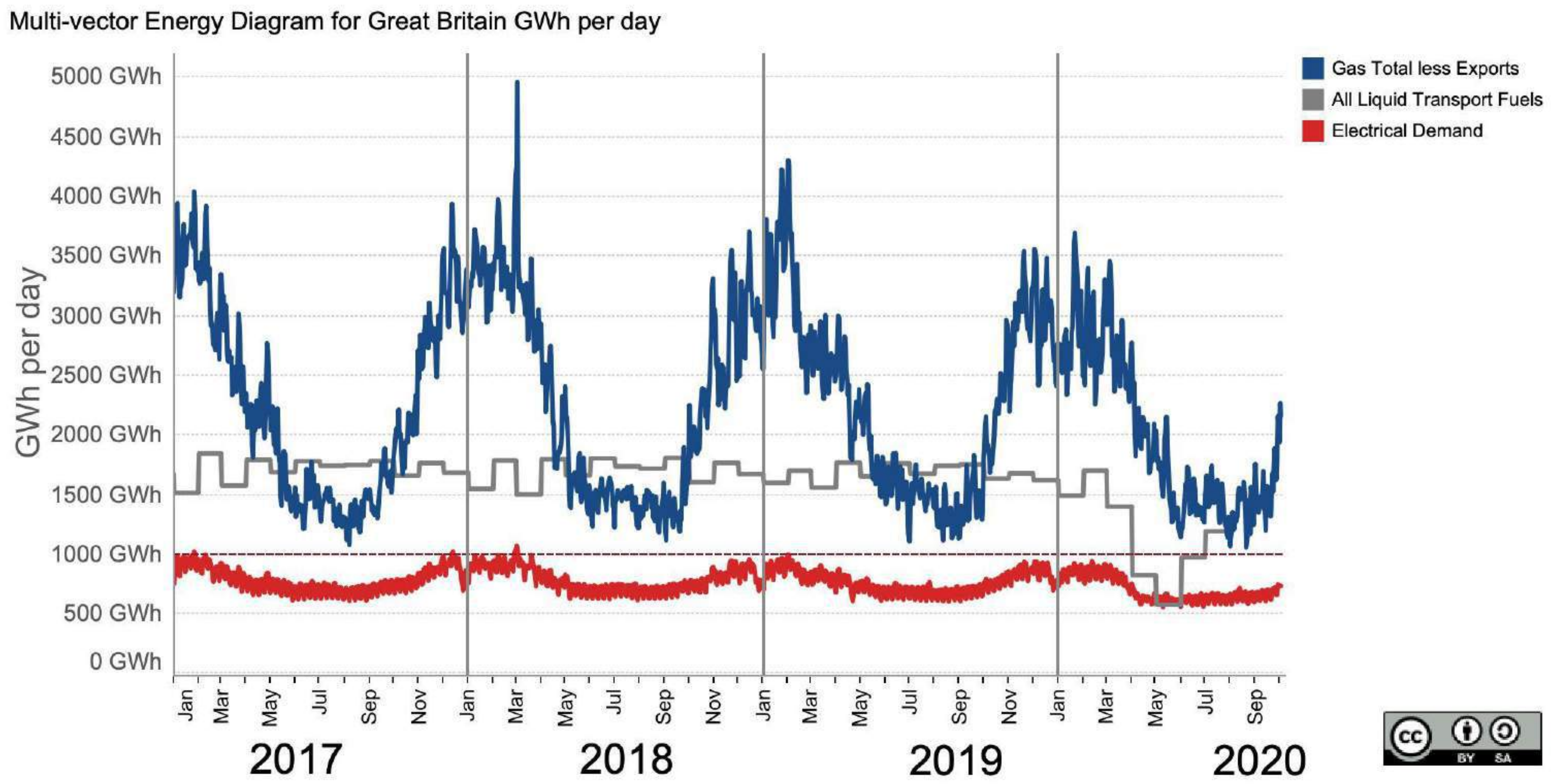
Hydrogen –The Future?



David Hogg

The Net Zero Challenge

ARUP



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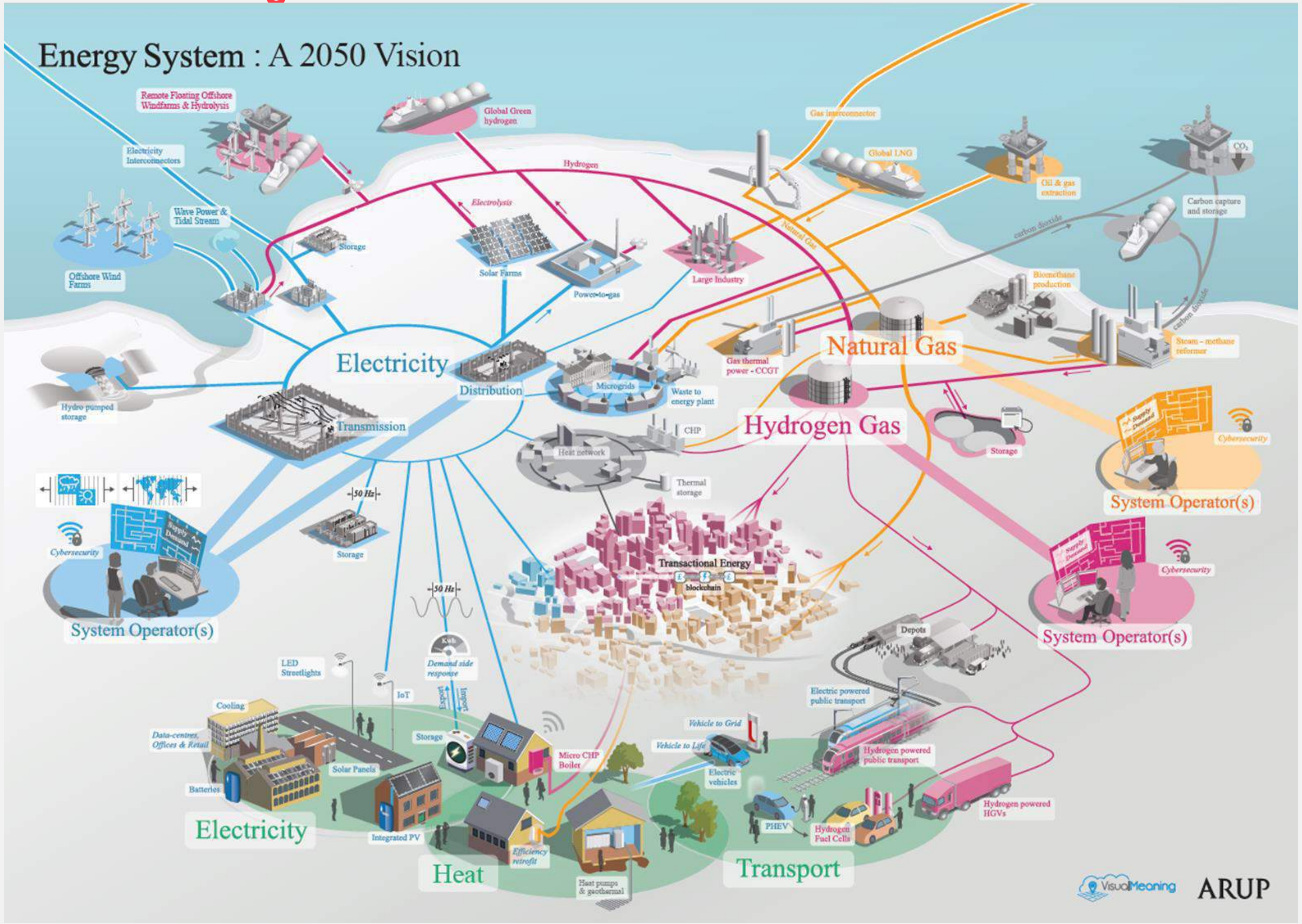
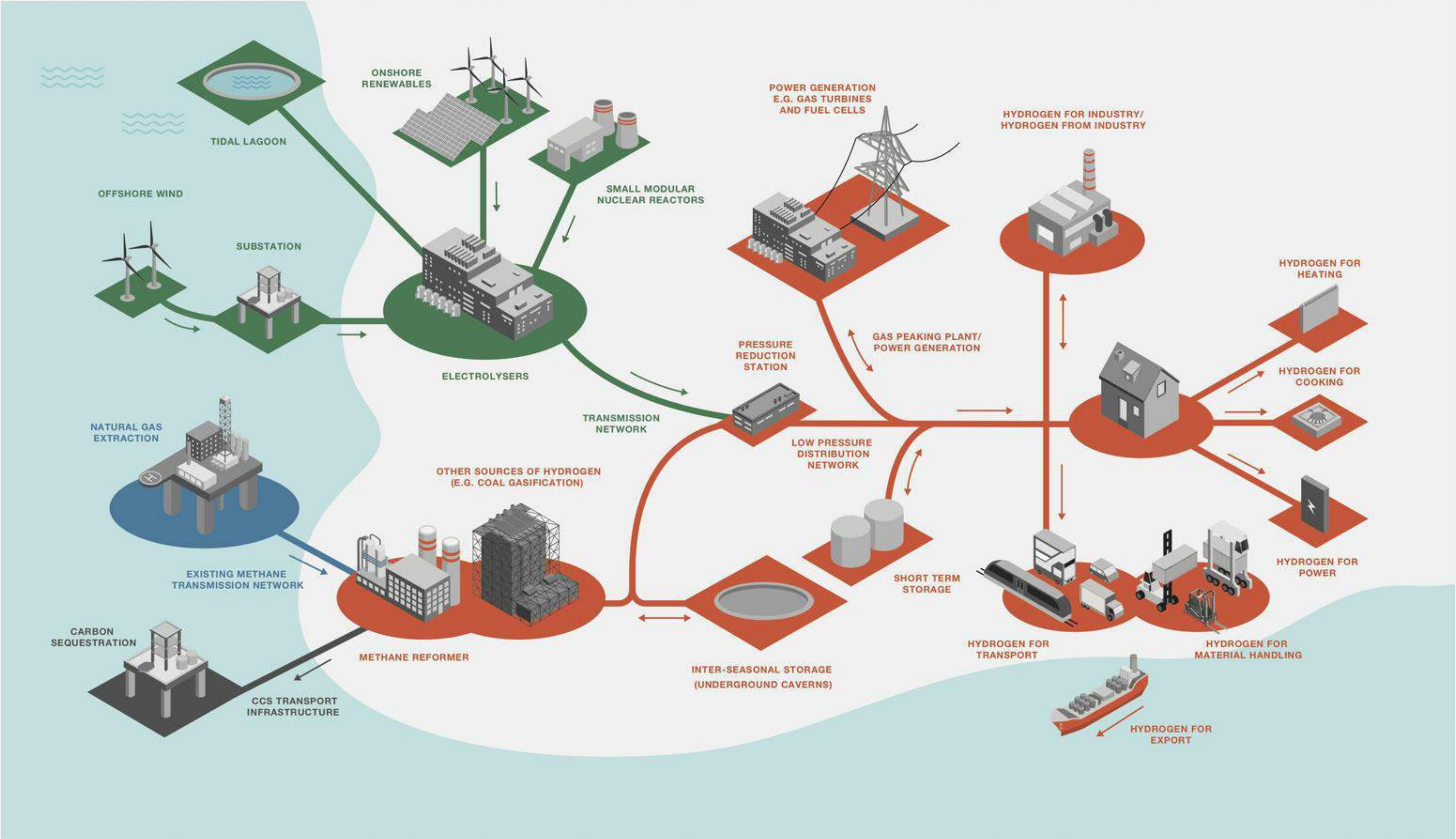
Underlying data are from National Grid, Elexon and BEIS
Figure created by Dr Grant Wilson: i.a.g.wilson@bham.ac.uk
Energy Informatics Group, University of Birmingham
slidepack available from https://doi.org/10.5281/zenodo.3930970

Whole System Thinking

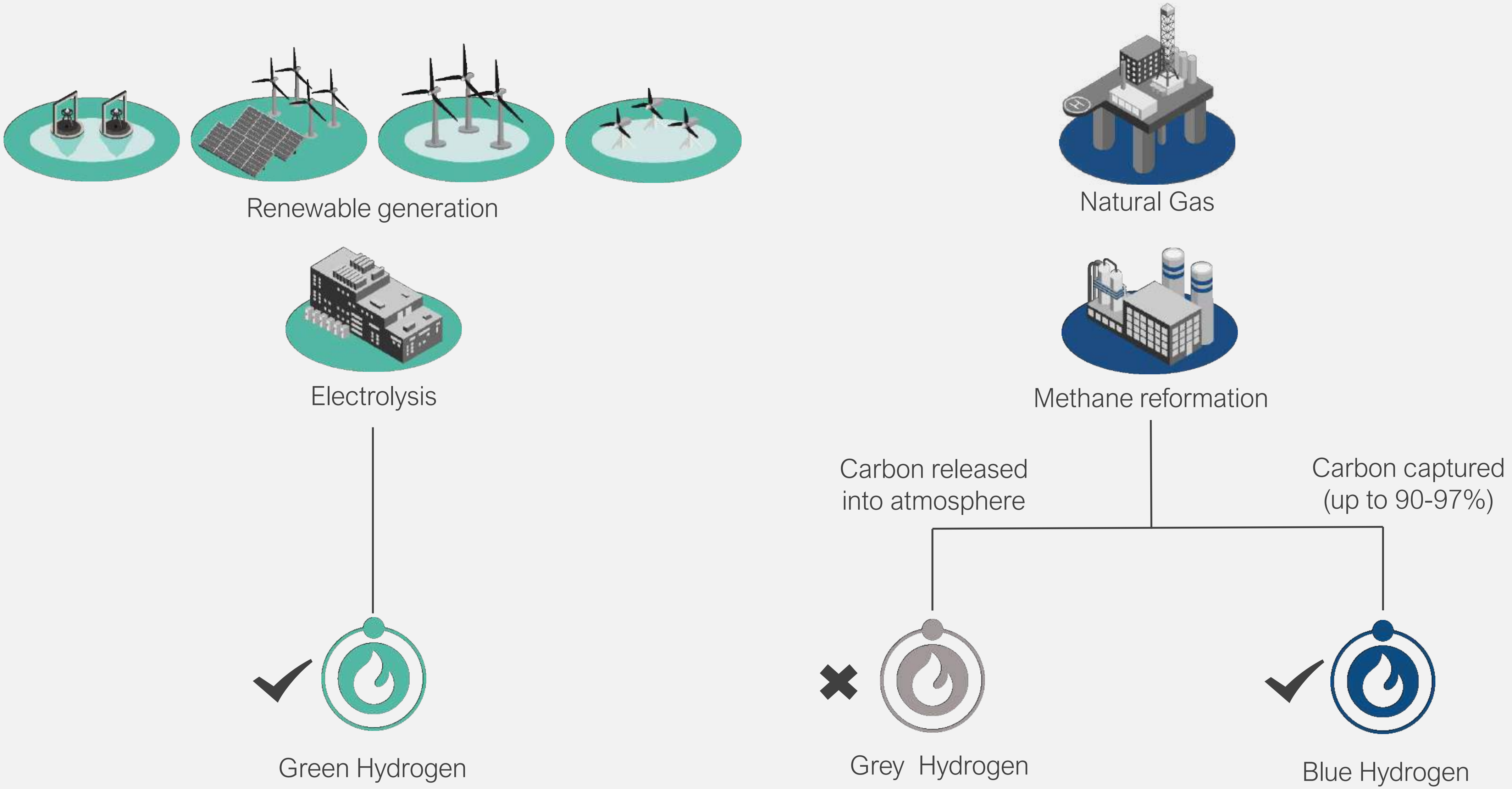
ARUP



The Hydrogen Economy



Hydrogen Production



ARUP

How Close is the Hydrogen Revolution?

Hy4Heat

To establish if it is technically possible, safe and convenient to replace natural gas with hydrogen in residential and commercial buildings and gas appliances.

BEIS - £25m

H100

Develop site specific evidence to support the construction of a 100% hydrogen demonstration project

SGN (Ofgem)

H21

To establish the safety case evidence supporting the conversion of gas distribution networks to 100% hydrogen in Leeds

Northern Gas Networks/ Cadent/ SGN £10m

Hydrogen Accelerator

Enabling effective and efficient implementation of hydrogen technologies into Scotland and supporting economic growth in this important low carbon transport sector.

Scottish Government

Hydrogen Supply Competition

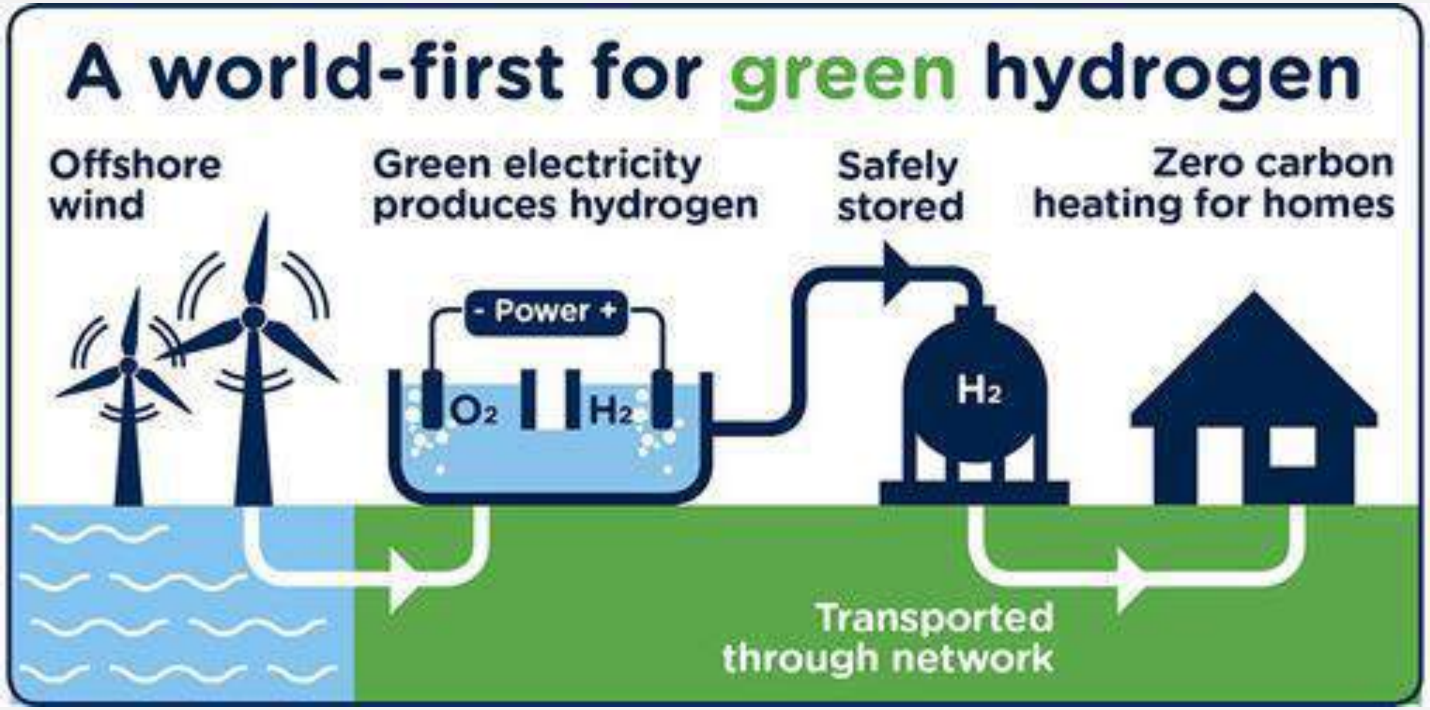
To accelerate the development of low carbon bulk hydrogen supply solutions

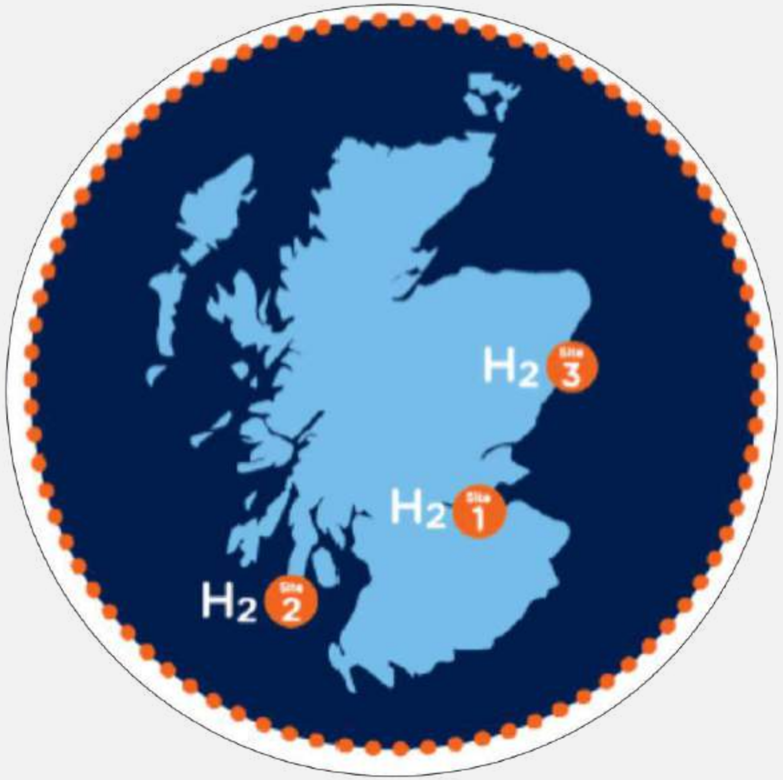
BEIS - £20m

ARUP

Hydrogen Deployed

H100 and Project Methilltoune



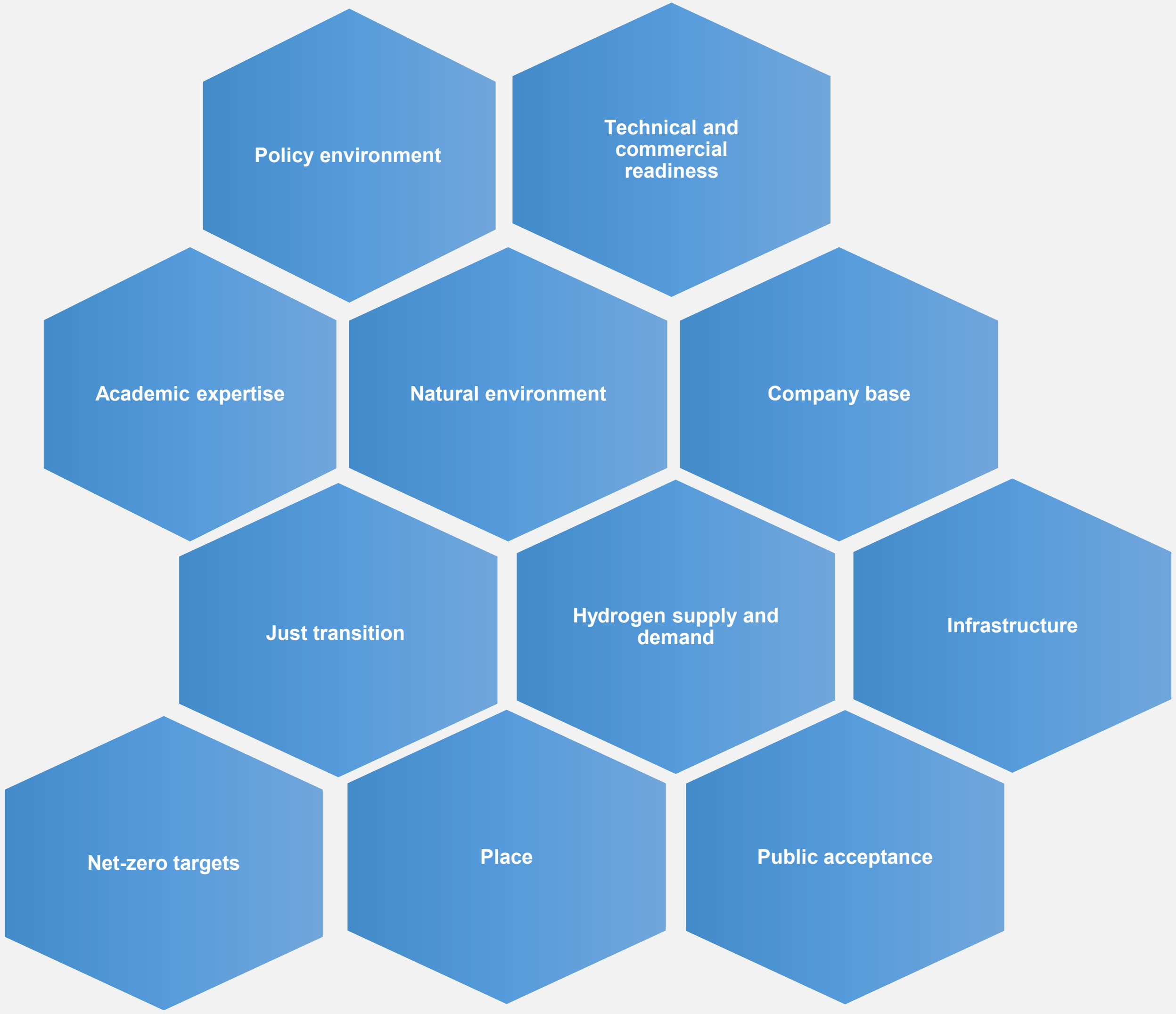


Project Cavendish

- Potential of hydrogen production in Isle of Grain
- Hydrogen pipeline to London
- Assessing how and where hydrogen production would be most beneficial
- Looking to supply:
    - Transport
    - Industrial Use
    - Power
    - Heating

Scottish Hydrogen Assessment Project

- Generate hydrogen baseline for Scotland
- Create scenarios of how hydrogen might develop
- Assess the economic impacts of those scenarios
- Project will gather the evidence base for Scotland’s hydrogen policy statement and action plan



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Future Scottish Applications

- Constrained and Non Economic Renewables
- Ferries and Shipping
- Rail
- Heating
- Improving Resilience
- Economic Opportunities

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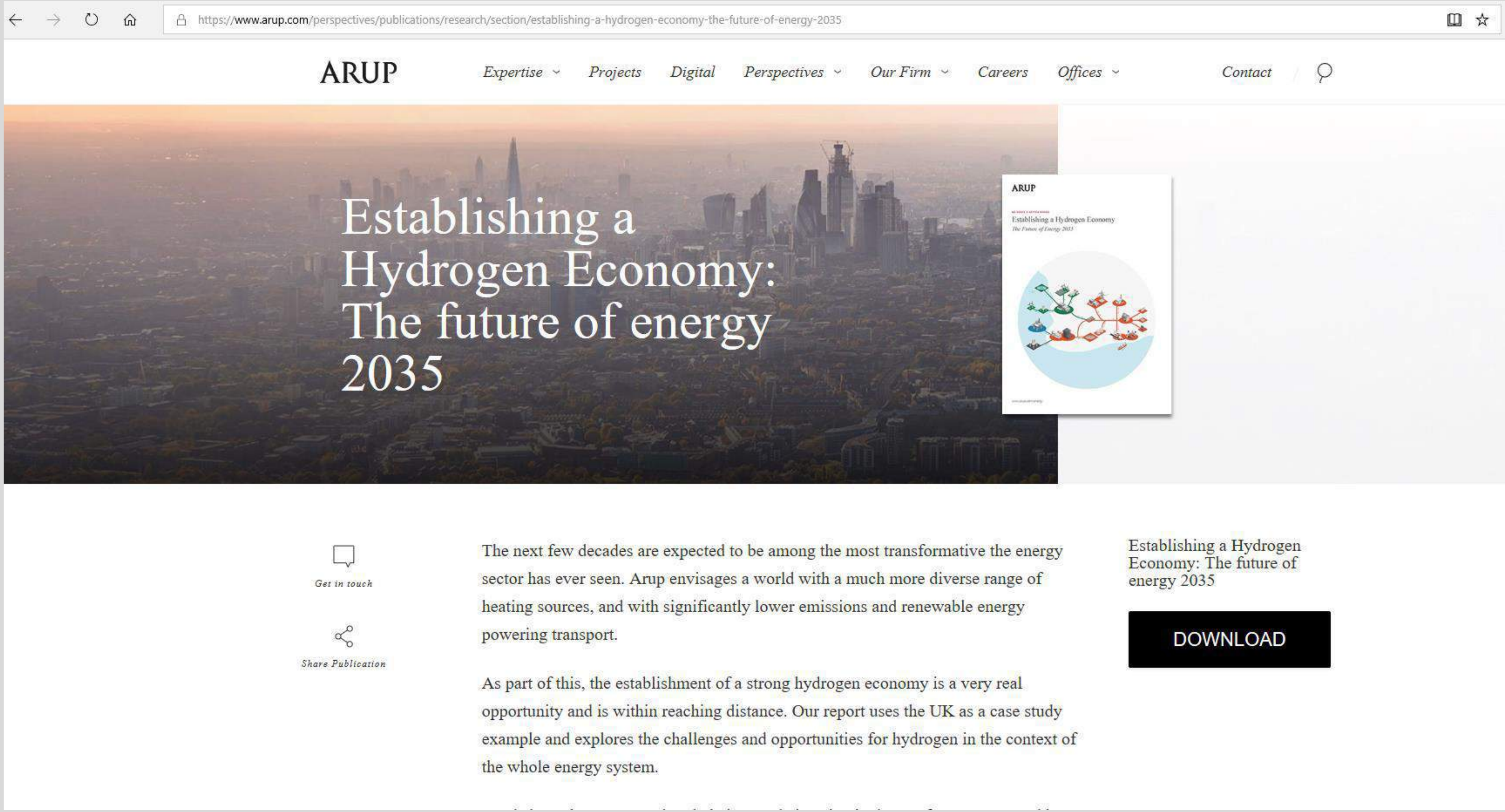
https://www.arup.com/perspectives/publications/research/section/establishing-a-hydrogen-economy-the-future-of-energy-2035

ARUP

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Establishing a Hydrogen Economy: The future of energy 2035

Get in touch

Share Publication

The next few decades are expected to be among the most transformative the energy sector has ever seen. Arup envisages a world with a much more diverse range of heating sources, and with significantly lower emissions and renewable energy powering transport.

