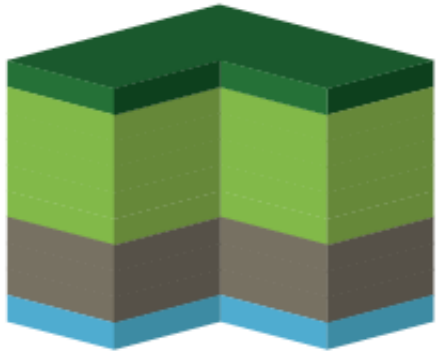


HyStorPor

Hydrogen Storage in Porous Media

Professor Stuart Haszeldine

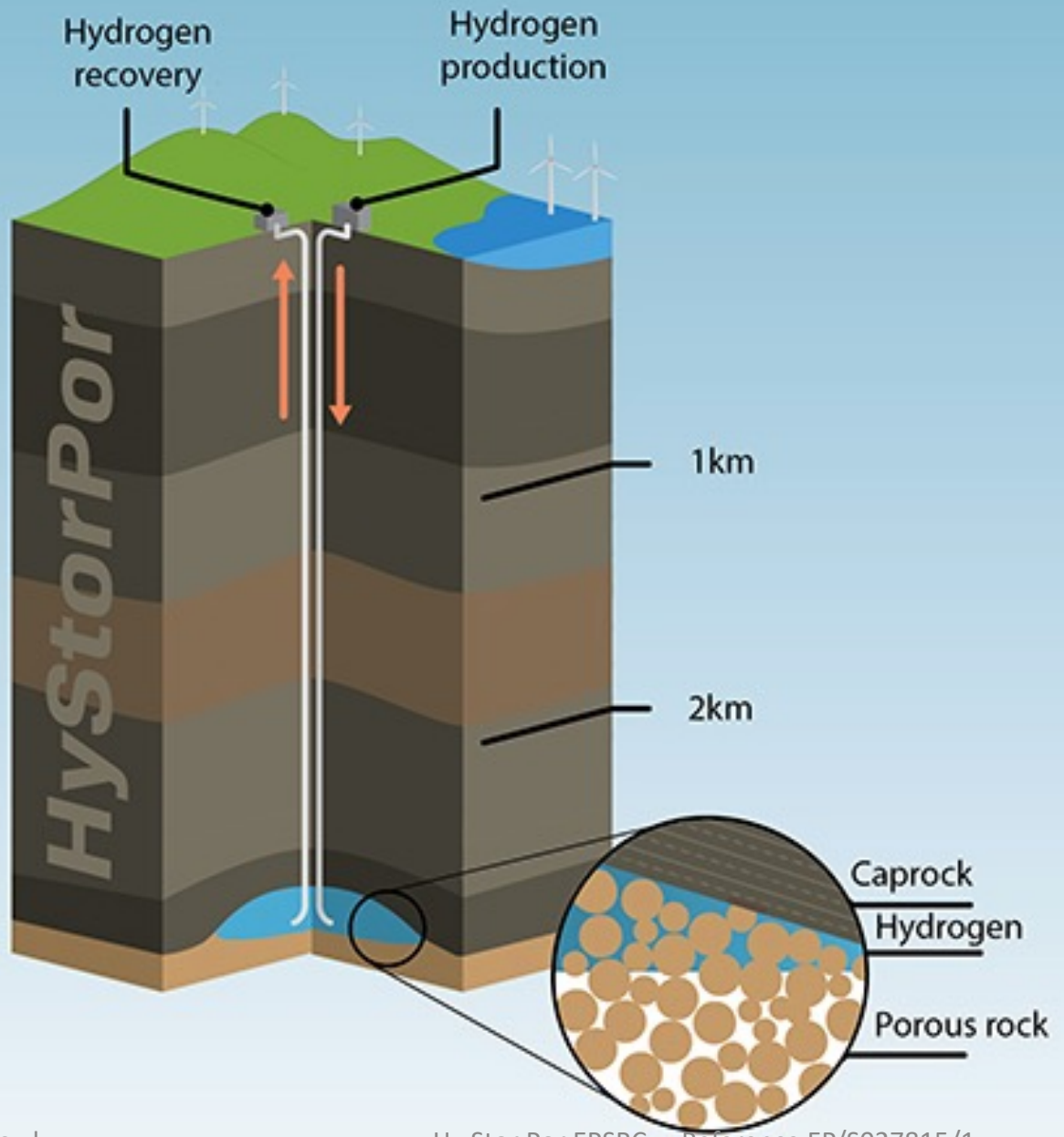
First meeting 12th Nov 2020

Formal finish meeting 12th July 2023

EPSRC reference: EP/S027815/1

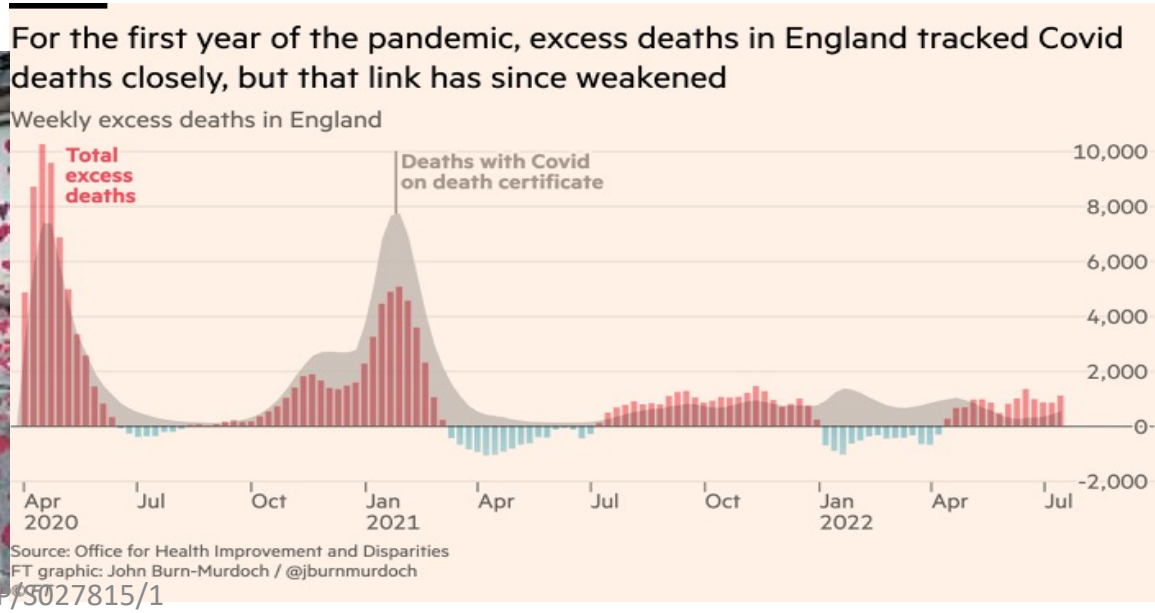
At the start

https://blogs.ed.ac.uk/hystorpor/contact/



- Sustainable electricity
- Low carbon heat
- Energy storage
- Zero carbon products
- Clean transport

Not the easiest of times to run a project



HyStorPor

Project partners

centrica

THE UNIVERSITY of EDINBURGH

HERIOT WATT UNIVERSITY

SCOTTISH ASSOCIATION for MARINE SCIENCE

DOOSAN

ATKINS

Industry Partners

Environment Agency

EMEC
THE EUROPEAN MARINE ENERGY CENTRE LTD

Quintessa

CGG
Passion for Geoscience

Pale Blue Dot.

SCOTTISH Hydrogen & Fuel Cell ASSOCIATION

SGN

equinor

HYDRENOR

Work plan

WP1 Chemical and Biological Reactions of Reservoir and Seal
Mark Wilkinson, mark.wilkinson@ed.ac.uk

WP2 Hydrogen Fluid Flow Property Experiments
Katriona Edlmann, katriona.edlmann@ed.ac.uk

WP3 Numerical Simulation of Hydrogen Injection, Storage and Reproduction
Niklas Heinemann, N.Heinemann@ed.ac.uk

WP4 Public and Stakeholder Perceptions
Leslie Mabon, leslie.mabon@sams.ac.uk

WP5 Dissemination and Pathways to Impact
Romain Viguier, romain.viguier@ed.ac.uk

Talk Plan

09:00-9:20 Registration & welcome
09:20-9:30 Prof Stuart Haszeldine, The University of Edinburgh – The HyStorPor project
09:30-09:40 Stuart McKay, Scottish Government - Introductory remarks
09:40-10:00 Keynote from Grant Wilson, University of Birmingham
10:00-10:10 Nigel Holmes, Scott Hydrogen & Fuel Cell Assocn
10:10 - 10:30 Coffee break