As part of this, the establishment of a strong hydrogen economy is a very real opportunity and is within reaching distance. Our report uses the UK as a case study example and explores the challenges and opportunities for hydrogen in the context of the whole energy system.

Establishing a Hydrogen Economy: The future of energy 2035

DOWNLOAD

https://www.arup.com/perspectives/publications/research/section/establishing-a-hydrogen-economy-the-future-of-energy-2035

ARUP

Thank you for listening

Other resources:

Hydrogen Economy Report

David.hogg@arup.com

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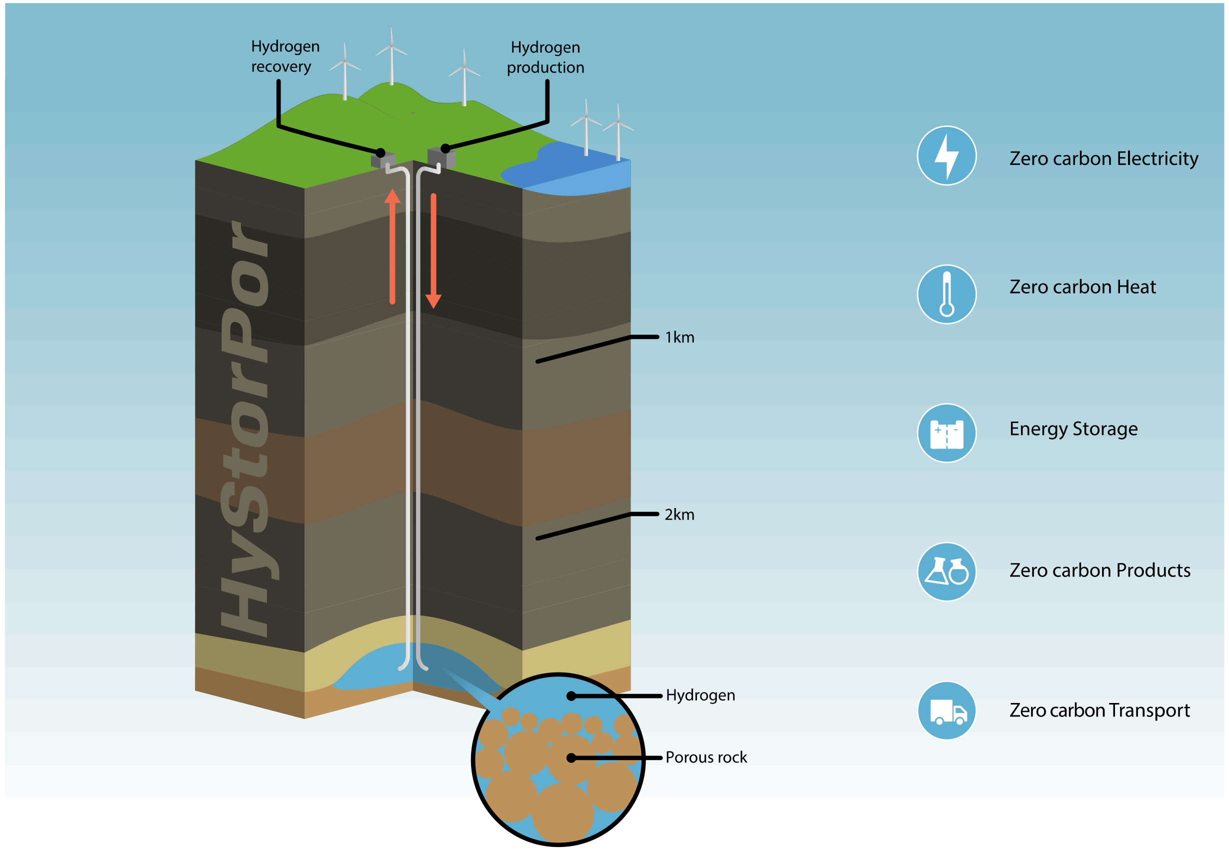


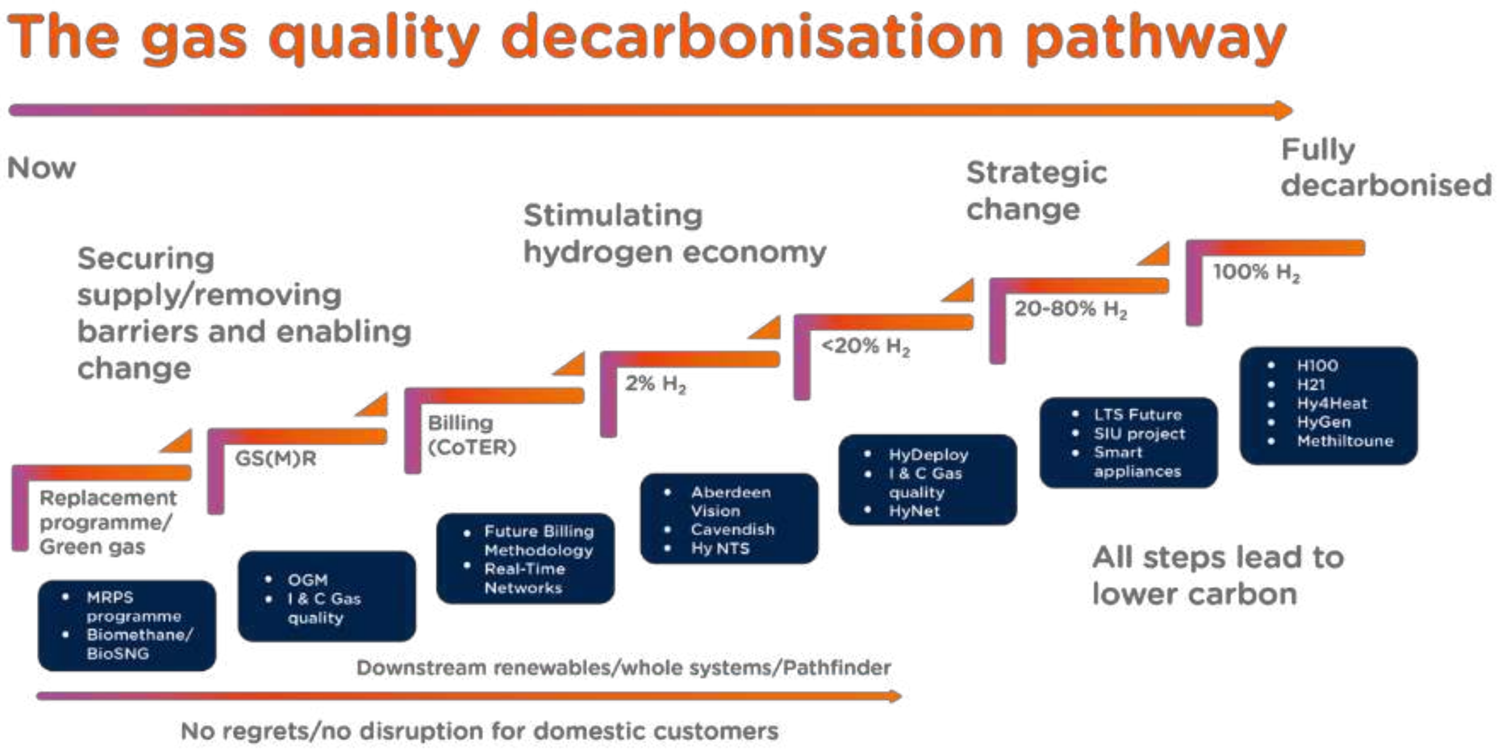
H100 Fife
HyStorPor - Industry Workshop

Mark Wheeldon

17th November

Hydrogen Context

- **H100 Fife is a key demonstration project with national significance in evidencing the role of hydrogen to decarbonise the gas networks.**



GAS GOES GREEN

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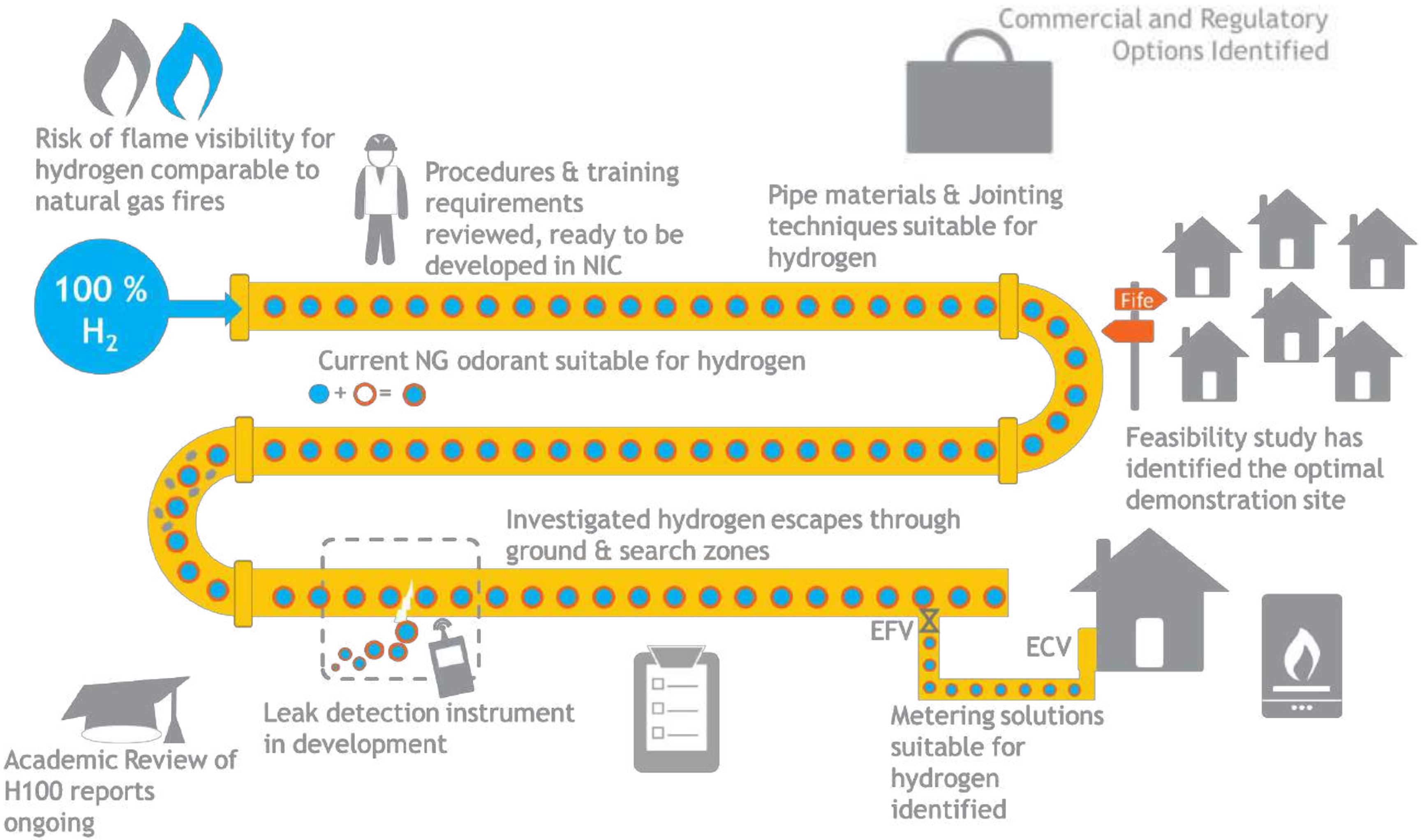
Hydrogen Evidence Base



& project partners

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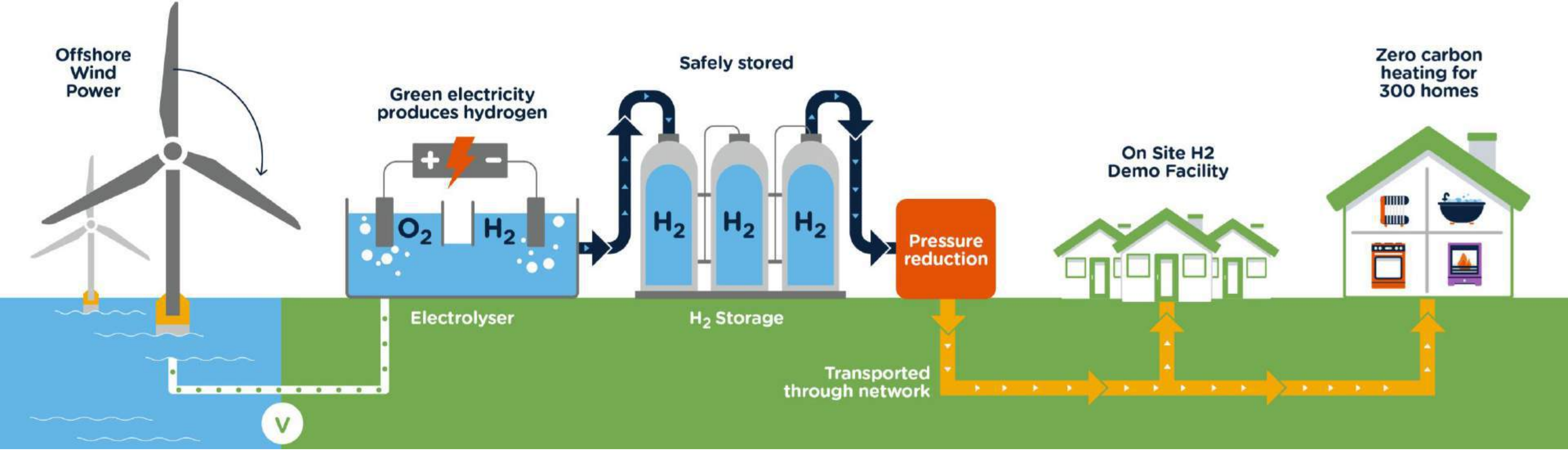
H100 Fife Animation

https://sgn.co.uk/H100Fife

H100 Fife – End to End Demonstration



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H100 Fife – Levenmouth Site

ORE Catapult 7MW Turbine

Energy Park Fife

Customer Engagement – Hydrogen Demonstration Facility

Hydrogen Demonstration Facility

Key Principles:

- Building customer confidence
- Providing interactive customer experience with hydrogen
- Maintaining customer choice model throughout project
- Customers can opt-in for a hydrogen supply or remain with existing natural gas supply
- Cost neutral to participate

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Funding - Ofgem Network Innovation Competition NIC

ofgem
Making a positive difference
for energy consumers

- **April 2020:** Passed the initial screening process
- **May-July:** Ofgem NIC submission preparation
- **July:** NIC bid submitted
- **August-October:** Ofgem review process with supplementary questions & bilaterals
- **October:** NIC final submission
- **November/December:** Expected NIC decision

If successful

- **April 2021:** NIC funding commences

Cadent Your Gas Network

Northern Gas Networks

WALES&WEST UTILITIES

SGN

Scottish Government
Riaghaltas na h-Alba
gov.scot

Funding - Scottish Government Grant

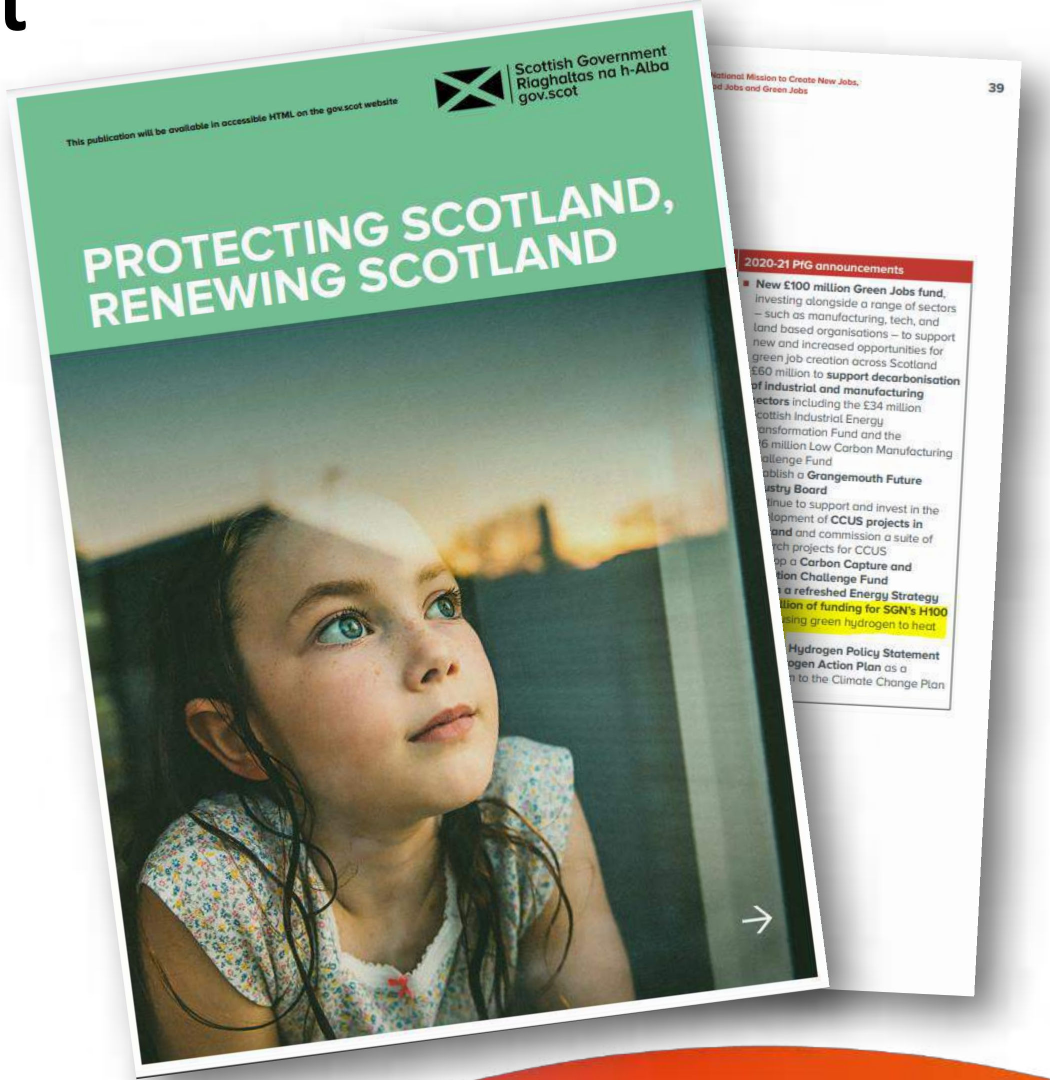
Subject to Ofgem NIC

The Government's Programme for Scotland 2020-2021

Hydrogen policy

We know that Scotland will require a diverse and balanced energy mix to meet our emissions targets. In order for the energy transition to be successful, security of supply, affordability and access to viable alternative options need to be combined with innovative and smart emissions reduction action. Against this backdrop, it is clear that hydrogen will play a key role in enhancing, supporting and completing the energy transition across a range of sectors, aiding economic recovery through production for the domestic market and export, and generating jobs.

Scotland has a strong track record of supporting Hydrogen innovation and we are committed to continuing this. **We will provide £6.9 million of funding for SGN's H100 project in Fife** which will be a world-first programme using green hydrogen to heat around 300 local homes and create an estimated 100 jobs in its first phase.



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H100 Fife Example Outcomes

- Prioritised learning to inform hydrogen system transformation
- Validation of 80% of 280000km network materials, components, construction and operation on a live network
- Quantifying and qualifying customer and social acceptance of hydrogen for heat in real-world trial
- End to end system interfaces management and learning across the whole system
- Statistically significant and scalable
- Future demand forecasting through heat profile data
- Informs heat policy decisions and future regulation
- Shared learning and knowledge transfer to facilitate hydrogen projects and roll out
- Market creation

SGN

FIFE

FIRST OF A KIND 100% HYDROGEN HEAT NETWORK

Futures Expansion Opportunities

- **Phase 1: 300 homes new network**
- **Phase 2: Increased homes & conversion**
- **Phase 3: Industrial & Commercial**
- **Phase 4: Transport**
- **Phase 5: Whole Systems & Hydrogen Coast**

SGN

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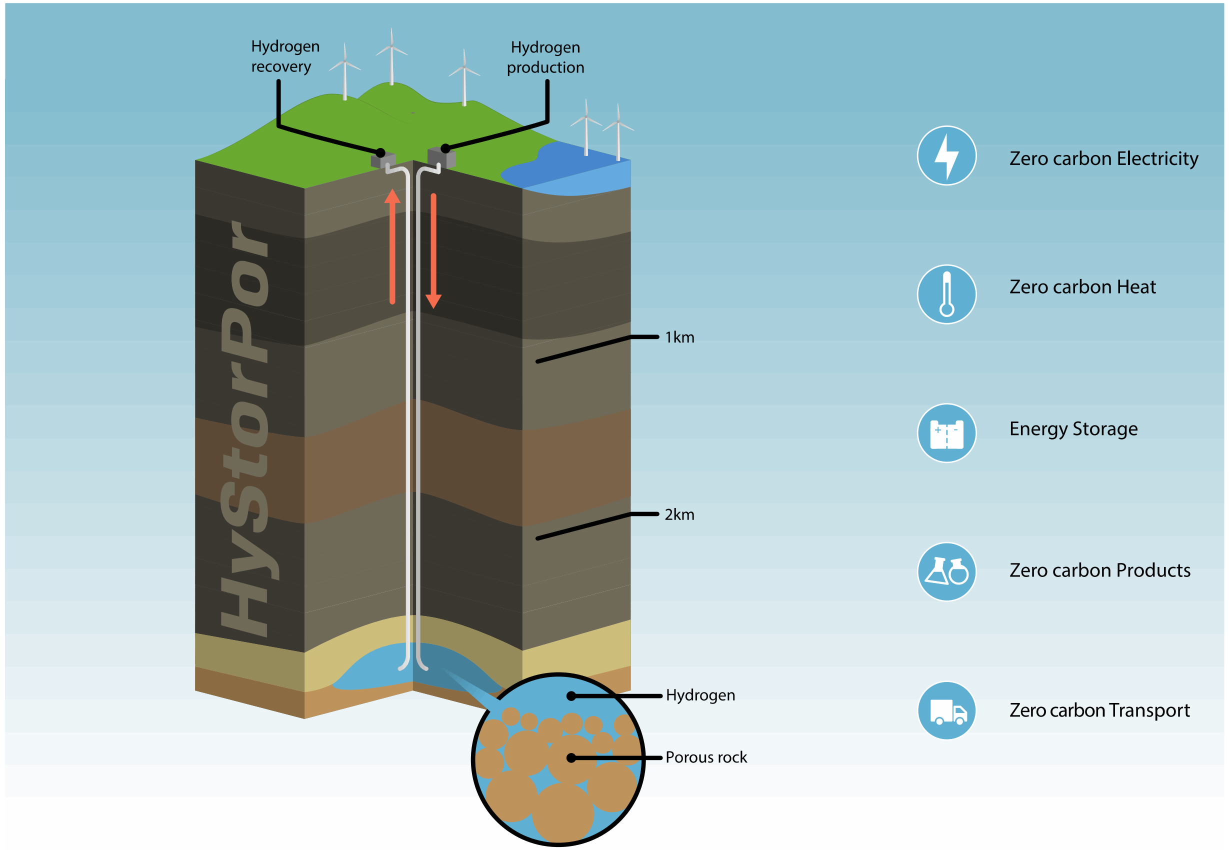

Large-scale hydrogen storage

Katriona Edlmann

Stuart Haszeldine, Niklas Heinemann, Mark Wilkinson, Chris McDermott, Ian Butler, Ali Hassanpouryouzband, Eike Thaysen, Julien Mouli-Castillo, Jonathan Scafidi, John Low (all UoE), Leslie Mabon (SAMS), Romain Viguier (SCCS), Gillian Pickup (HW), Sam Krevor (Imperial)

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SAMS Scottish Association for Marine Science

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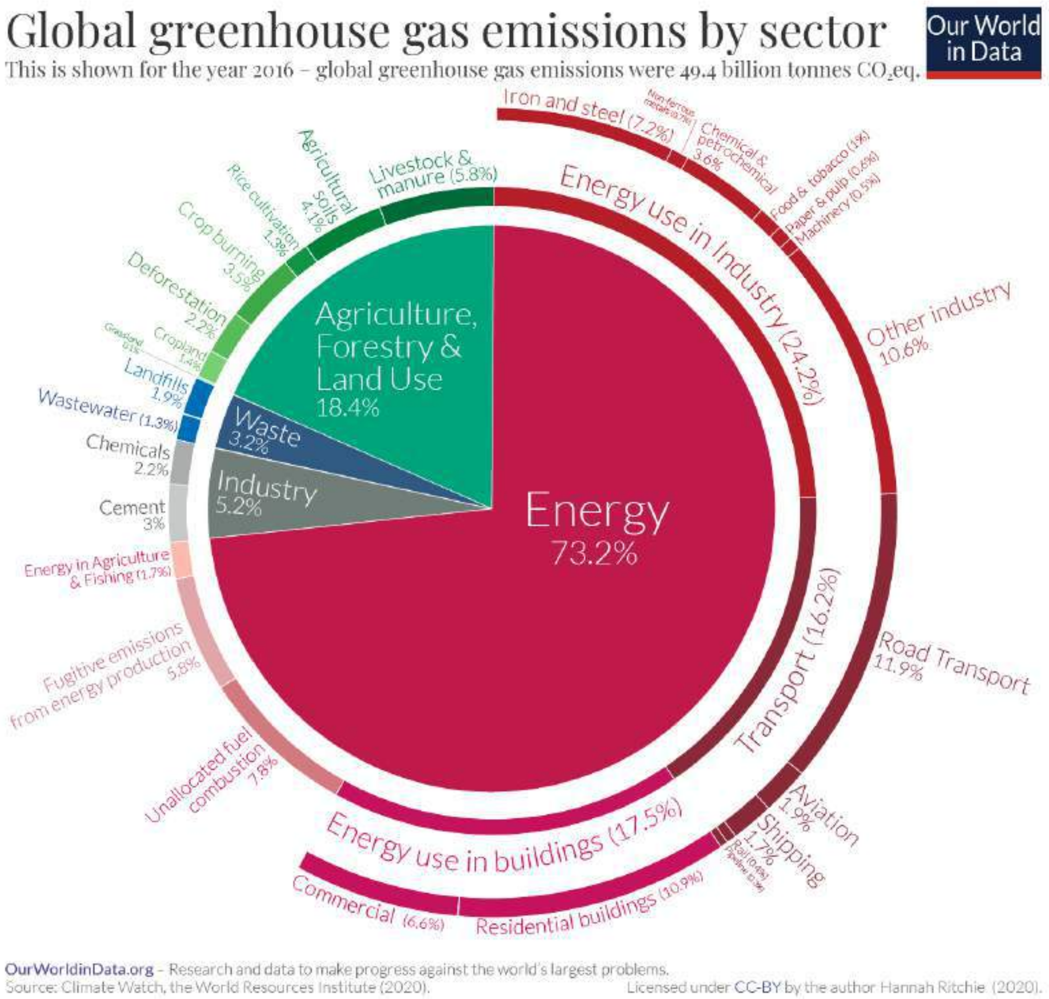
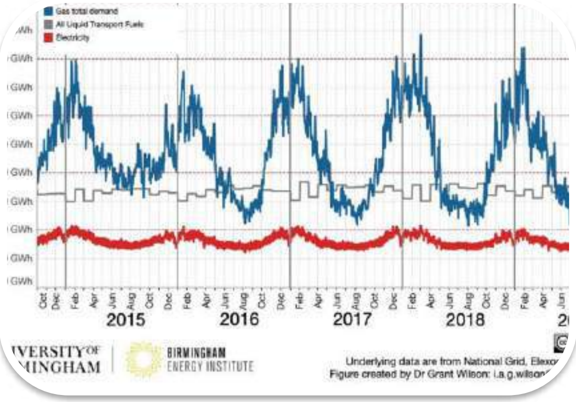
EPSRC
EP/S027815/1

The problem… Decarbonising Energy



The opportunities for hydrogen



Buffer large seasonal fluctuations in energy demand

Decarbonise aviation, road freight, rail & shipping

Replace hydrocarbon based Industrial feedstock

Provide energy storage for increased renewables and energy security

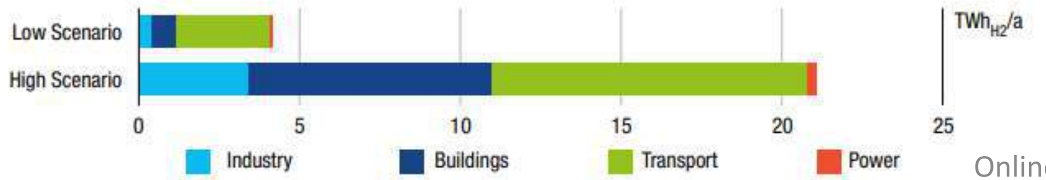
Images sources: Grant Wilson, Alstrom & Siemens

Hydrogen storage capacity requirements

- Estimates for UK hydrogen scenarios show a hydrogen requirement well in excess of 20 TWh. This excludes hydrogen export potential.

Estimated renewable/low carbon hydrogen demand for UK by 2030

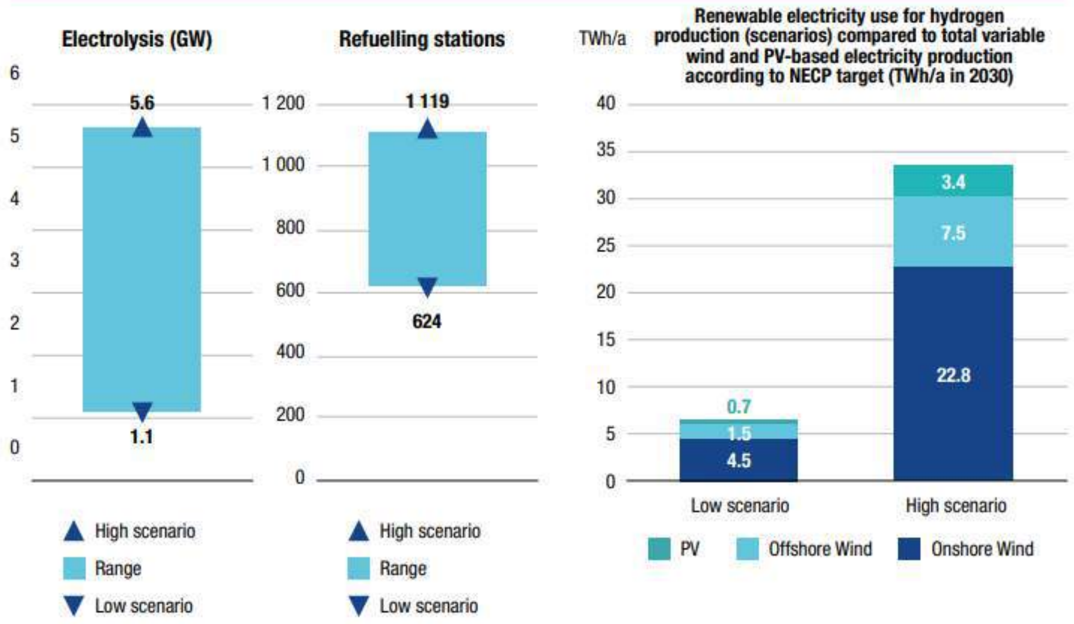
Hydrogen demand in the year 2030 has been estimated in a low and a high scenario covering the range of uncertainty. Today, conventional hydrogen mainly used in industry is produced from fossil fuels (e.g. through steam methane reforming) or is a by-product from other chemical processes. Both scenarios assume that in 2030 renewable hydrogen will be provided to partially substitute current conventional production and to cover additional demand (e.g. from transport sector).



Hydrogen generation, infrastructure and end users in UK by 2030

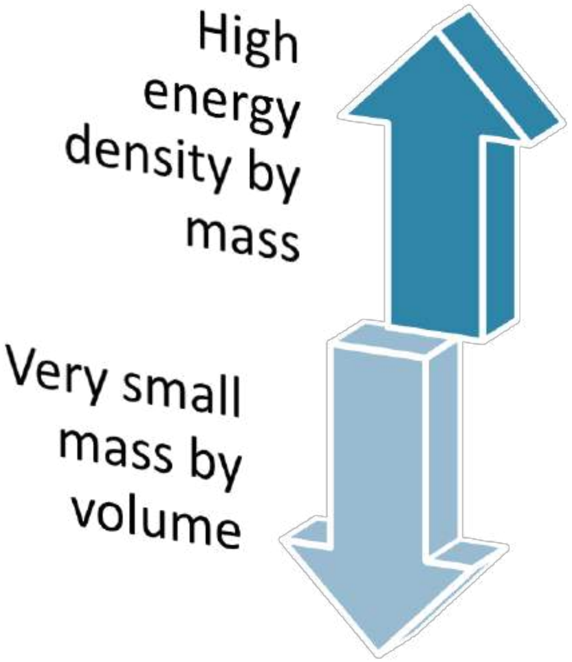
The analysis of renewable hydrogen generation, infrastructure and end use is based on the demand estimates presented above. Renewable hydrogen is generated from variable renewable power using electrolysis. The analysis covers only national hydrogen production to satisfy domestic demand and does not take into account any cross-border trade of hydrogen (i.e. hydrogen imports and exports are not included in this analysis).

Renewable hydrogen generation and infrastructure



Images from the EU FCH UK Opportunities for Hydrogen Energy Technologies Report, 2020

Scales of hydrogen storage: 700,000 metric tonnes



- **Line packing**: 2 million km 12” diameter pipe @70bar and 25°C
- 40,000 Olympic swimming pool sized **tanks** @ 100bar and 25°C
- 230 **salt caverns**
- ~1 large **offshore field** (e.g. Rough)

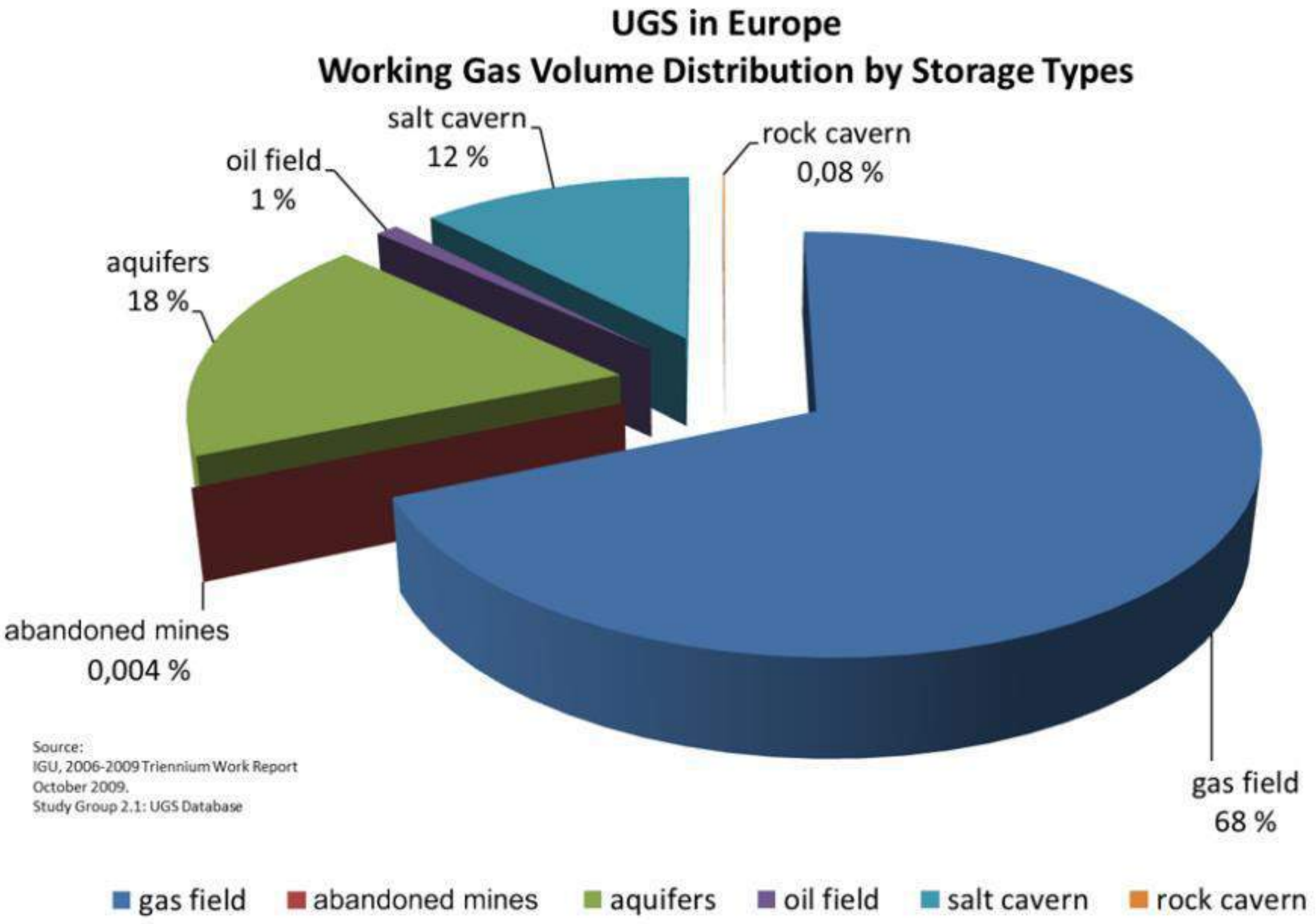
[1] Data courtesy of Julien Mouli-Castillo (julien.moulicastillo@ed.ac.uk), University of Edinburgh

Based on 2016 Scotland annual domestic gas demand (27,459 GWh), Using a Hydrogen mass equivalent conversion. Assuming no base load supply.

Underground gas storage experience

"Assessment of the potential, the actors and relevant business cases for large scale and seasonal storage of renewable electricity by hydrogen underground storage in Europe"

HyUnder



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Potential of hydrogen storage in porous media

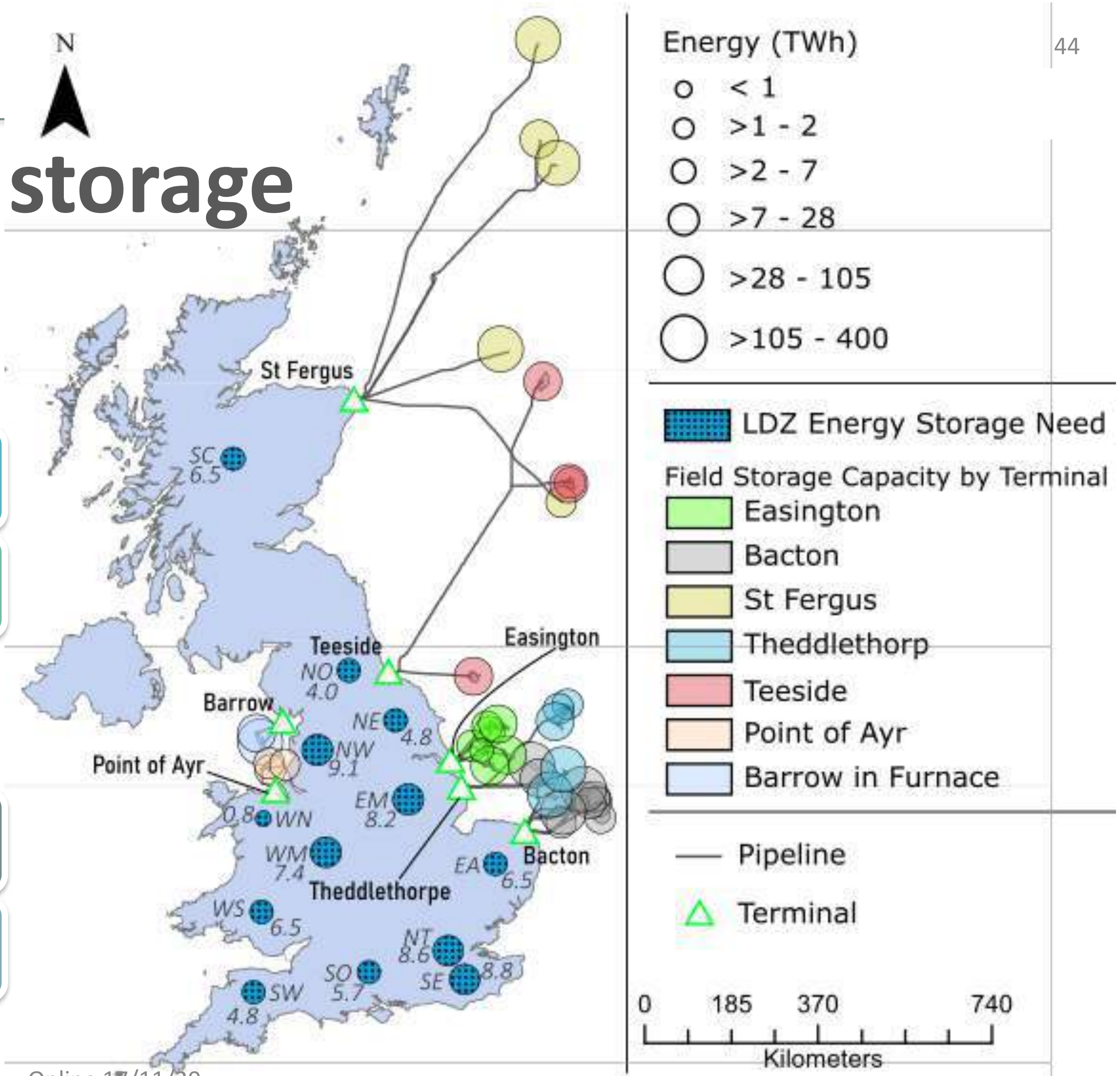
100's of TWh of theoretical hydrogen storage capacity in depleted gas fields directly connected to UK gas terminals.

These are first stage static volumetric capacity estimates. They do not take into account recovery efficiencies etc.

- The methodology uses the original gas in place and recoverable gas data for each field and as such can be considered a reasonable proxy for estimating the dynamic recovery capacity of hydrogen in the reservoir.
- It is however not a replacement for accurate and history matched recovery data and matched capacity estimates

Limited competition with other subsurface geo-energy applications, such as CCS or geothermal.

Switching from natural gas to hydrogen will reduce the storage capacity of existing energy storage facilities by about 2/3rd



Data courtesy of Julien Mouli-Castillo (julien.moulicastillo@ed.ac.uk), University of Edinburgh

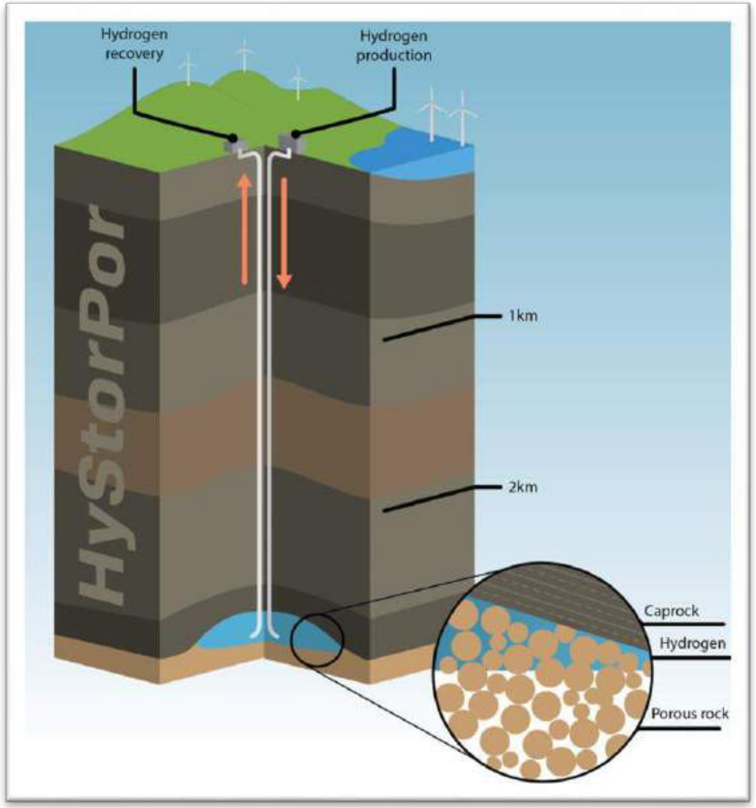
Worldwide Underground hydrogen storage experience

	Type	Gas (%)	p/T	Volume (m^3)	Capacity (sm^3)	Depth (m)	Start-up	Status
Germany								
Ketzin	Aquifer	CO_2 62 % H_2	-	-	-	200-250	-	closed
Kiel	Salt cavern	62 % H_2	80-100 bar	32,000	-	-	-	operating with natural gas
United Kingdom								
Teesside	Salt cavern	95 % H_2 3-4 % CO_2	50 bar	-	1.000.000	400	1959	operating
USA								
Spindletop	Salt cavern	95 % H_2	-	906,000	-	1,340	-	operating
Clemens Dome	Salt cavern	95 % H_2	70-135 bar	580,000	30.000.000	1,000	1980s	operating
Moss Bluff	Salt cavern	-	-	566,000		1,200	2007	operating
France								
Beynes	Aquifer	50 % H_2	-	-	385.000.000	430	1956 - 1972	operating with natural gas
Czech Republic								
Lobodice	Aquifer	50 % H_2 25 % CH_4	90 bar / 34°C	-	-	430	1965	operating
Argentina								
Diadema (Hychico)	Depleted gas reservoir	10 % H_2	10 bar / 50°C	-	-	600	2009	-
Austria								
Underground Sun Storage	Depleted gas reservoir	10% H2	78 bar / 40 °C		1.150.000	1000	2015 - 2017	operating

From the Netherlands Enterprise Agency Publication number: RVO-079-1701/RP-DUZA and https://www.energy.gov/sites/prod/files/2020/01/f70/fcto-fcs-h2-scale-2019-workshop-19-meeks.pdf

Caprock integrity? Pore blocking reactions?
Bacterial consumption? Recovery efficiencies?
Gas segregation? Cushion gas mixing?
Well integrity? Reliability of operational facilities?
How can I communicate our hydrogen research effectively? ….

HyStorPor Project Goals: Fundamental understandings



To identify if **biological and chemical reactions** between the rock, fluids, cushion gas and hydrogen could compromise storage.

To determine what **flow processes** will influence hydrogen migration and trapping during injection and withdrawal.

Reservoir simulations to estimate what volumes of hydrogen can be stored and recovered from storage sites of varying scales.

To **clarify what citizens and opinion shapers think about hydrogen storage.**

Need all the tools in the tool box....

Electric vehicles

Carbon capture and storage

Fuel cell vehicles

Reduce waste

Peatland restoration

Batteries

Electrification

Energy efficiency

Direct air capture of CO_2

Thermal storage

Consumer behaviour

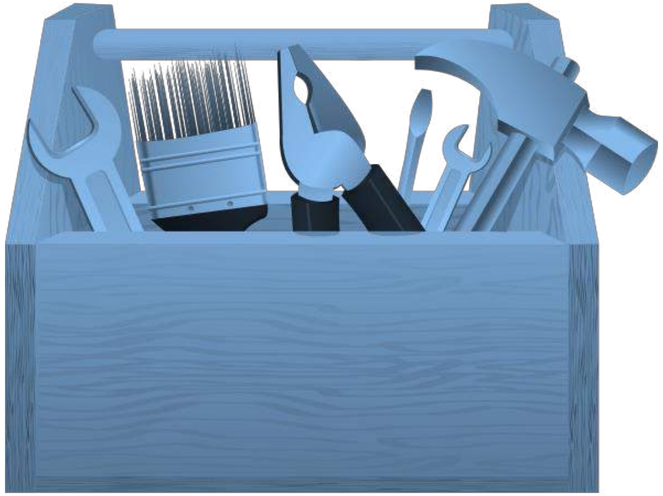
Reuse/recycle

afforestation

Flywheels

Ammonia

Hydrogen



Compressed air energy storage

Nuclear

Heat pumps

Magnetic

Biomass

Pumped hydro

Supercapacitors

Heat networks

Geothermal

Salt caverns

Tidal

Solar PV

Porous media storage

Wind

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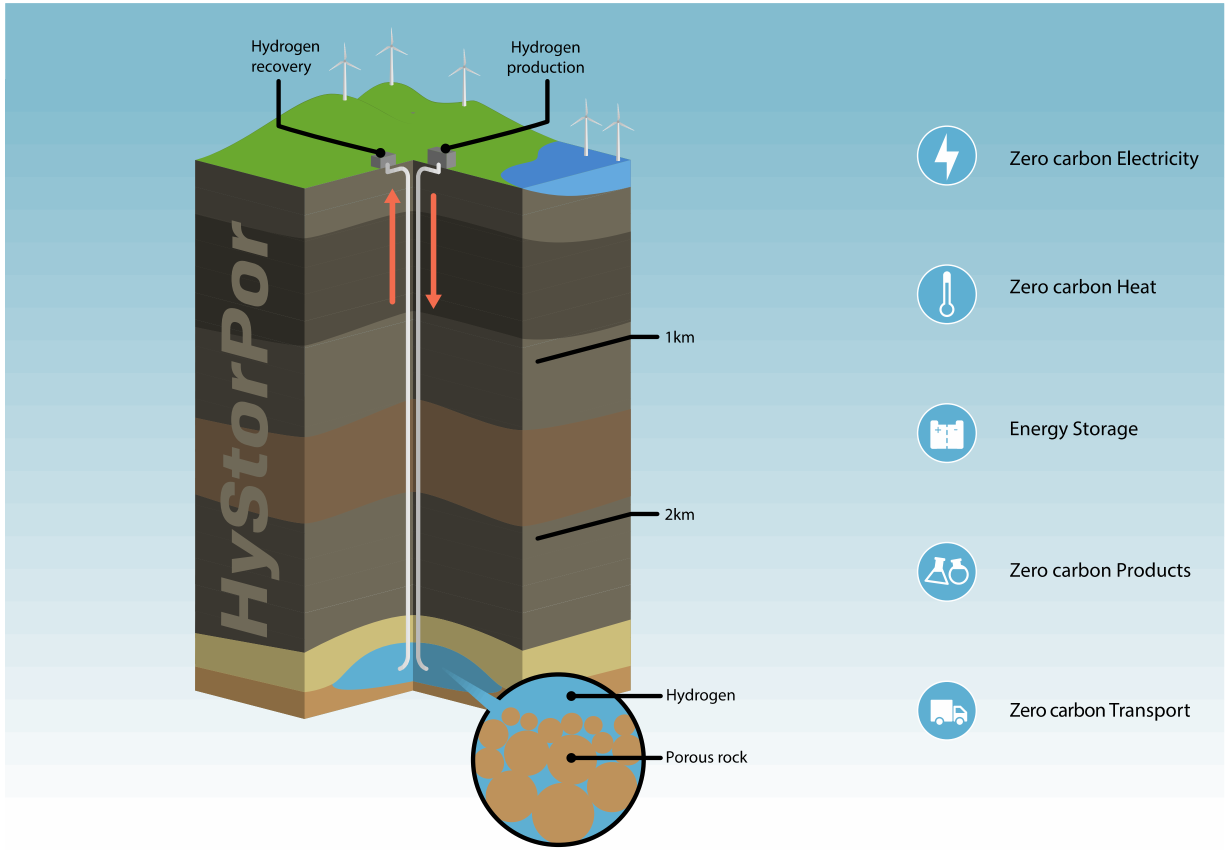

Session 1 Panel Discussion

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Break / Poster session
14:10-14:25

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Session 2: Hydrogen Economy

Chair: Stuart Haszeldine, University of Edinburgh

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14:10 – 14:25 Break / Poster Session

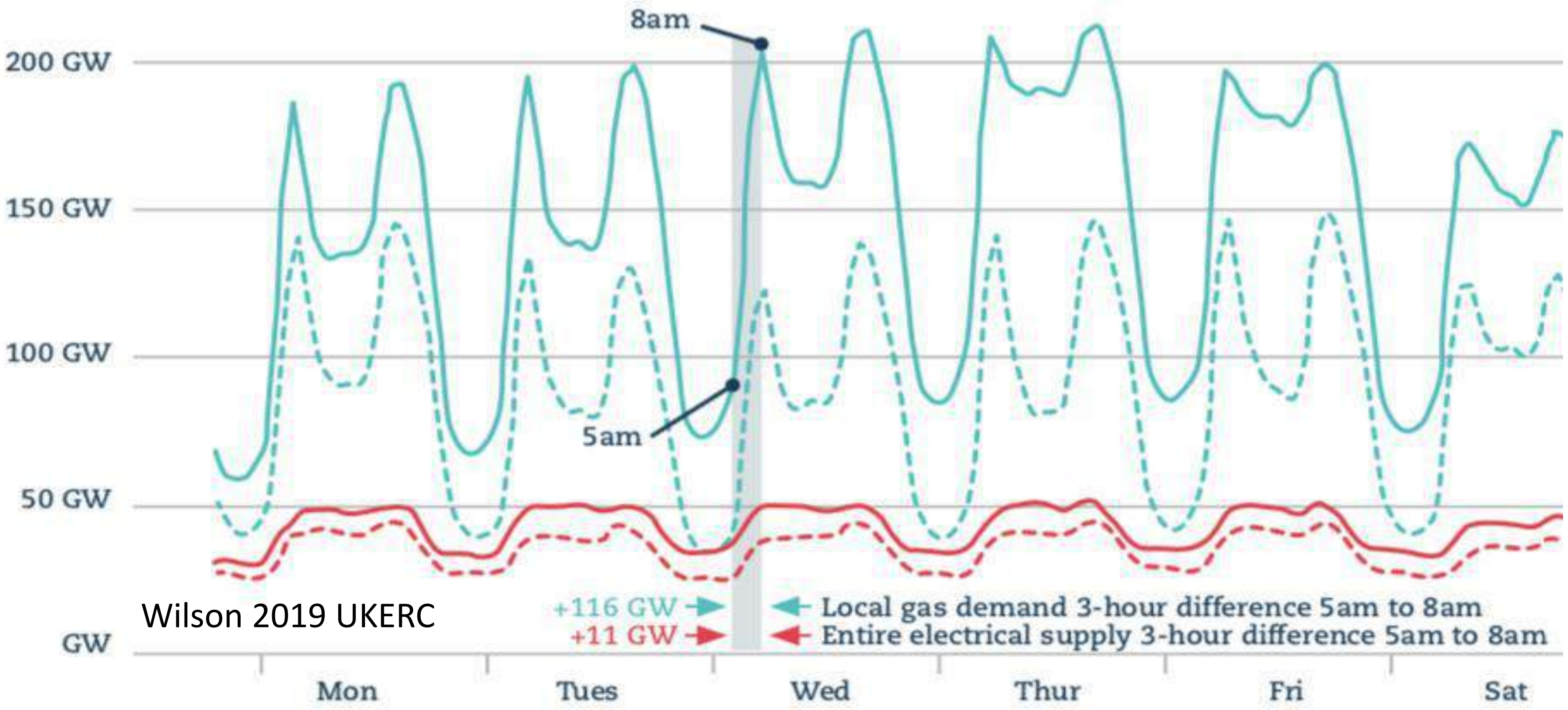
Session 2 – Hydrogen Storage
Chair: Stuart Haszeldine
14:25 – 14:35 Stuart Haszeldine, University of Edinburgh
14:35 – 14:50 Grégoire Hévin, Storengy
14:50 – 15:05 Simonas Cerniauskas, Jülich
15:05 – 15:20 Katriona Edlmann, HyStorPor
15:20 – 15:45 Panel Discussion

15:45 – 15:55 Closing remarks

Hydrogen Storage in Porous Media
What is the purpose ?

Professor Stuart Haszeldine, University of Edinburgh

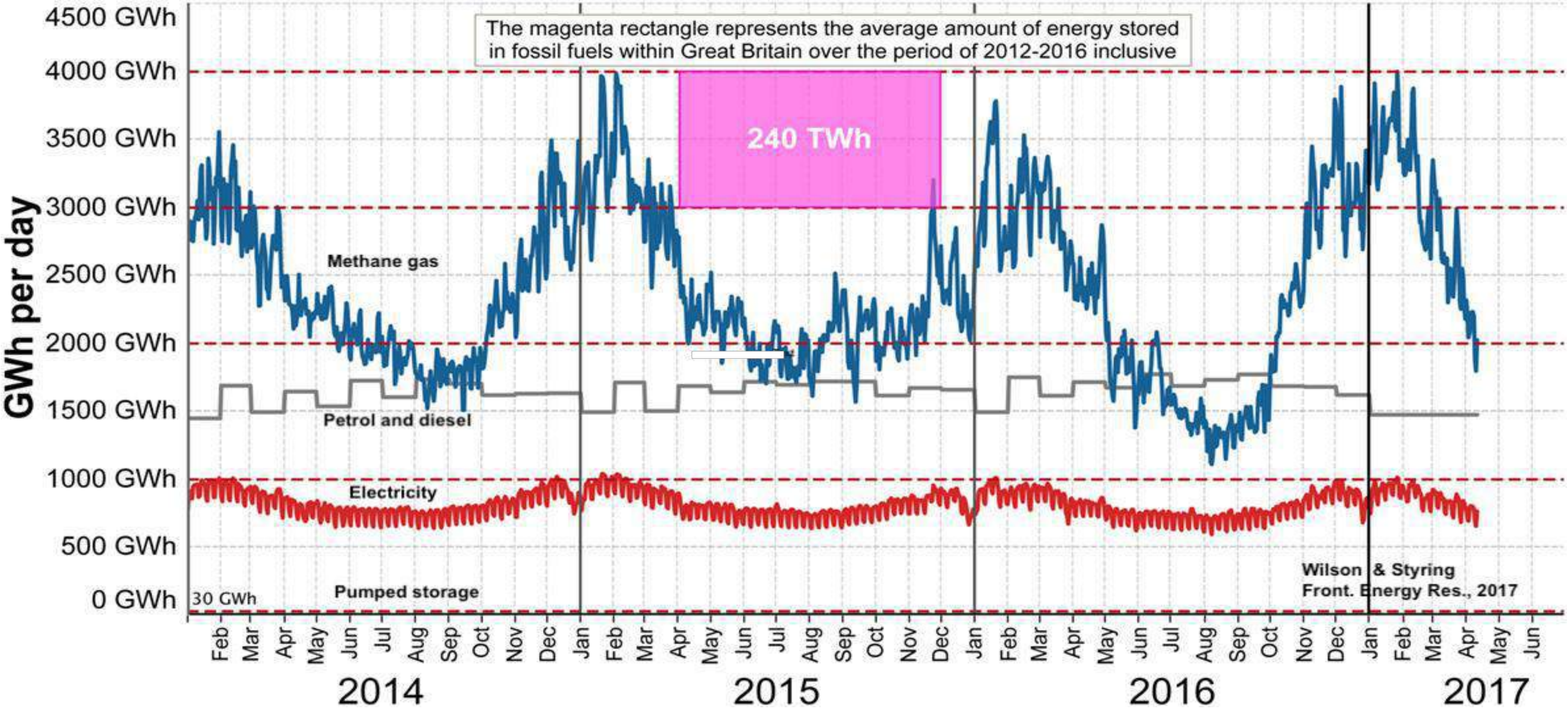
Daily need for massive gas storage -linepack
Max - Feb 2017, mode Jan 2017



Wilson 2019 UKERC

HysStorPor

Seasonal need for massive energy (gas) storage



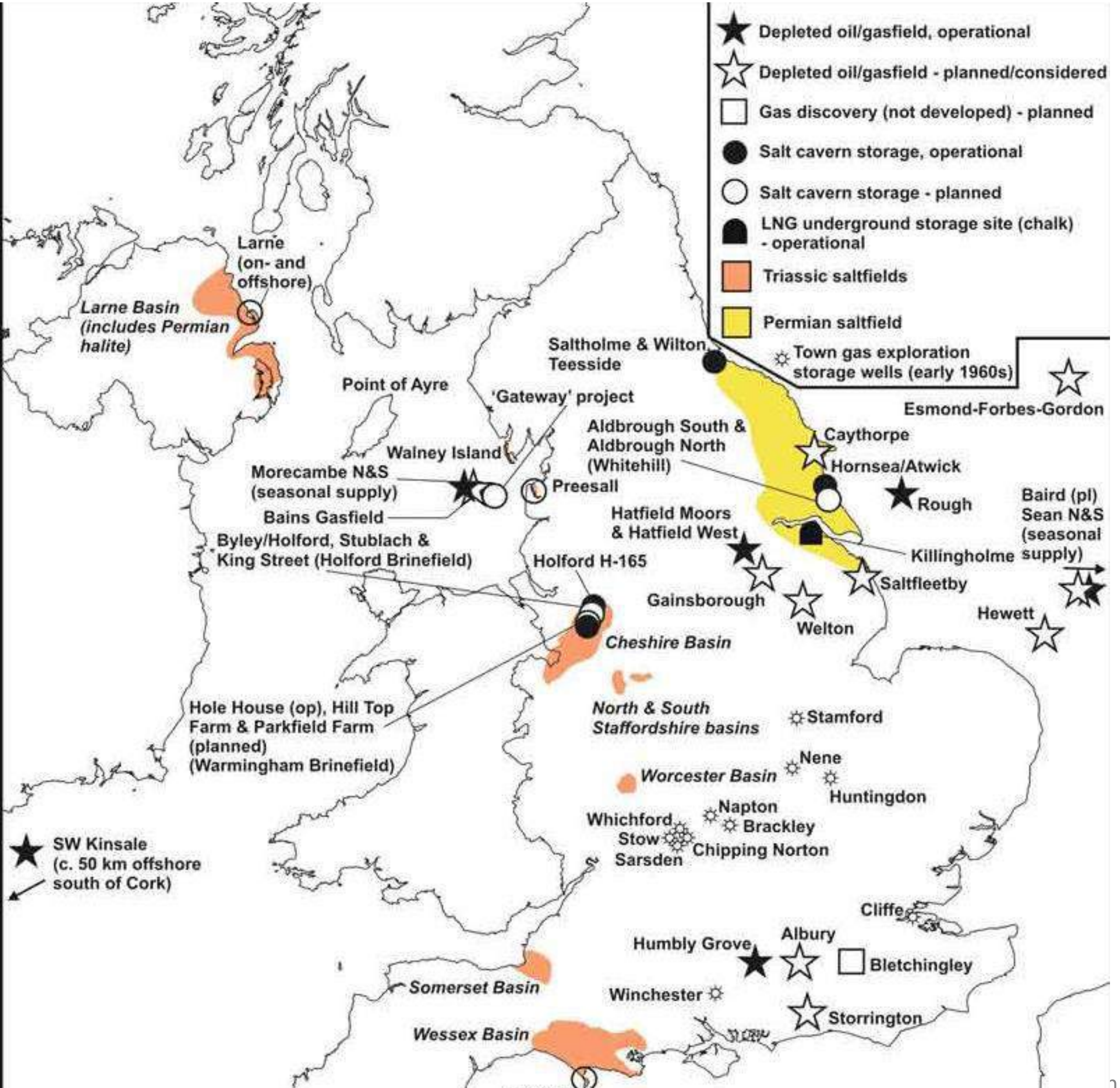
UK storage - (with batteries !)

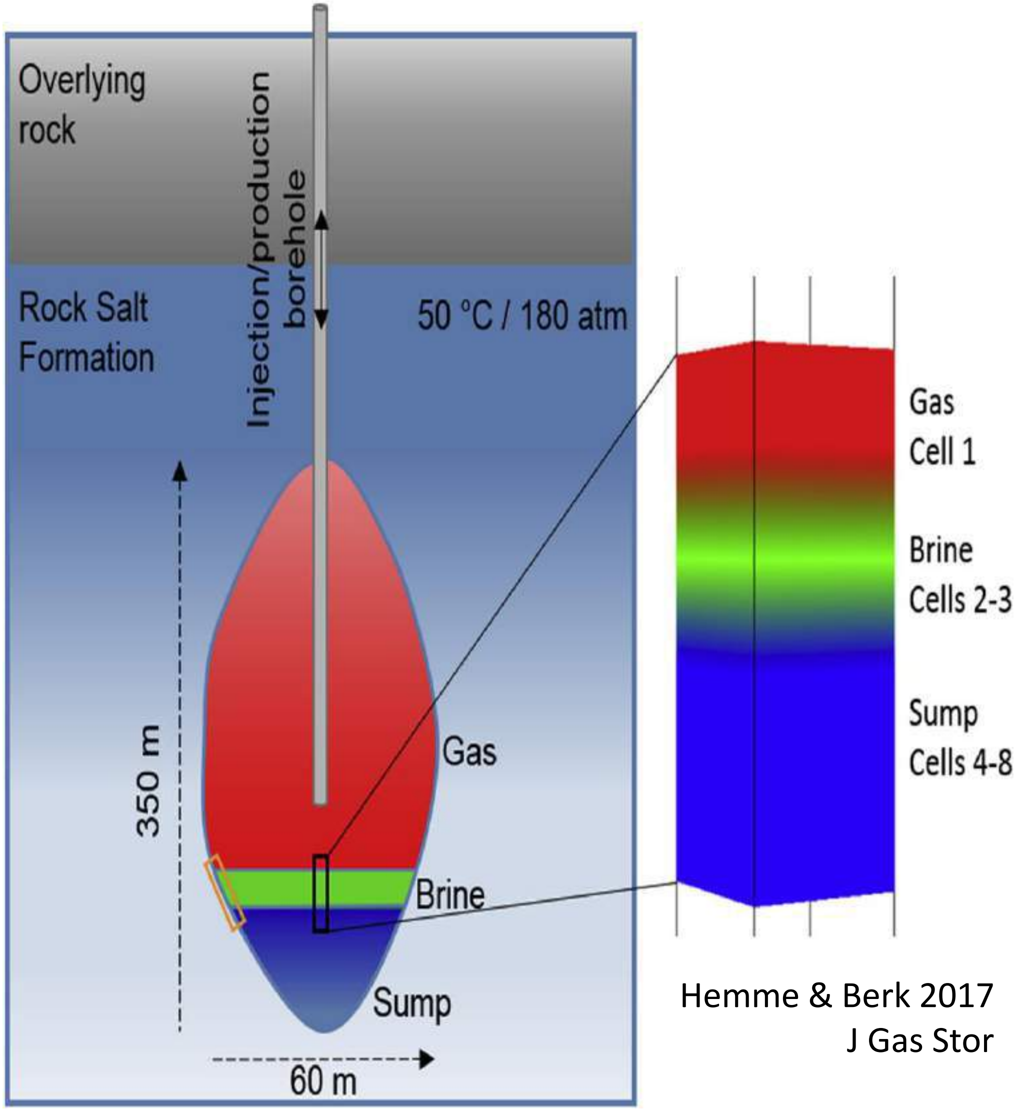
Gresham House said that it has completed its investment in the 50MW / **75MWh** Thurcroft battery storage site in South Yorkshire, which is in northern England. Energy Storage news 4Nov 2020

Construction work has begun on Technology provider Highview Power's 50MW / **250MWh** liquid air energy storage (LAES) facility in Greater Manchester, England, together with UK-based independent power station developer Carlton Power and is to enter into commercial operation in 2023, HighViewPower.com. 6Nov2020

Another 400,000 CryoBatteries needed …. ?

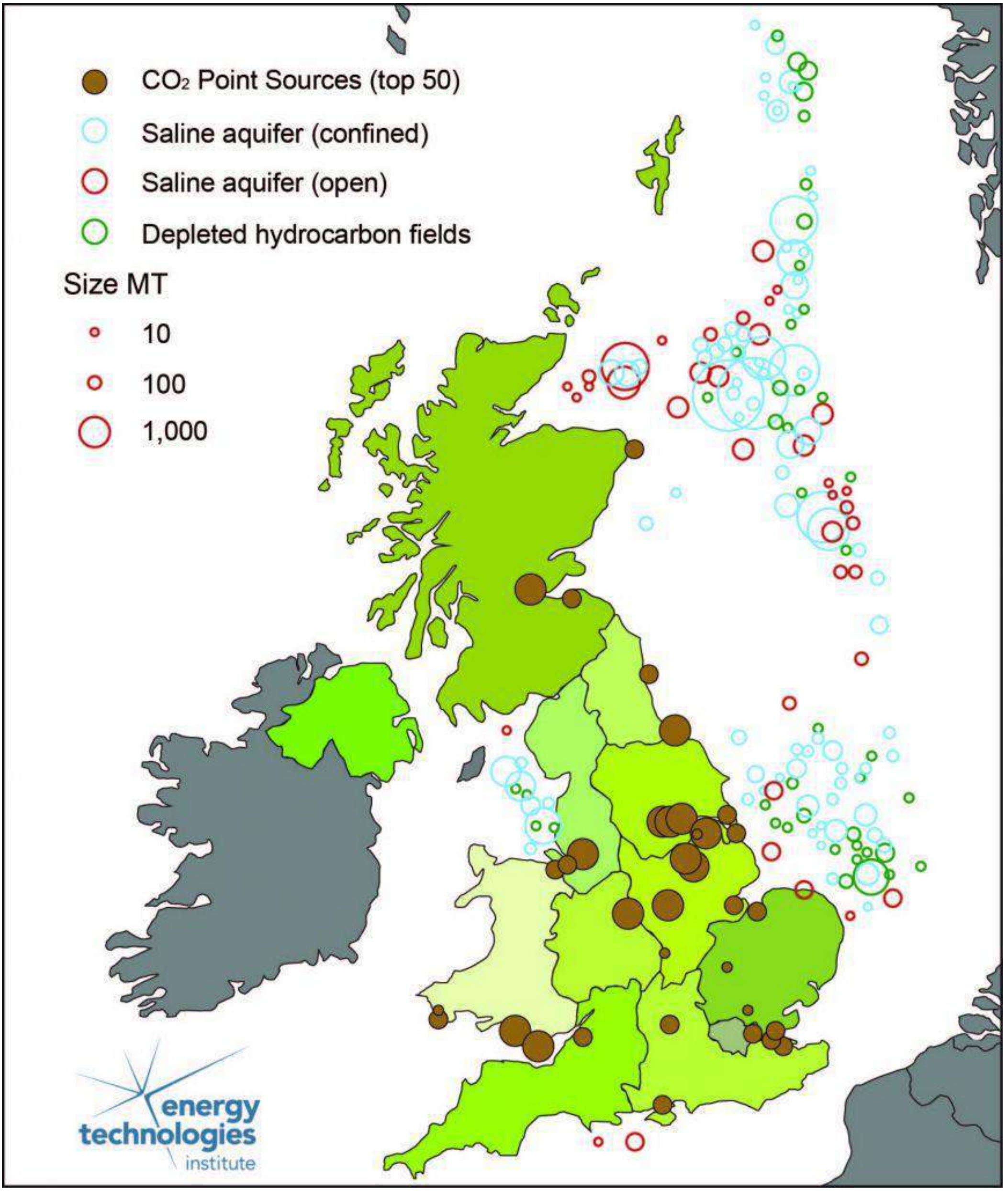
Storage of gas Underground in salt

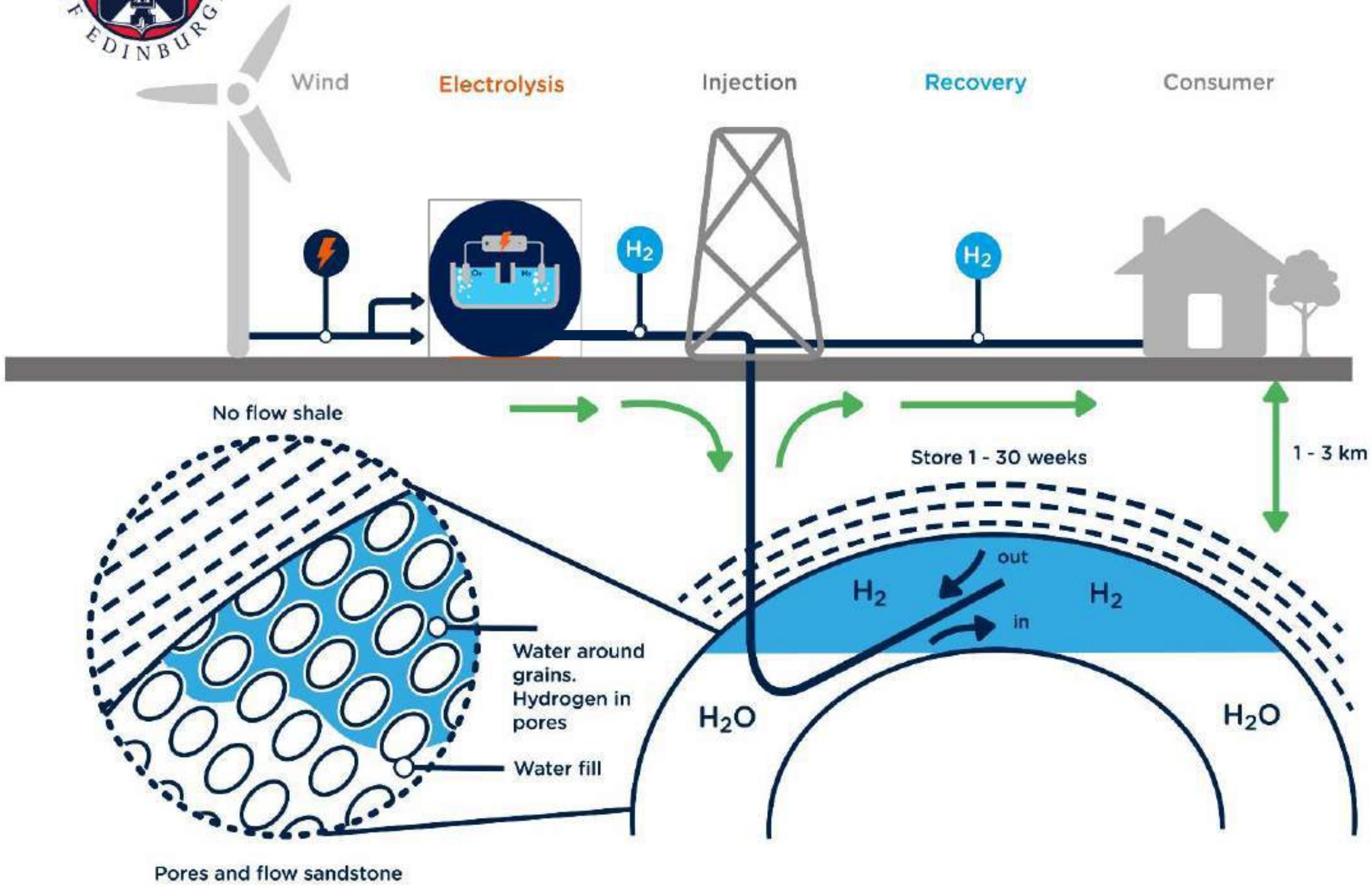




Hemme & Berk 2017
J Gas Stor

Gas in Sandstones

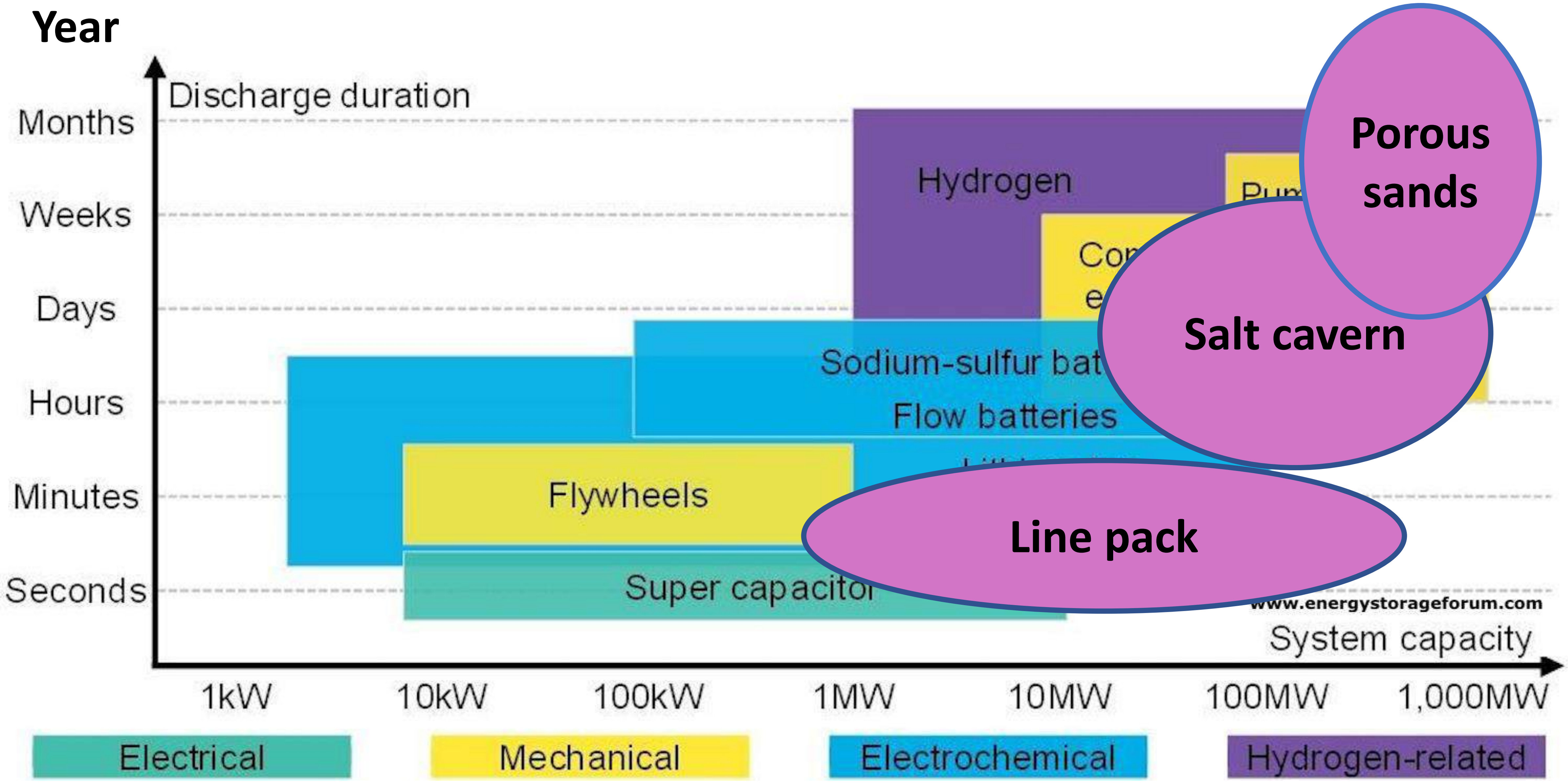




Abundant porous sandstones and gas fields offshore around UK, and small gas fields onshore. Could be re-used

Energy storage

Construction work has begun on Technology provider Highview Power's 50MW / **250MWh** liquid air



HyStorPor : publications

Thermodynamic and transport properties of hydrogen containing streams./ H2ThermoBank software
Hassanpouryouzband, A., Joonaki, E., Edlmann, K., Heinemann, N. and Yang, J., 2020.
Accurate estimation of the thermodynamic and transport properties of H2 mixed with other gases
Nature *Scientific Data*, *7*(1), pp.1-14.

Gas hydrates in sustainable chemistry
Hassanpouryouzband, A., …..Edlmann, K. 2020
Chem. Soc. Rev., 2020, **49**, 5225-5309
properties of gas hydrates as well as their formation and dissociation kinetics and effects of chemical additives

Estimating Microbial Hydrogen Consumption in Hydrogen Storage in Porous Media as a Basis for Site Selection. In review 2021. Eike M Thaysen, Sean McMahon, Gion Strobel, Ian Butler, Bryne Ngwenya, Niklas Heinemann, Mark Wilkinson, Ali Hassanpouryouzband, Chris McDermott, Katriona Edlmann.
https://eartharxiv.org/repository/view/1799/

Mapping geological hydrogen storage capacity and regional heating demands: An applied UK case study.
In review in Applied Energy 2021. Mouli-Castillo, J., Heinemann, N., Edlmann, K.,

Estimating Microbial Hydrogen Consumption in Hydrogen Storage in Porous Media as a Basis for Site Selection.
Submitted to Renewable and Sustainable
Energy Reviews. 2021 Thaysen, E., McMahon, S., Strobel, G., Butler, I., Ngwenya, B., Heinemann, N., Wilkinson, M., Hassanpouryouzband, A., McDermott, C., Edlmann.K.,

Industry Workshop: Hydrogen Infrastructure for a Decarbonised Energy System

17 November 2020; 13:00 – 17:00 (GMT)
This workshop organised by the HyStorPor project will bring together experts from industry and academia to discuss the development of the hydrogen economy. This includes the need for substantial infrastructure to connect hydrogen production with users, and to provide large-scale hydrogen storage to balance supply with demand.

HyStorPor : related publications

Seasonal storage of hydrogen in a depleted natural gas reservoir. Amid, A., Mignard, D. and Wilkinson, M., 2016. *International journal of hydrogen energy*, *41*(12), pp.5549-5558.

Hydrogen storage in porous geological formations–onshore play opportunities in the midland valley (Scotland, UK). Heinemann, N., Booth, M.G., Haszeldine, R.S., Wilkinson, M., Scafidi, J. and Edlmann, K., 2018. *International Journal of Hydrogen Energy*, *43*(45), pp.20861-20874.

Quantitative Risk Assessment Of A Domestic Property Connected To A Hydrogen Distribution Network 2021 J. Mouli-Castillo, Haszeldine, R.S., Kinsella K., Wheeldon, M. and McIntosh, A., *International Journal of Hydrogen Energy*, *Submitted*

Olfactory appraisal of odorants for 100% hydrogen networks. 2020 Mouli-Castillo, J., Bartlett, S., Murugan, A., Badham, P., Wrynne, A., Haszeldine, S., Wheeldon, M. and McIntosh, A., *International Journal of Hydrogen Energy*. 45, 11875-11884

Calculating porous rock hydrogen storage capacity from national carbon storage databases. 2021 Int J HydrEnergy. Scafidi, J. Wilkinson, M, Gilfillan, S.M.V. Haszeldine, R.S. In review

Porous rock hydrogen storage capacity in an onshore depleted gasfield - Cousland . 2021 [Scafidi, J. Wilkinson, M, Gilfillan, S.M.V. Schirrer, L. Haszeldine, R.S.]. Int J Hydrogen Energy. In preparation

Enabling large-scale hydrogen storage in porous media – the scientific challenges. 2021 Niklas Heinemann, Juan Alcalde, Johannes M. Miocic, ……. Aliakbar Hassanpouryouzband, ……..Katriona Edlmann, Mark Wilkinson, Eike Marie Thaysen, ….. R. Stuart Haszeldine, ….. *Energy Environmental Science. In review*

Comparative evaluation of battery electric and hydrogen fuel cell electric vehicles for zero carbon emissions road vehicle fuel in Scotland. 2021 Low, J., Haszeldine, S. and Mouli-Castillo, J., in preparation. https://engrxiv.org/dcjrt/

Partners

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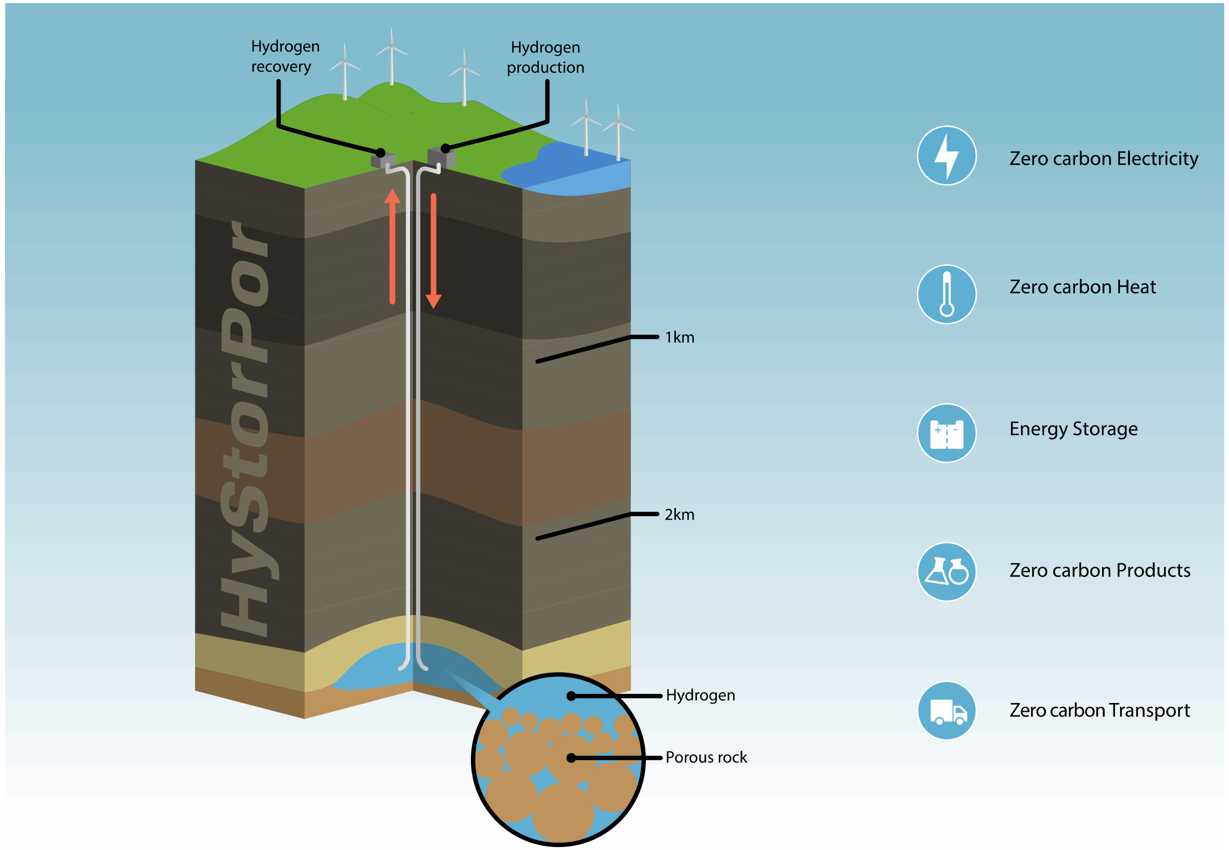
Imperial College London

SAMS



Underground storage of Hydrogen in salt caverns

HyStorPor November 17th 2020

Dr. Grégoire Hévin – Storengy

1

Underground Gas Storage in Salt Caverns

What is it ?

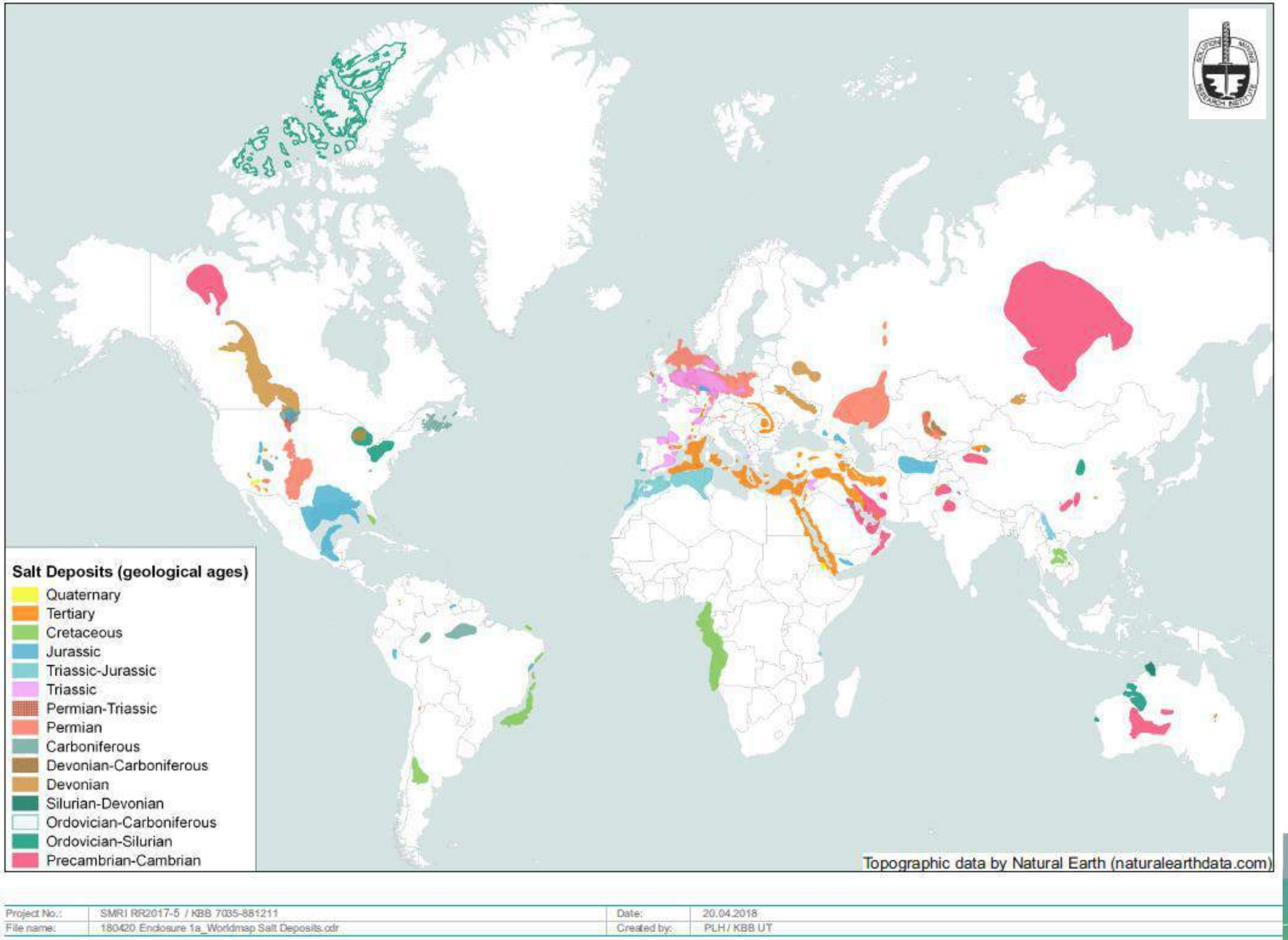
The Salt

Sodium Chloride - NaCl - Halite

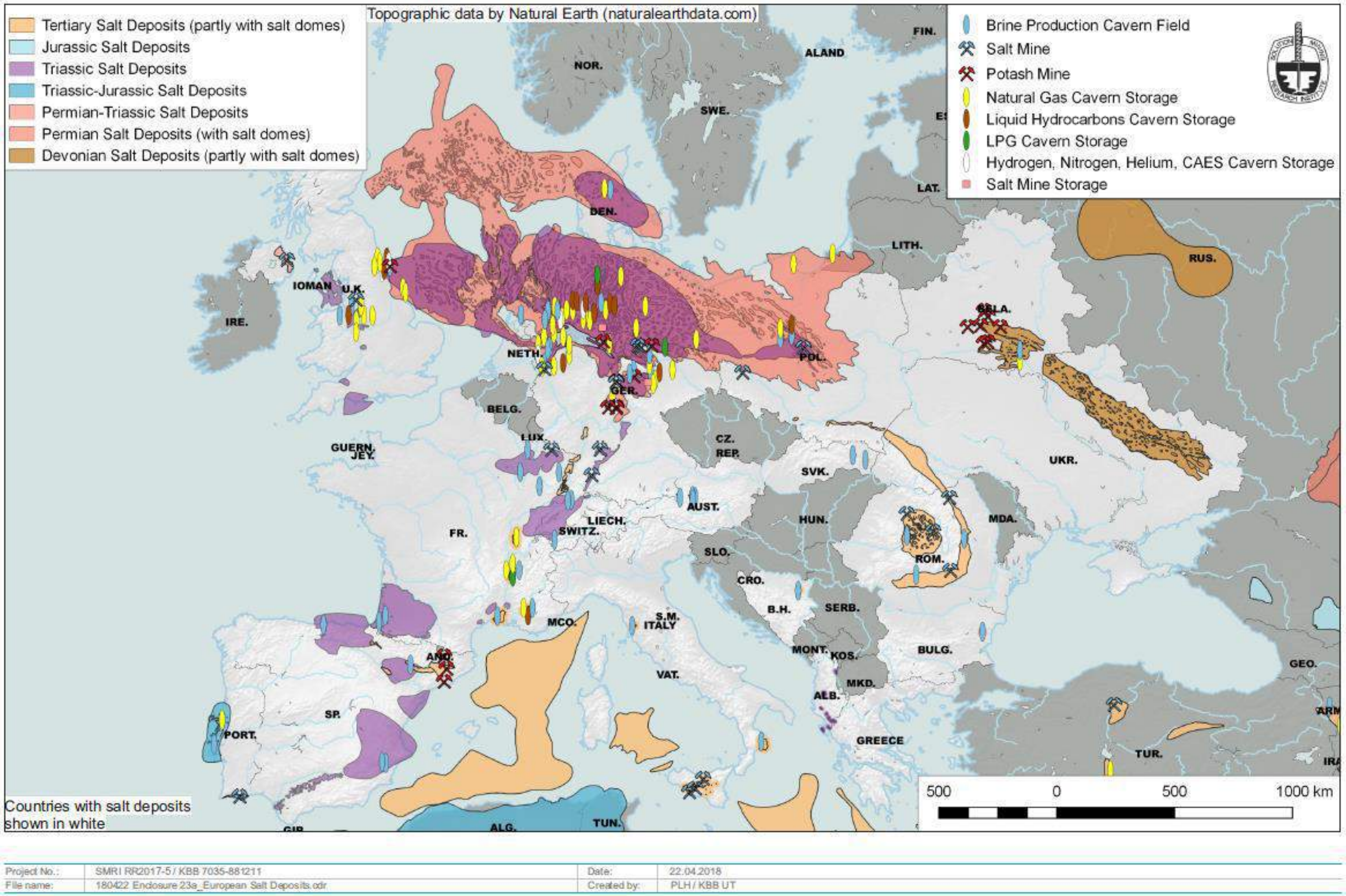
2 major properties of rock salt :

- Naturally very **tight**
- **Soluble** in water

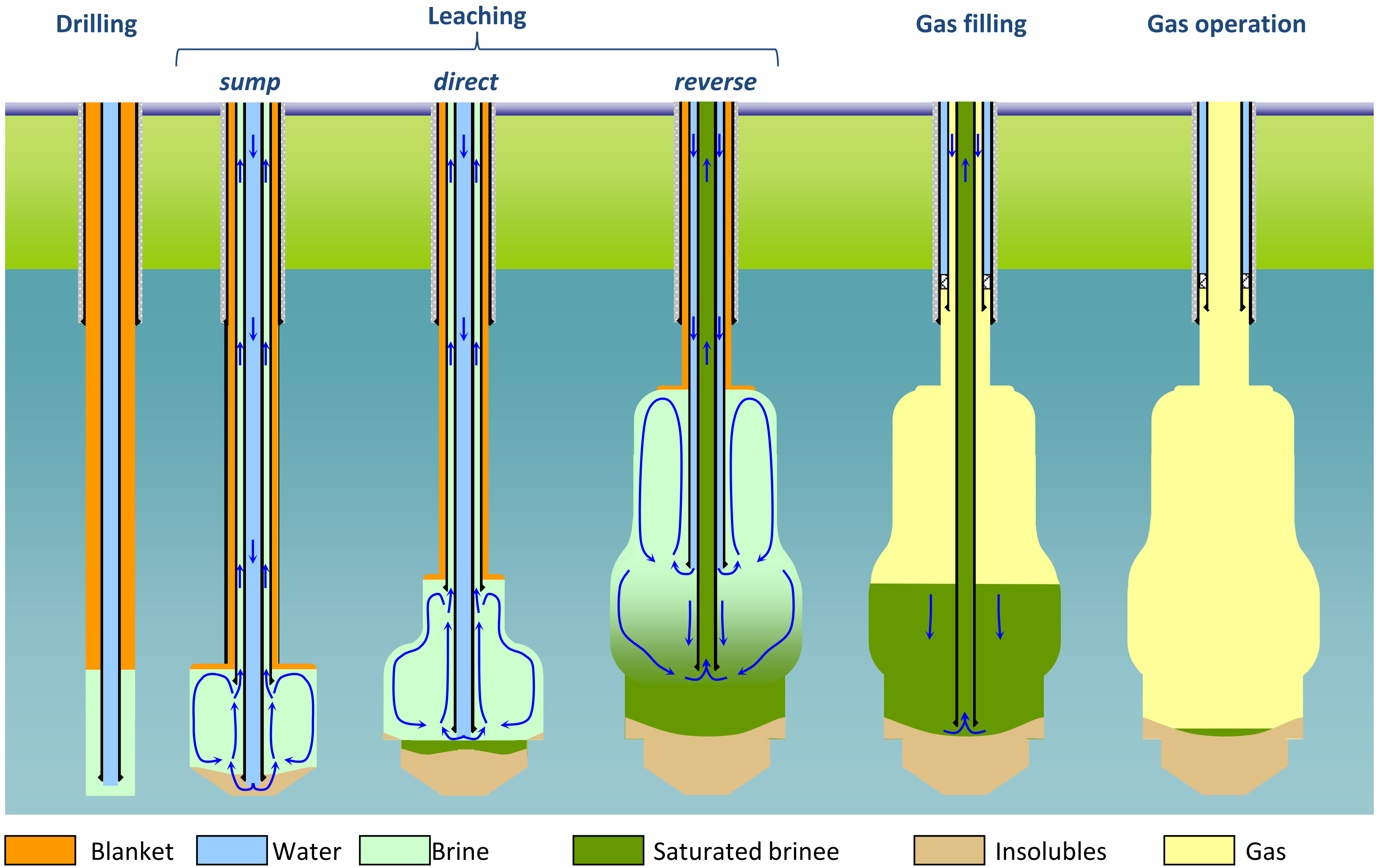
Salt deposits in the world



Salt deposits and cavern fields in Europe



Steps of cavern creation



Example of Gas storage Cavern Design

Salt Cavern in
Stublach site
(Cheshire)

V= 350 000 m3

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2 Challenges for hydrogen caverns

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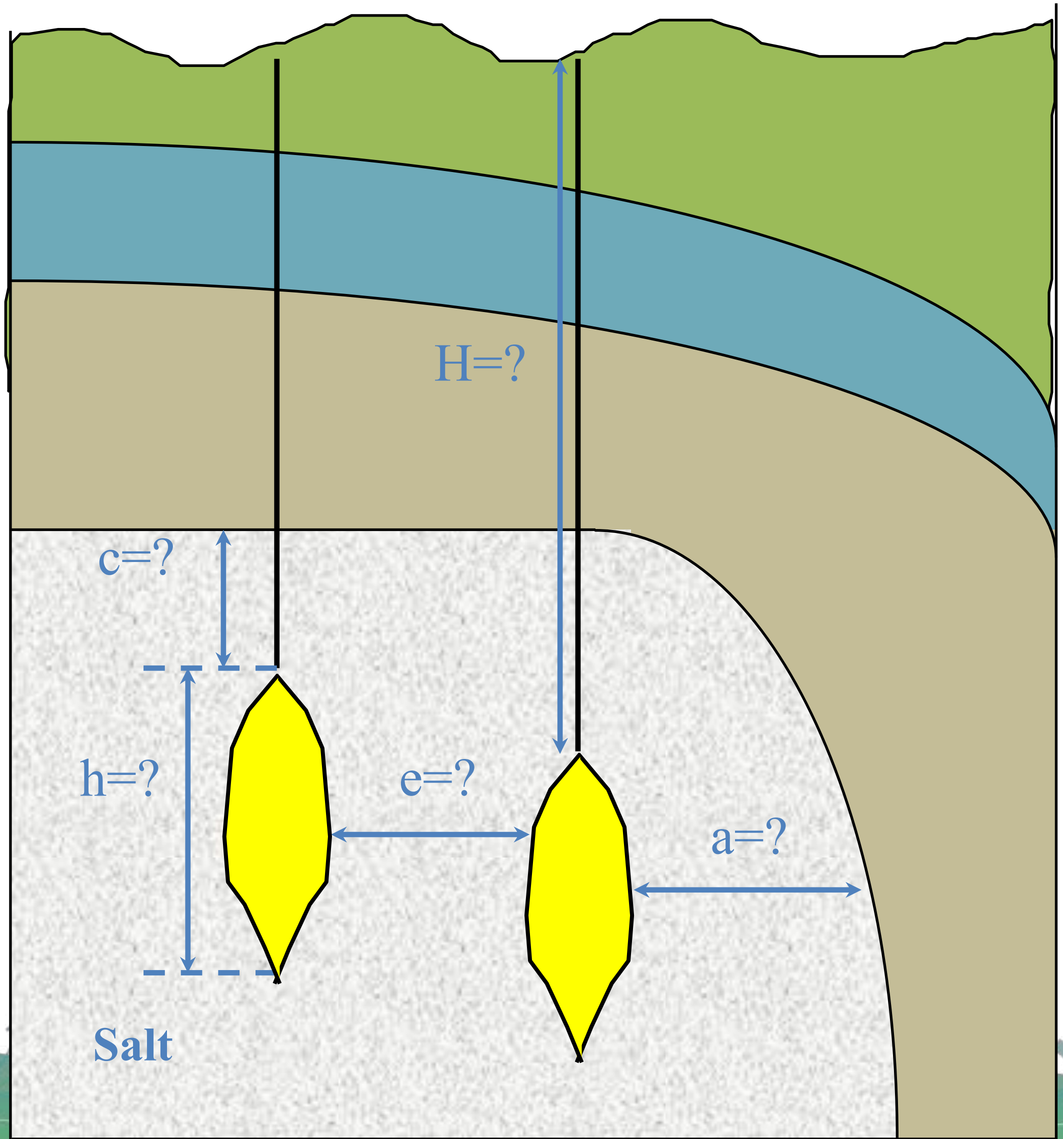
Question of Design

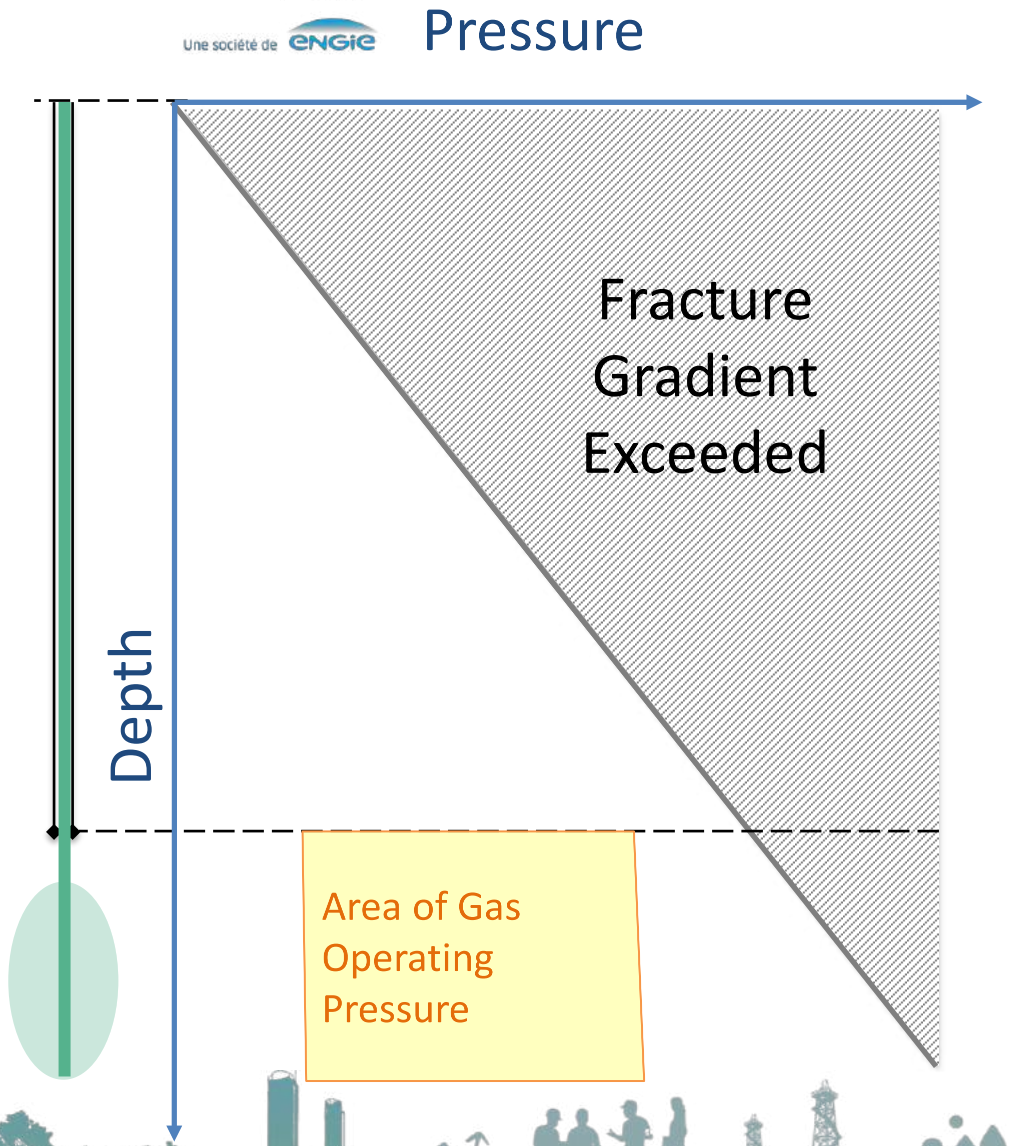


LOCATION ?

DEPTH ?

VOLUME ?

WELL DESIGN ?



Example:
What how to fix operating pressure ?

- The Maximum and Minimum Operating Pressure are **imposed by cavern depth**

3 Hydrogen in salt cavern

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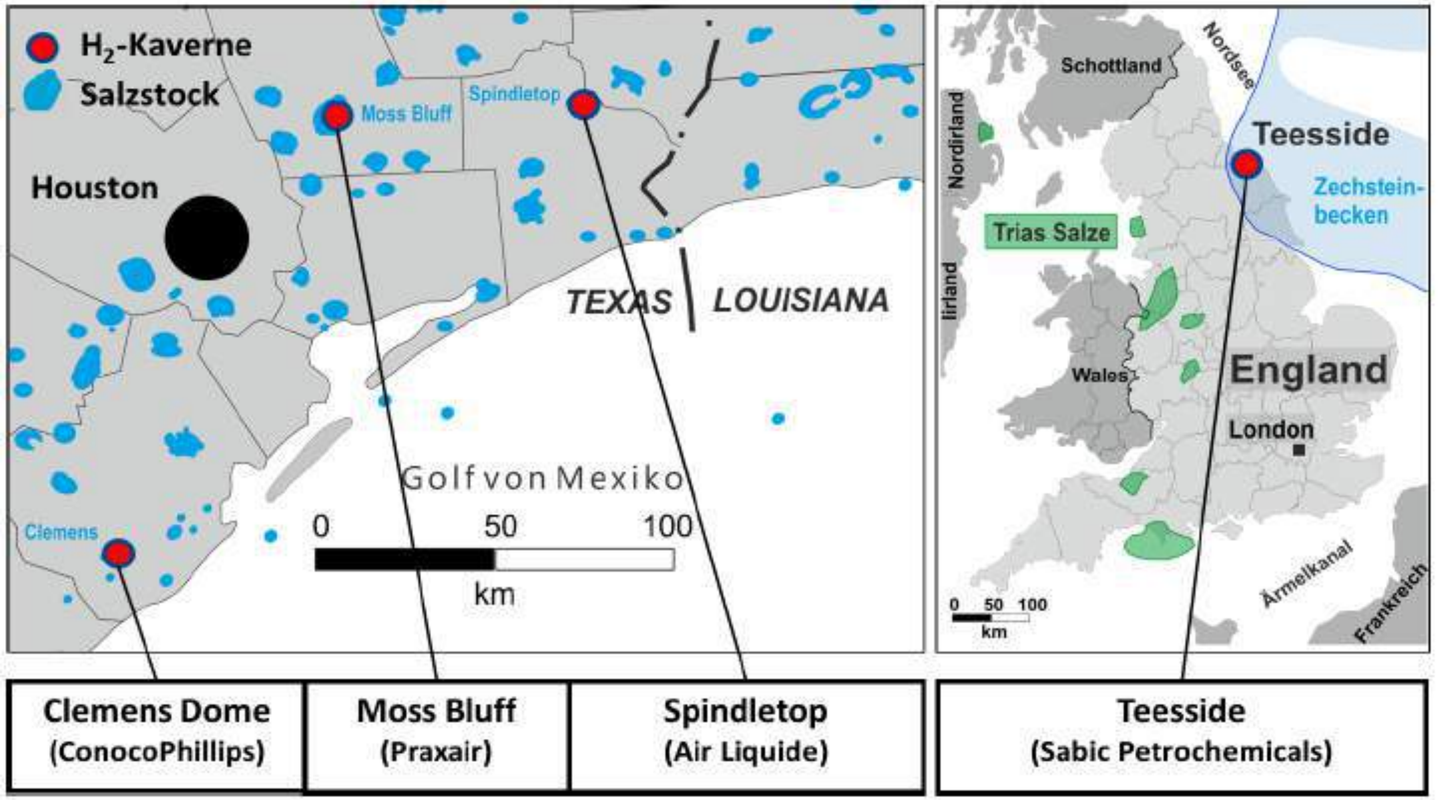
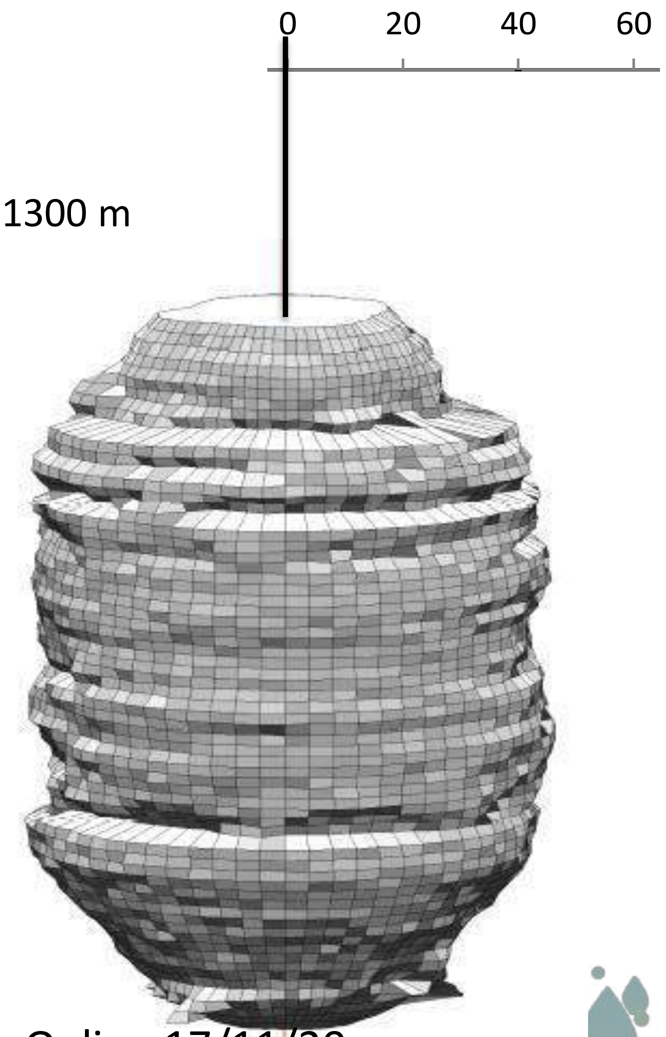
4 sites of Hydrogen Storage in Salt Caverns in the world

Localisation	Clemens Dome (US)	Moss Bluff (US)	Spindletop (US)	Teeside (UK)
Operator	Conoco Philips	Praxair	Air Liquide	Sabic
Start	1983	2007	2014	1972
Volume (10^3 m^3)	580	566	>580	3*70
Pressure (bar)	70-135	55-152	Confidential	45
Energy (GWh)	92	120	>120	25



Potential for Hydrogen storage in a real cavern in France



Online 17/11/20

Geometrical Volume :

570 000 m3

Volume of Hydrogen

- **Total stock :** 100 000 000 Nm3
- **Usable stock :**

- 70 000 000 Nm3
- 250 GWh
- 6 300 tons H_2

- **Pmin :** 60 bar
- **Pmax :** 240 bar

Advantages of hydrogen salt cavern storage

- High Reactivity (from days to season)
- Safety (in comparison with surface storage solutions)
- Experience of more than 40 years of natural gas storage in salt cavern
- Adapted or adaptable size

Thank you

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STOPIL-H_2

Development of a industrial pilot of hydrogen storage in a real salt cavern in France

Consortium:

storengy, AIR LIQUIDE, GEOSTOCK ENTREPOSE, BROUARD CONSULTING, ARMINES, INERIS, brgm

Co-funding:

INVESTISSEMENTS D'AVENIR, GEODENERGIES – Le sous-sol pour la transition énergétique

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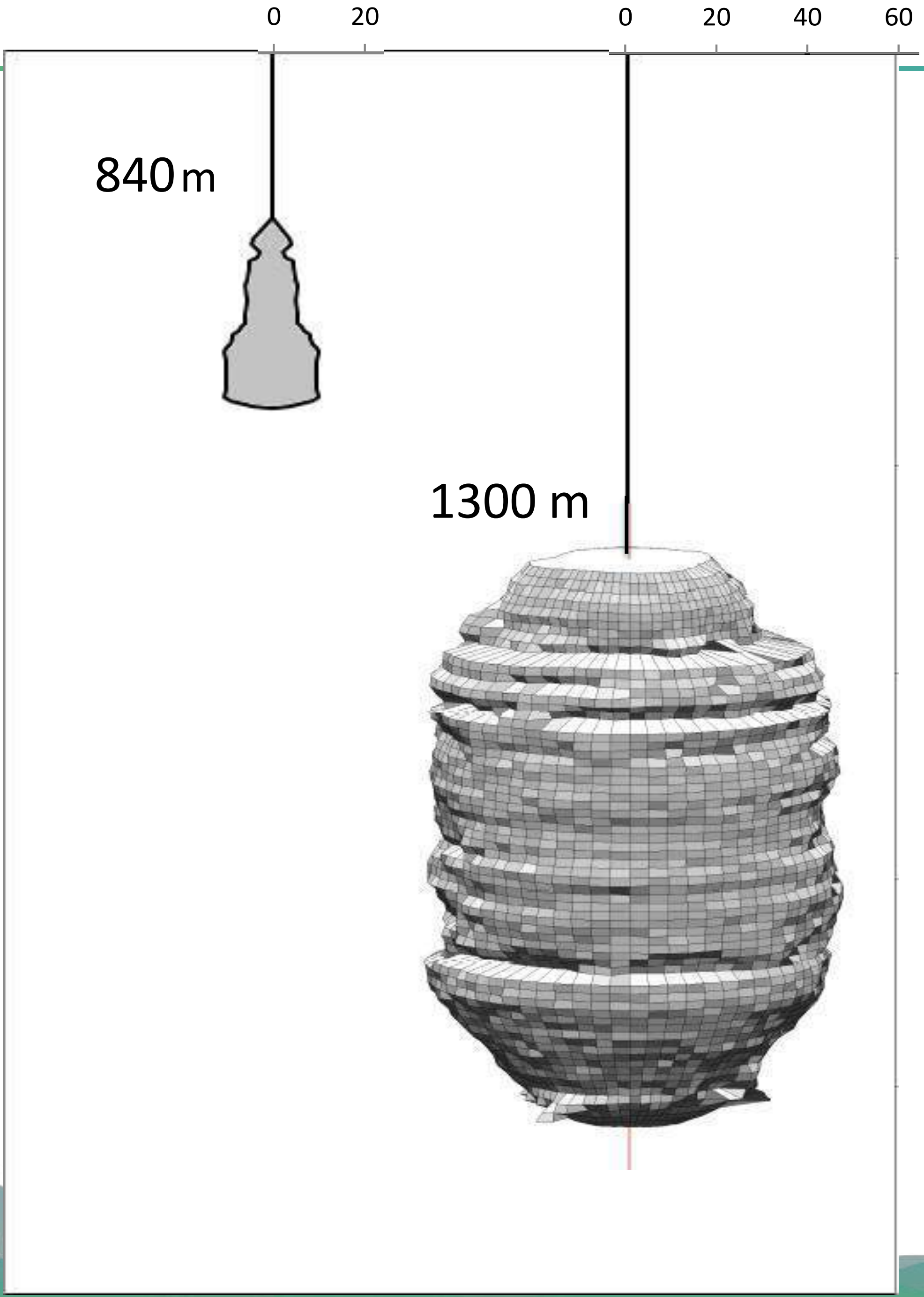


Geometric volume :

7 000 m3

Hydrogen volume

- **total :** 900 000 Nm3
- **usable :**
  - 500 000 Nm3
  - 1.7 GWh
  - 44 tons H_2
- **Pmin** : 60 bar
- **Pmax** : 165 bar

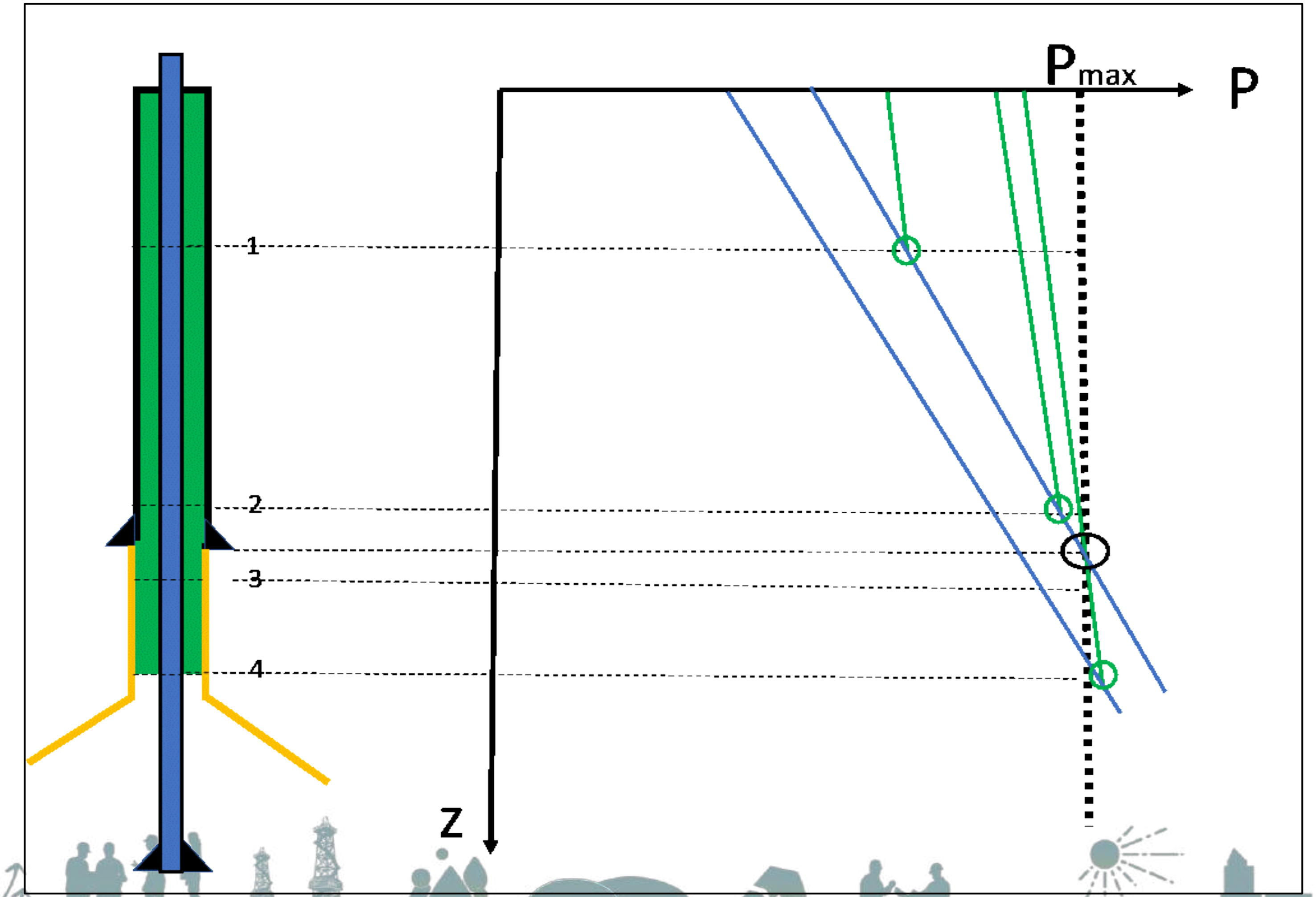
Geometric volume :

570 000 m3

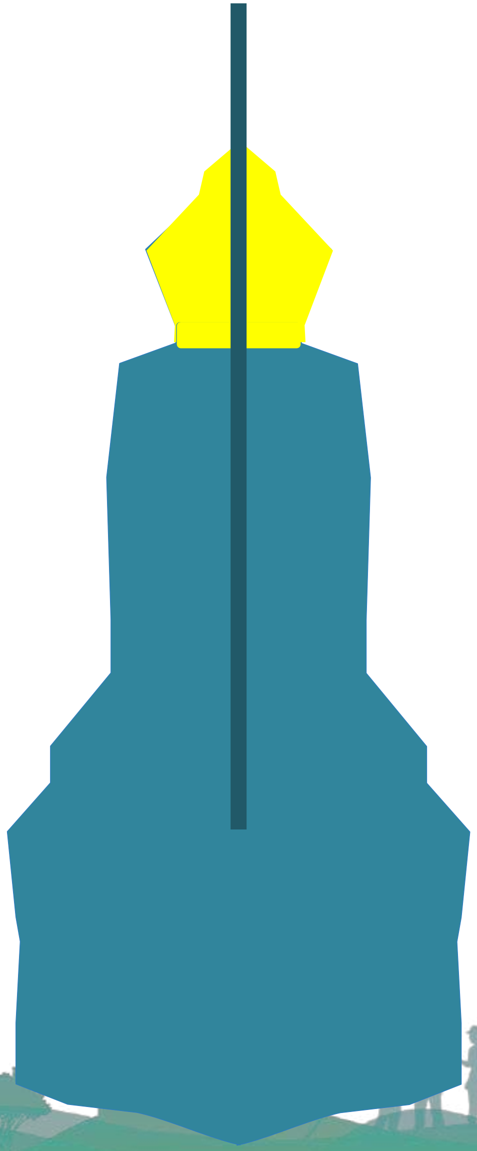
Hydrogen volume

- **total :** 100 000 000 Nm3
- **usable :**
  - 70 000 000 Nm3
  - 250 GWh
  - 6 300 tons H_2
- **Pmin :** 60 bar
- **Pmax :** 240 bar

Tightness test for STOPIL H2 : 4 steps of test



Hydrogen cycling



- Pressure variations of hydrogen by injection and withdrawal of brine
- Simulation of different cycles
- Final withdrawal of hydrogen

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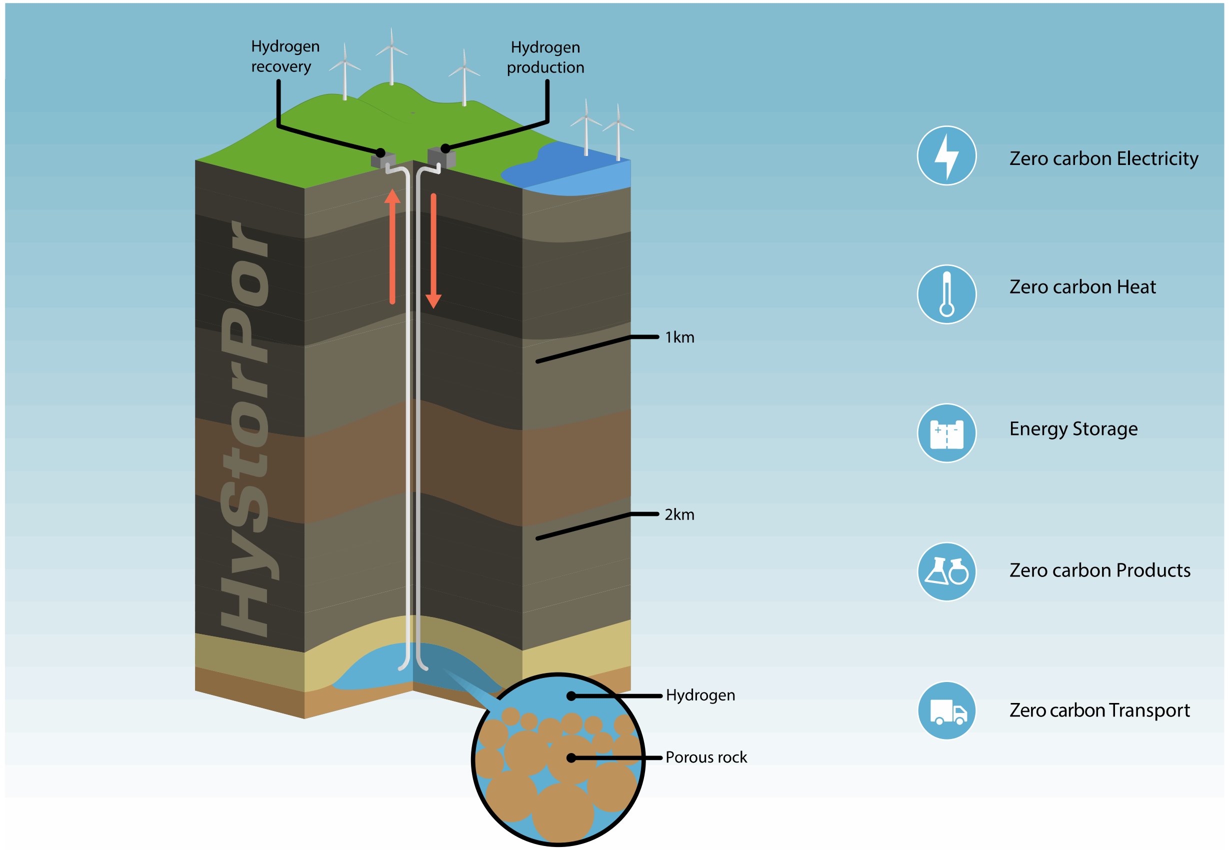
Imperial College London

SAMS



Large scale hydrogen storage in porous rocks

Learnings from the first year of the HyStorPor project

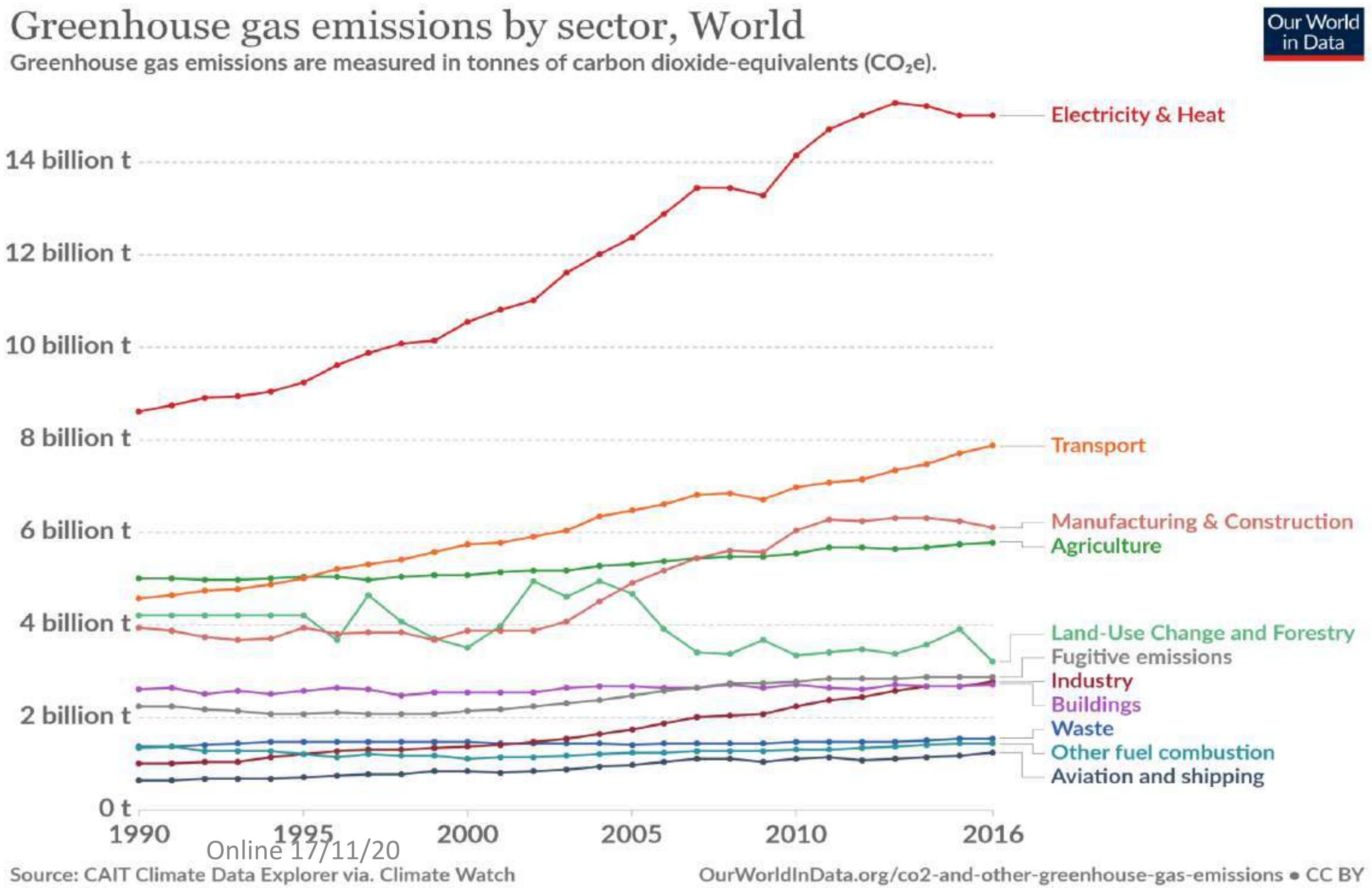
Katriona Edlmann

Stuart Haszeldine, Niklas Heinemann, Mark Wilkinson, Chris McDermott, Ian Butler, Ali Hassanpouryouzband, Eike Thaysen, Julien Mouli-Castillo, Jonathan Scafidi, John Low (all UoE), Leslie Mabon (SAMS), Romain Viguier (SCCS), Gillian Pickup (HW), Sam Krevor (Imperial)

THE UNIVERSITY of EDINBURGH
SAMS Scottish Association for Marine Science
HERIOT WATT UNIVERSITY
Imperial College London
EPSRC
EP/S027815/1

Why do we need large scale hydrogen storage

- Decarbonise energy, transport, manufacturing
- Buffer seasonal fluctuations in energy demand.
- Support increased renewables and energy security
- Replace hydrocarbon based industrial feedstock



Hydrogen Storage challenges

High energy density by mass

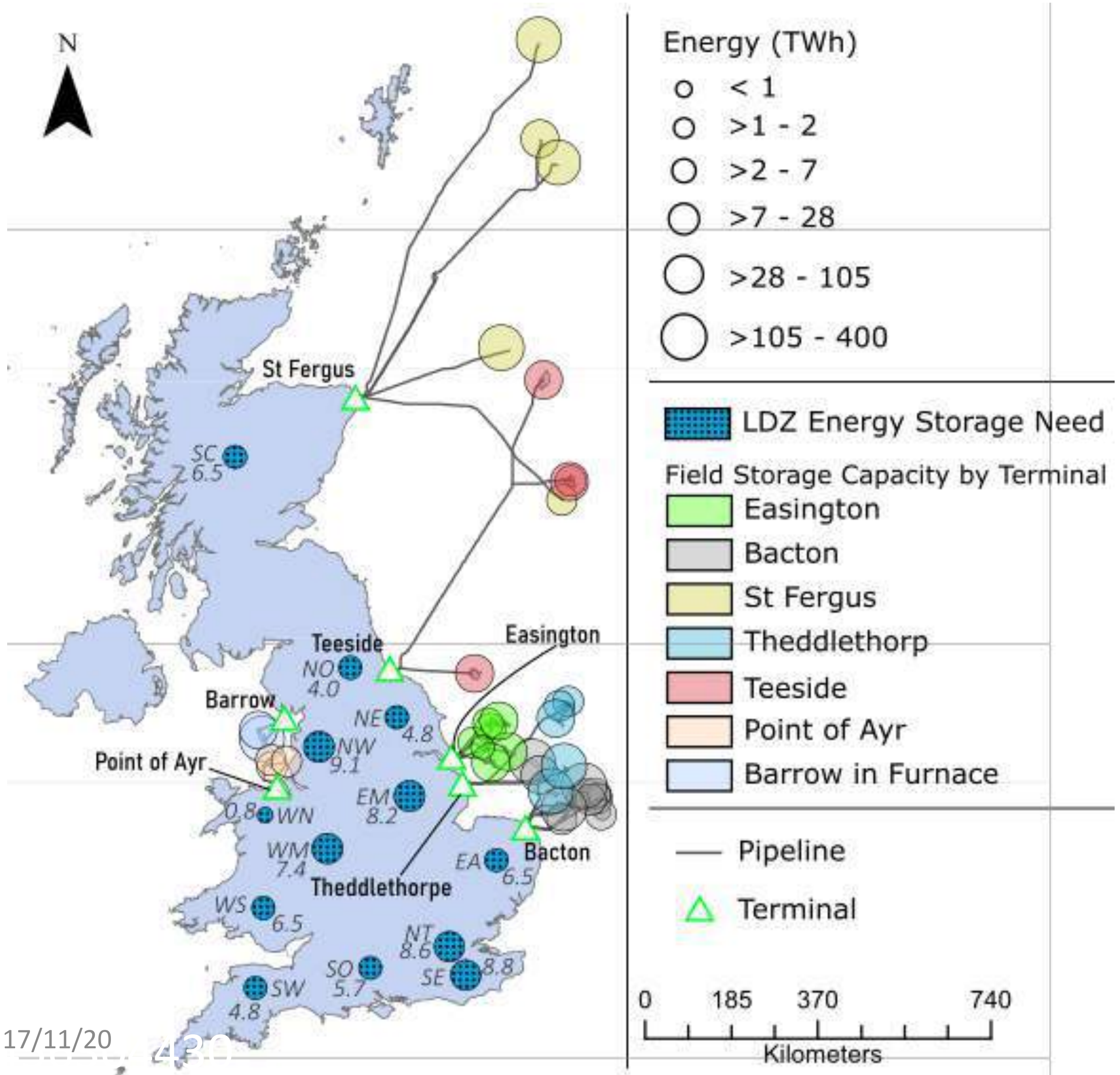
Very small mass by volume

Even when liquefied (-252°C) energy density per volume of hydrogen is only ¼ that of petrol.

Hydrogen for effective net zero decarbonisation will require large volumes of storage.

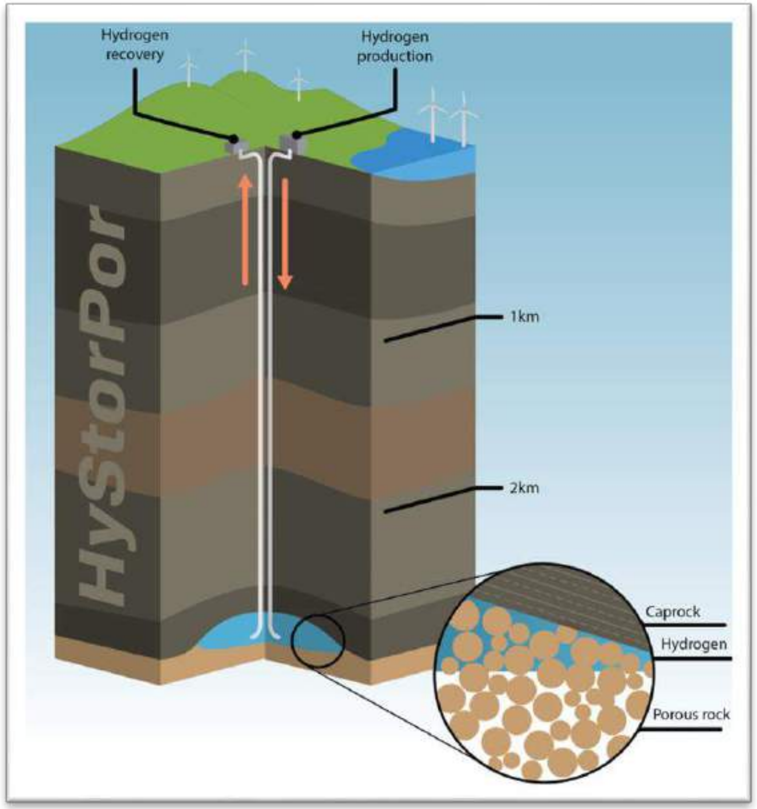
Porous rock storage

- Switching from natural gas to hydrogen will reduce the storage capacity of existing gas storage facilities by about 2/3rd
- 100's of TWh of storage connected to UK gas terminals
- Enough capacity to store regional seasonal heat needs
- These are first stage static volumetric capacity estimates, they are not matched dynamic capacities.



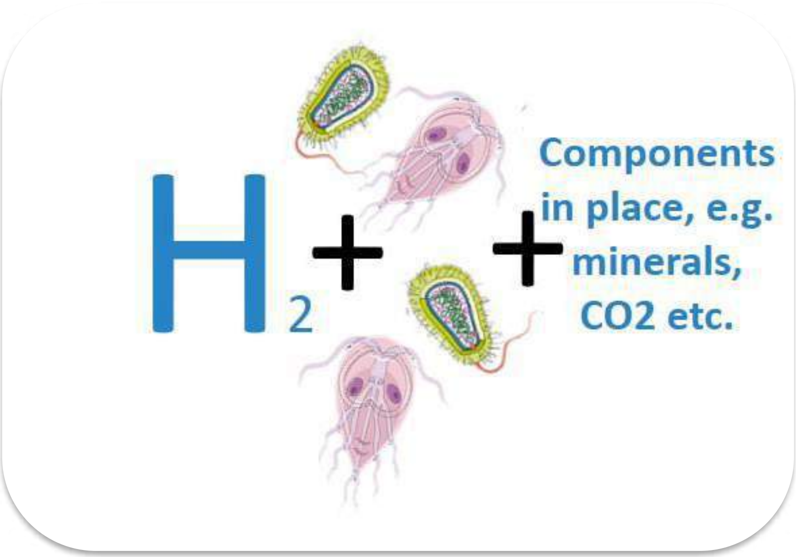
Julien Mouli-Castillo julien.moulicastillo@ed.ac.uk

HyStorPor Project Goals: establish fundamental understandings for hydrogen storage in porous rocks

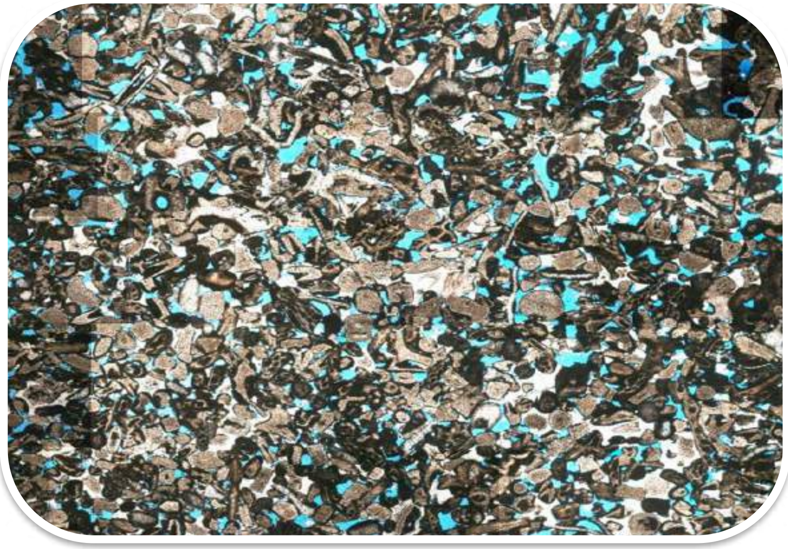


- To identify if **biological and chemical reactions** between the rock, fluids, cushion gas and hydrogen could compromise storage.
- To determine what **flow processes** will influence hydrogen migration and trapping during injection and withdrawal.
- **Reservoir simulations to estimate what volumes of hydrogen can be stored and recovered** from storage sites of varying scales.
- To **clarify what citizens and opinion shapers think about hydrogen storage.**

Work Package 1: Biological and chemical reactions in the reservoir and seal



Review key **microbial processes** and their impact on the reservoir



Geochemical reaction of hydrogen with rock and brine under reservoir temperatures and pressures

Data to benchmark modelling

Work Package 1 lead: Mark Wilkinson (Mark.Wilkinson@ed.ac.uk)

Impact of chemical and biological reactions

Biological reactions

- **Hydrogen loss**
  - Consumption of hydrogen
- **Permeability alteration**
  - Precipitation of iron sulphide
  - Biofilm formation
- **Hydrogen contamination**
  - Production of methane
  - Contamination (souring) of the stored hydrogen gas by hydrogen sulphide
- **Operational degradation**
  - Microbial influenced Metal Corrosion

Chemical reactions

- **Permeability alteration**
  - Carbonate and sulphate mineral dissolution
  - Feldspars and clay minerals of the chlorite group dissolution
  - Anhydrite dissolution
  - Pyrite reduction and re-precipitation
  - Illite or iron sulphide precipitation
  - Clay swelling
- **Hydrogen contamination**
  - Production of toxic gasses (SOx) from sulphide minerals
- **Operational degradation**
  - Well cement integrity
  - Well casing integrity
- **Environmental Risk**
  - Toxic metal mobilisation

Biological reaction for hydrogen storage

Temperature, **pH** and **salinity** are the key environmental controls on the growth of microorganisms, in addition to **nutrients** and **water**

Temperature limits

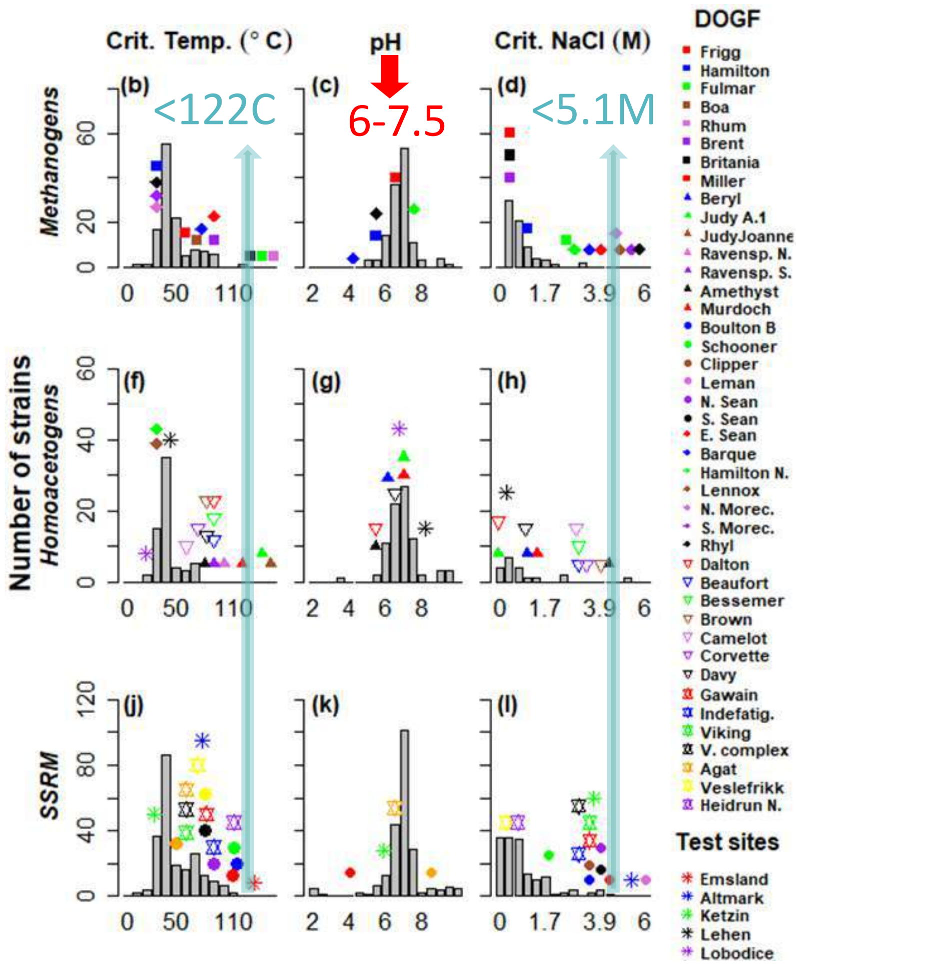
- Methanogens (methane as a metabolic by-product) up to 122C
- Homoactogens (acetate as a metabolic by-product) up to 72C
- Sulphur species reducing microorganisms (SSRM) up to 113C

pH values of 6-7.5 are preferred for all

Salinity limits

- Methanogens grow up to 3.4 M (199,000 ppm)
- Homoactogens grow up to 5.1 M (298,000 ppm)
- SSRM grow up to 4.2 M (245,000 ppm)

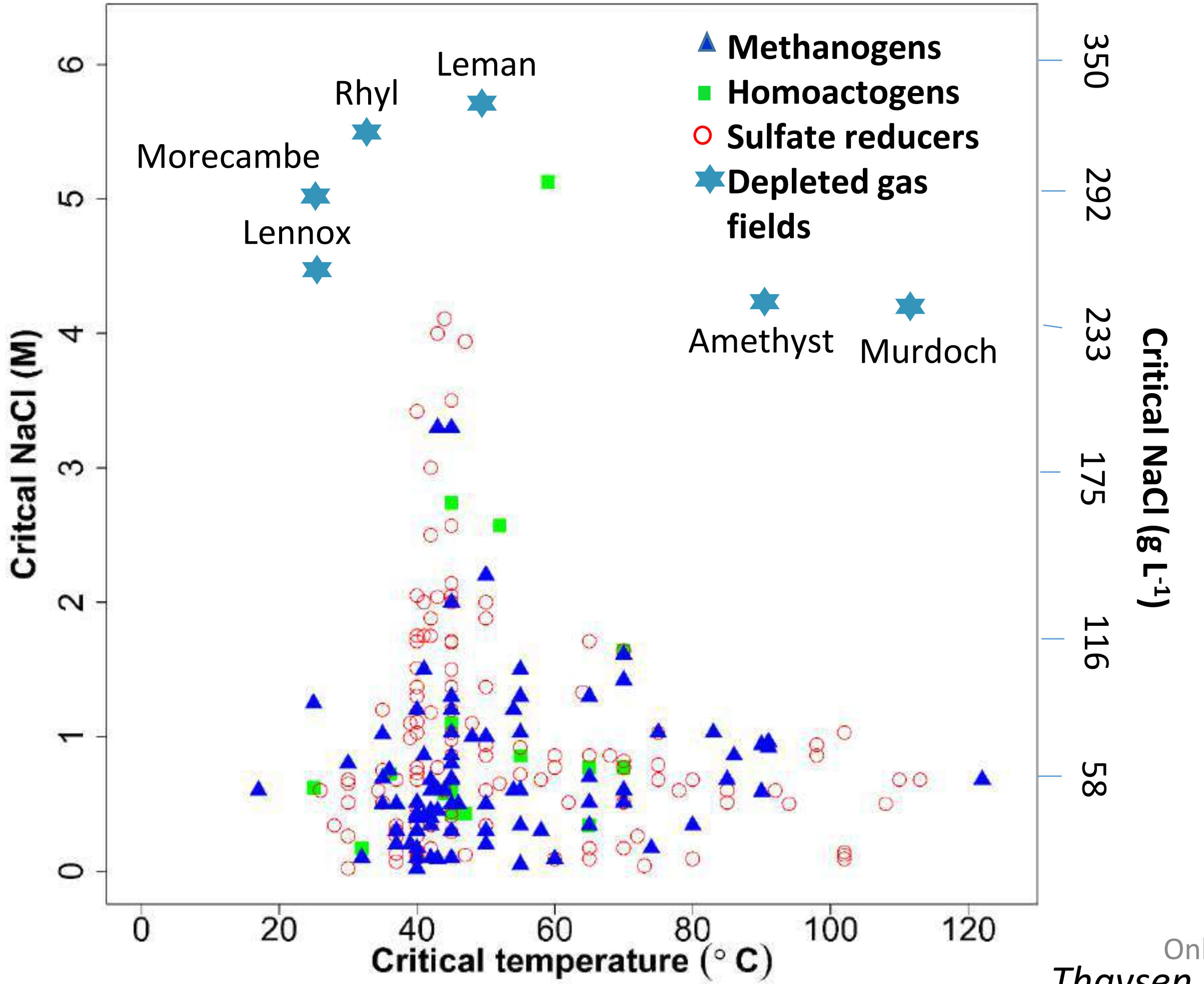
Physicochemical data for 42 depleted UK North Sea gas fields (DGF) and 5 H_2 storage test sites



Online 17/11/20

Thaysen et al. https://eartharxiv.org/repository/view/1799/ *(eike.thaysen@ed.ac.uk)*

Biological H_2 storage site selection tool



The most important factors controlling growth are **salinity** and **temperature.**

Storing hydrogen at temperatures >122 °C and >5.1 M NaCl eqv salinity reduces the risk of H_2 loss

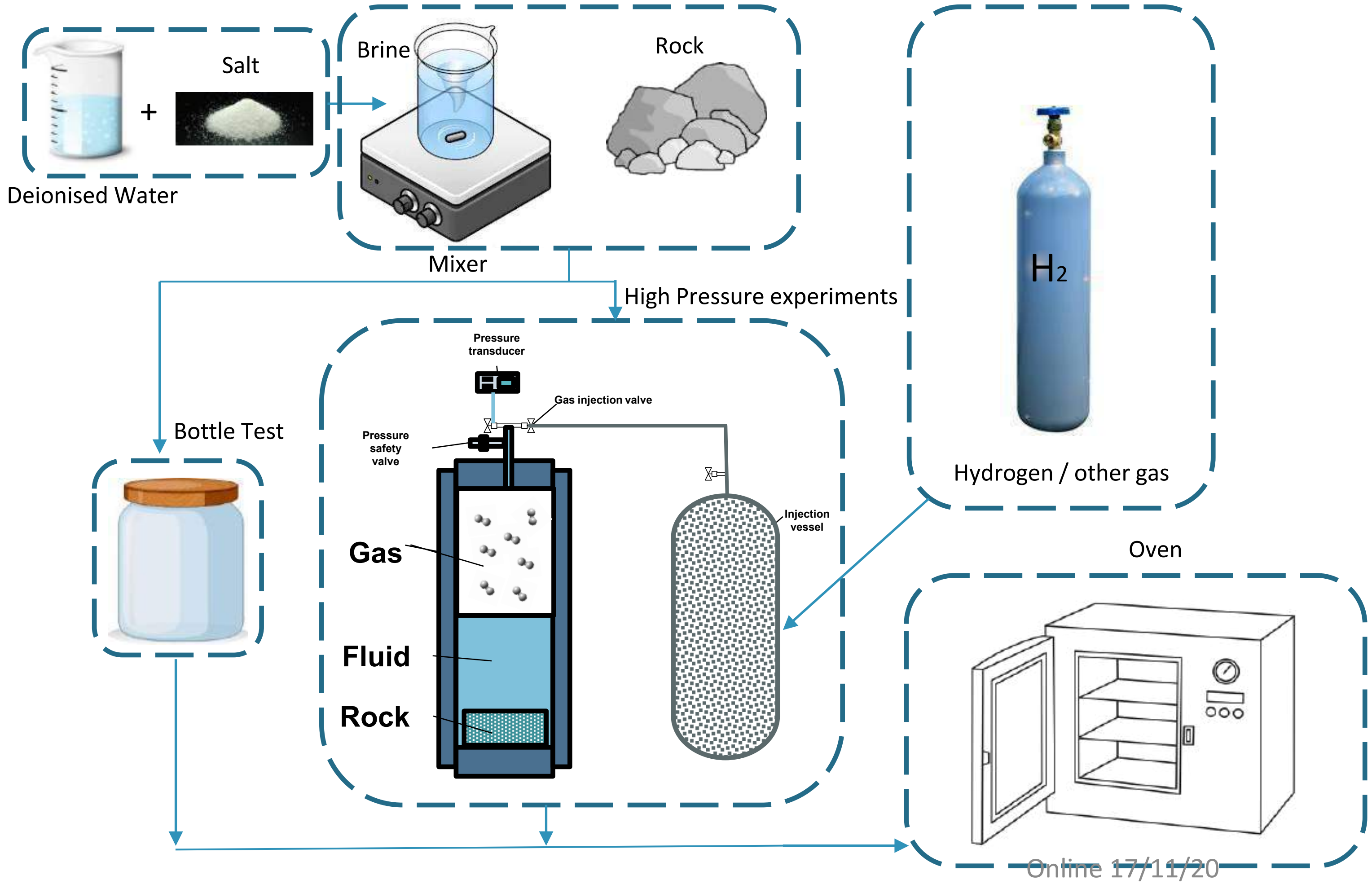
6 out of the 47 fields studied are unfavourable to microbial growth

*Limitation of our analysis is that the data is based on **cultivated species and studies on the microbial ecology** – not directly from hydrocarbon reservoirs.*

Thaysen et al. https://eartharxiv.org/repository/view/1799/ *(eike.thaysen@ed.ac.uk)*

Geochemical reaction for hydrogen storage

Reactions of hydrogen with rock and brine (static batch reactions)



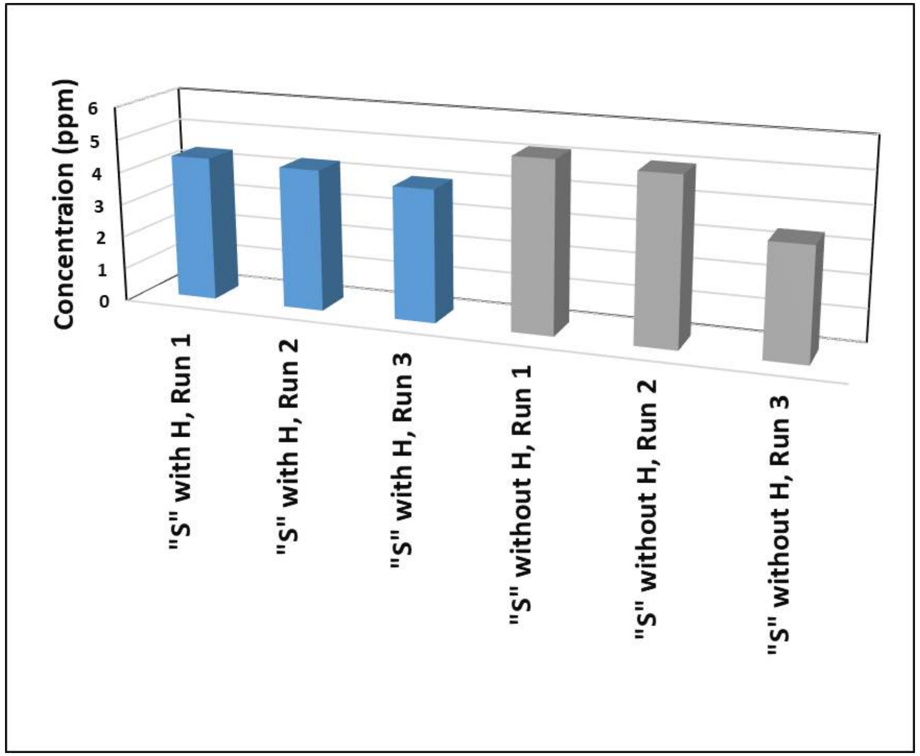
We can run 40 experiments at the same time with:

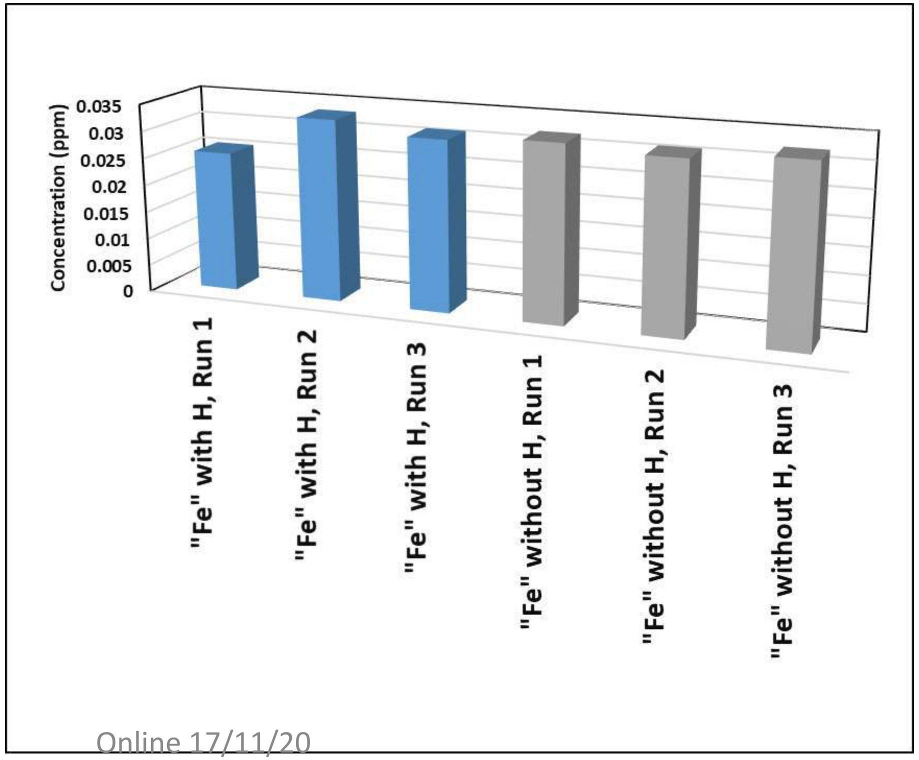
- Pressures up to 55MPa.
- Temperatures up to 80oC
- Any fluid/gas mixture.
- Any rock type, up to 30mm diameter.
- Accurately record pressure and temperature.
- Fluid chemistry and rock analysis.

Ali Hassanpouryouzband (hssnpr@ed.ac.uk)

Clashach sandstone results for at 1MPa, 50oC and 3.5% NaCl (35,000ppm)

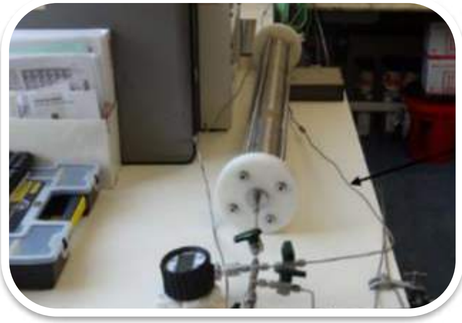
Considering our most likely reactions which will involve pyrite
we **observe no changes in concentration of Sulphur (S) and Iron (Fe)**
after 4 weeks contact with hydrogen



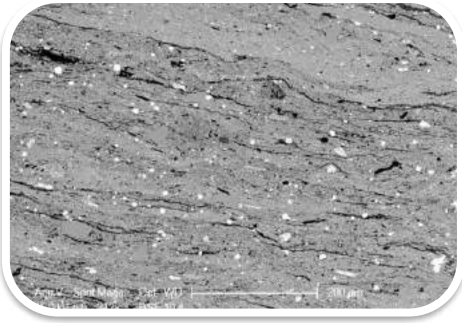


any differences are well within the natural variability expected between samples

Work Package 2: Flow behaviour of hydrogen



Mass transport properties of hydrogen and cushion gas through porous rocks



Sealing of caprocks to hydrogen

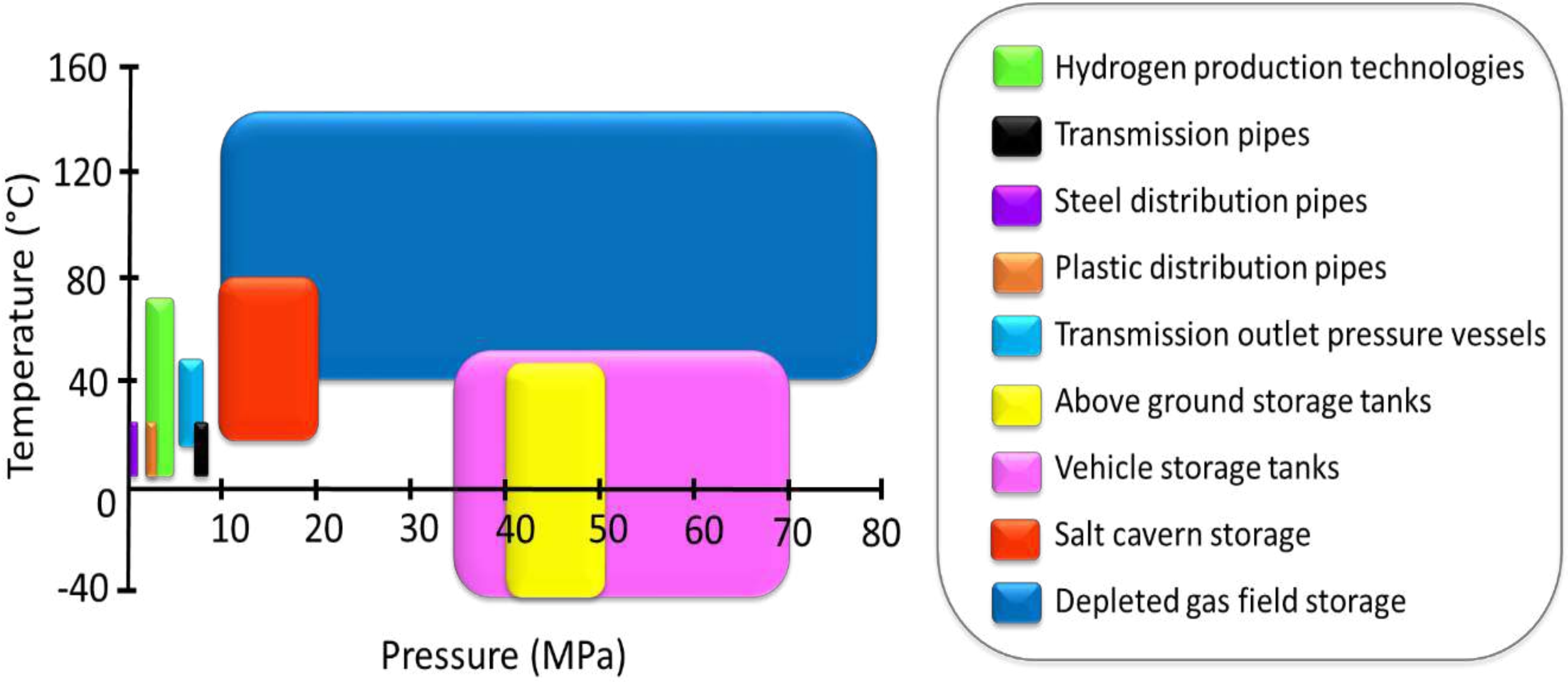
First time **imaging of hydrogen flow** through porous rocks using X-ray CT.

Recovery efficiency over multiple cycles of injection and withdrawal?

Data to benchmark modelling

Work Package 2 lead: Katriona Edlmann (katriona.edlmann@ed.ac.uk)

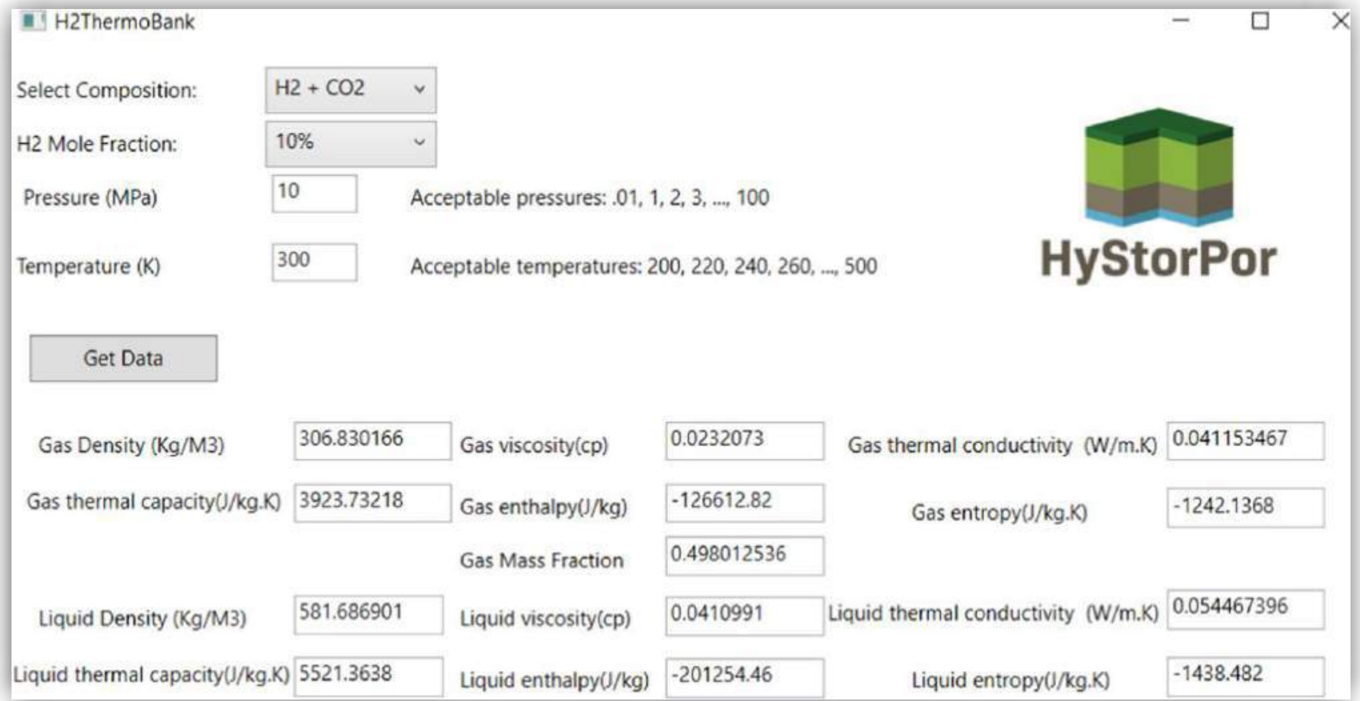
Mass transport properties: Thermodynamic properties of hydrogen gas stream mixtures.



H_2 Thermobank: Thermodynamic properties of hydrogen gas stream mixtures

✓ Developed an **online tool to generate thermodynamic properties of hydrogen mixtures**, including CO_2, N_2, CH_4 and a typical UK North Sea Natural Gas.

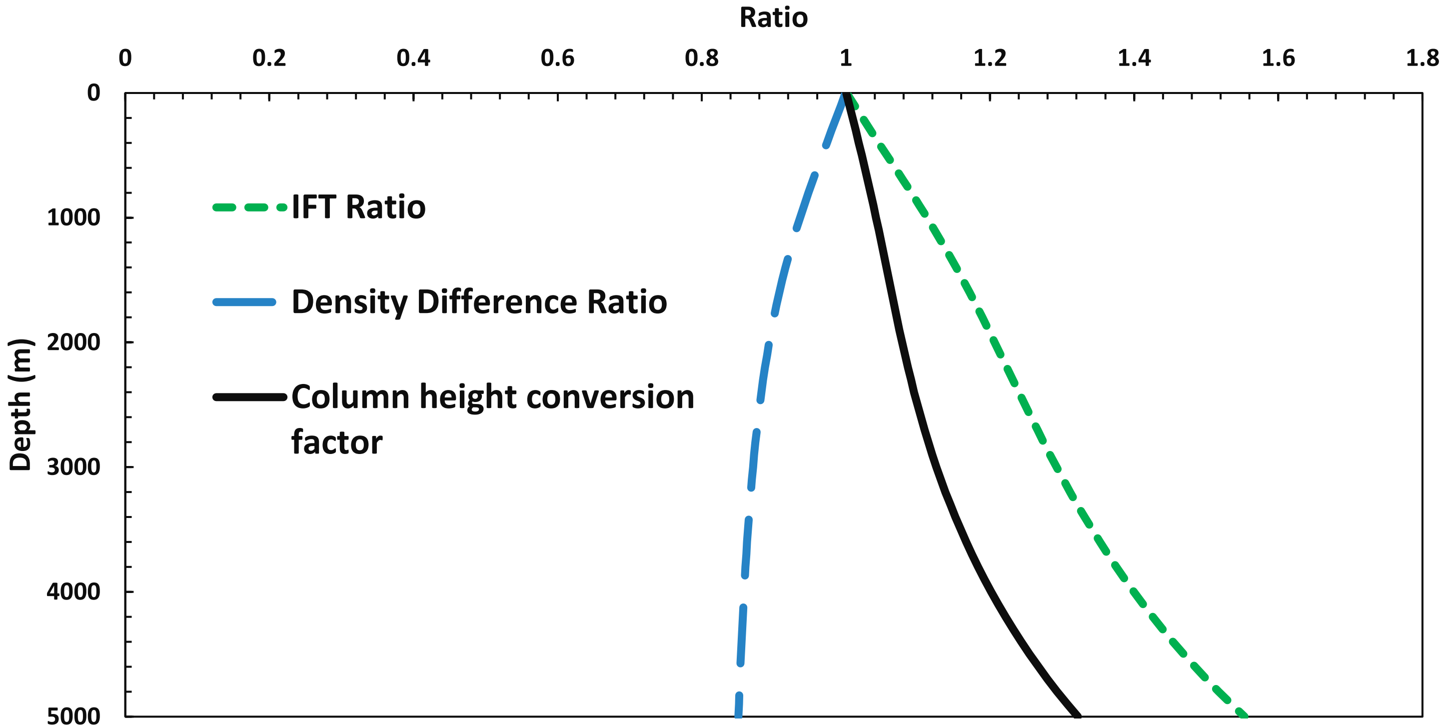
- Mole fractions of hydrogen from 10-90 mole %.
- Pressure from 0.01 – 100 MPa.
- Temperatures from 200-500 K (-73C to 227C).



https://www.nature.com/articles/s41597-020-0568-6
https://github.com/aliakbarhssnpr/H2ThermoBank

Ali Hassanpouryouzband (hssnpr@ed.ac.uk)

Caprock sealing: Column Height Conversion Factors from known pre-production gas column heights



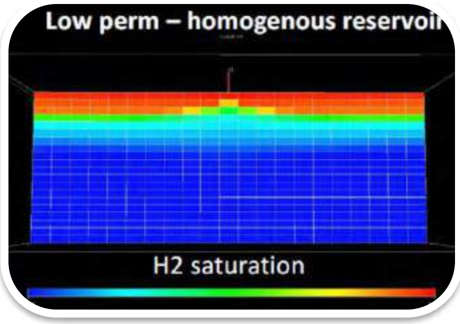
Calculated column height ratios for gas fields from the UK Southern North Sea

Field Name	Column Height Correction Factor
Amythest	1.07
Barque	1.08
Camelot	1.09
Cleeton	1.09
Clipper	1.08
Leman	1.10
Ravenspurn S	1.07
Rough	1.06
Sean S	1.14
Sean N	1.13
West Sole	1.07

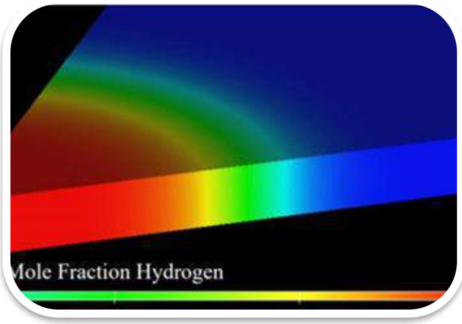
The column height conversion factor shows a increase column height of hydrogen, which increases with depth, meaning the caprock will sustain a higher pressure for hydrogen than it would with methane.

Ali Hassanpouryouzband (hssnpr@ed.ac.uk)

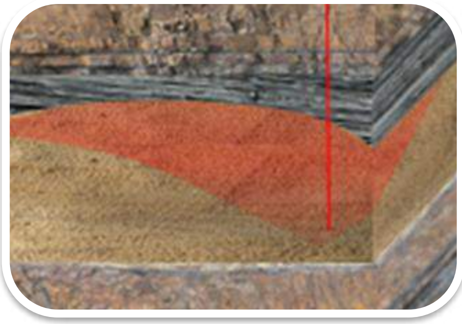
Work Package 3: Numerical Simulation of Hydrogen Injection, Storage and Withdrawal



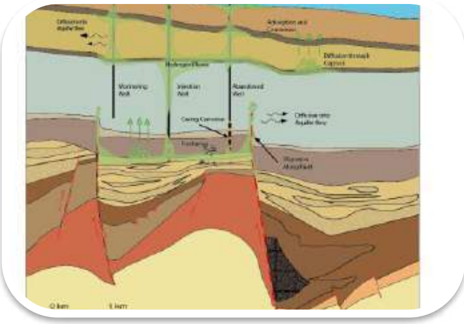
Benchmarking of experimental data to calibrate numerical simulators for use with Hydrogen



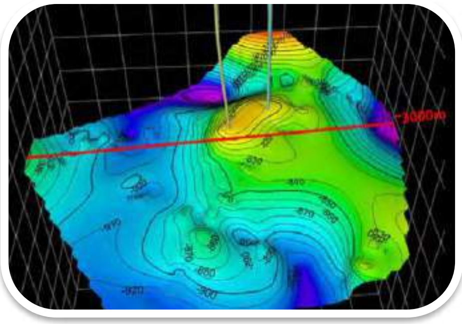
Understanding of **the impact of different cushion gasses**



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 3 lead: Niklas Heinemann (N.Heinemann@ed.ac.uk)

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.

Work Package 4 lead: Leslie Mabon (Leslie.Mabon@sams.ac.uk)

Society, policy and governance

- Key societal issue not just risk perception and safety, but rather **finding the place of hydrogen** – and the geological storage of hydrogen – within a net-zero society;
- Technical and scientific research into the feasibility of geological storage of hydrogen will inevitably be received and interpreted within this wider context;
- **Value of learning from early deployments of hydrogen energy such as H100 Project**;
- Also importance of not getting drawn into ‘electrification *or* hydrogen’ debates – **recognise and message around fact we need both**.

No showstoppers… so far….

- ✓ Biological site selection screening: We suggest that **storage reservoirs over 122 C or with salinities above 5.1 M NaCl equivalent** will be less favourable to microbial growth.
- ✓ **No significant geochemical reactions** have been observed in our reactive experiments – still a wide range of rock types to test.
- ✓ **Column height calculations indicate hydrogen will have a higher column height than methane** and that this increases with increasing depth.
- ✓ Provide **high accuracy hydrogen mixtures (CO_2, N_2, CH_4, natural gas) thermodynamic property** estimations over a range of temperatures and pressures.
- ✓ **Significant storage capacity in depleted gas fields**, minimising subsurface competition with other low carbon geoenergy applications.

Thank you

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Partners

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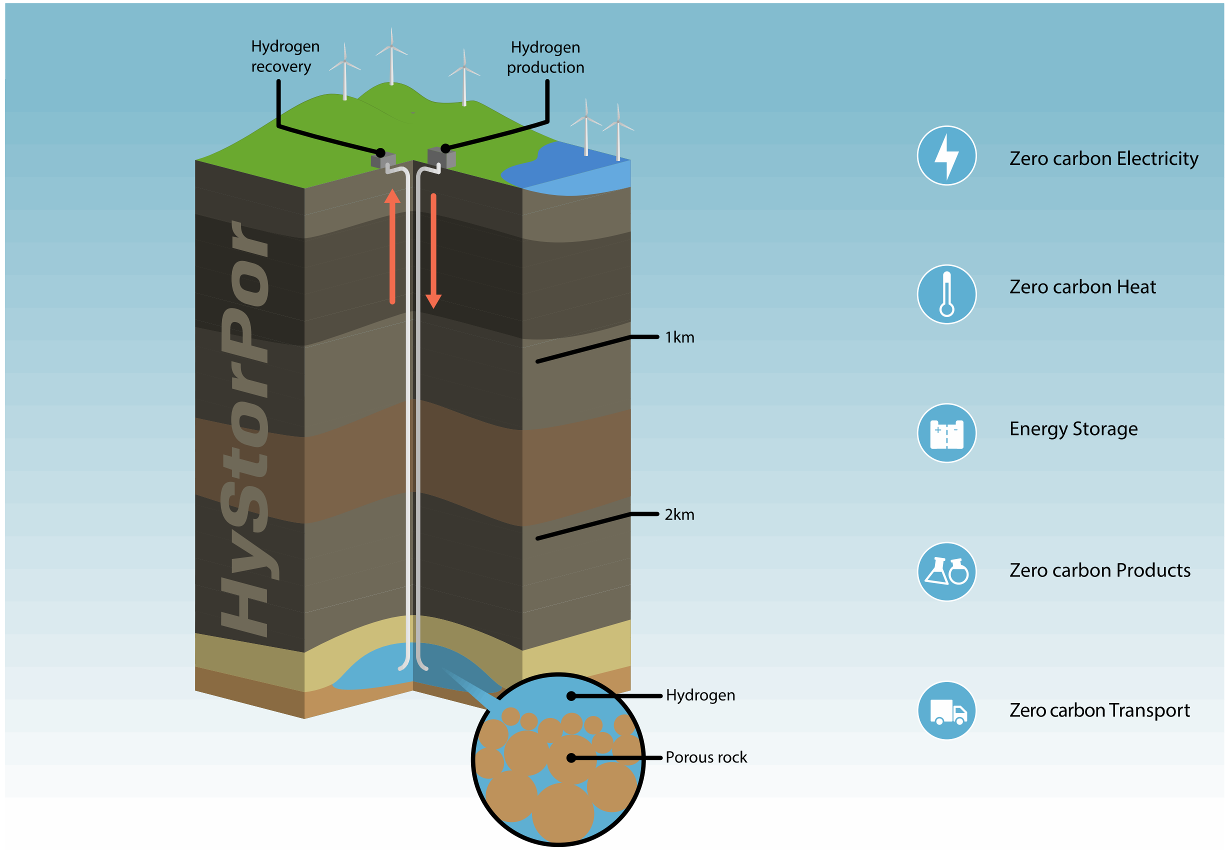

Session 2 Panel Discussion

Chair: Stuart Haszeldine

Nigel Holmes, SHFCA; **Stuart McKay**, Scottish Government

David Hogg, ARUP; **Mark Wheeldon**, SGN

Katriona Edlmann, **Stuart Haszeldine**, University of Edinburgh

Gregoire Hevin, Storengy; **Simonas Cerniauskas**, Jülich

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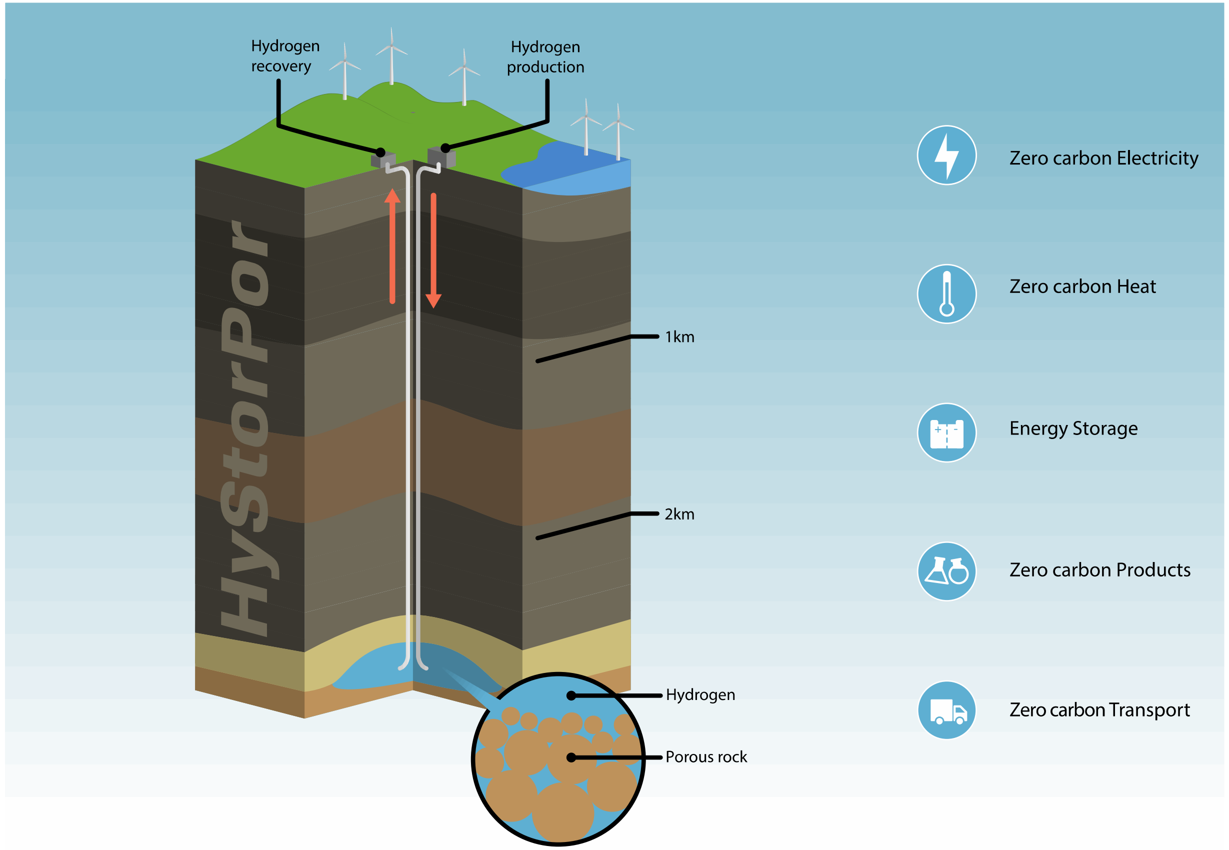

Thank you for attending today’s webinar.

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