Public perception & public engagement
10:30-11:00 Arlan Harris, Ballard - *Ballard UK Education Programme: Putting fuel cells in the hands of the next generation*
11:00-11:30 Eilidh Graham, SGN - *Public engagement and hydrogen projects*
11:30-12:00 Leslie Mabon, The Open University/HyStorPor - *Geological storage of hydrogen and its place in the UK's net-zero energy mix: a stakeholder perspective*
12:00-12:30 Joel Gordon, Cranfield University - *Public perceptions of hydrogen risks, costs and benefits: Insights from a multigroup analysis*
12:30 - 13:45 Lunch & posters

Technical results overview
13:45-13:55 Introductory remarks - Courtney West, SGN
13:55-14:20 Katriona Edlmann, The University of Edinburgh/HyStorPor - *Integration of hydrogen storage into the energy system (the UK Hydrogen Storage database)*
14:20-14:45 Eike Thaysen, HyStorPor - *Microbiological risks during hydrogen storage in porous rocks*
14:45-15:10 Niklas Heinemann, The University of Edinburgh/HyStorPor - *Hydrogen storage capacity in porous media sites*
15:10 - 15:40 Coffee break

15:40-16:05 Mark Wilkinson, The University of Edinburgh HyStorPor & Hyuspre - *European hydrogen storage database*
16:05-16:30 Aliakbar Hassanpouryouzband, The University of Edinburgh/HyStorPor - *Implications of Hydrogen's Physical and Chemical Reactivity for Geological Storage*
16:30-16:55 Katriona Edlmann, The University of Edinburgh/HyStorPor - *Understanding multiphase flow and residual trapping risks during cyclic hydrogen injection and production*

16:55-17:00 Closing remarks

Publications from HyStorPor project x34 (1)

HyStorPor publications
The first one ….!

- Amid, A., Mignard, D. and Wilkinson, M., 2016. Seasonal storage of hydrogen in a depleted natural gas reservoir. *International journal of hydrogen energy*, *41*(12), pp.5549-5558. https://doi.org/10.1016/j.ijhydene.2016.02.036

- **Project website** HyStorPor. blogs.ed.ac.uk/hystorpor
- **Twitter** @HyStorPor. @ScotCCS

Heinemann, N., Alcalde, J., Johnson, G., Roberts, J., Mccay, A., Booth, M.G., 2019. Low-Carbon GeoEnergy Resource Options in the Midland Valley of Scotland, UK". Scottish Journal of Geology, accepted.

Adie, K., Heinemann, N., Papageorgiou, G., Wilkinson, M., Haszeldine, S., Thompson, C. and West, C., 2023. *Hydrogen storage pilot: geological characterisation of an onshore aquifer structure in Fife, Scotland* (No. EGU23-13688). Copernicus Meetings.

Talukdar, M., Blum, P., Heinemann; N., Miocic, J., Techno-economic analysis of underground hydrogen storage in Europe. In review

Miocic, J., **Heinemann, N.**, Alcalde, J., Edlmann, K., Schultz, R., 2023. Enabling secure subsurface storage in future energy systems: an introduction. Geological Society, London, Special Publications 528.

Scafidi, J., Schirrer, L., Vervoort, I., **Heinemann, N.,** 2023. An open-source tool for the calculation of field deliverability and cushion gas requirements in volumetric gas reservoir storage sites. Geological Society, London, Special Publications 528.

Miocic, J., **Heinemann, N.,** Edlmann, K., Alcalde, J., Schultz, R., 2023. About this title-Enabling Secure Subsurface Storage in Future Energy Systems. Geological Society, London, Special Publications 528. .

Miocic, J., Alcalde, J., **Heinemann, N.,** Marzan, I., Hangx, S., 2022. Toward Energy-Independence and Net-Zero: The Inevitability of Subsurface Storage in Europe. ACS Energy Letters, 7/8.

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Mouli-Castillo, J., Heinemann, N., Edlmann, K., 2021. Mapping geological hydrogen storage capacity and regional heating demands: An applied UK case study. Applied Energy, 283, 116348. https://doi.org/10.1016/j.apenergy.2020.116348

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Heinemann, N., Alcalde, J., Miocic, J.M., Hangx, S.J.T., Kallmeyer, J., Ostertag-Henning, C., Hassanpouryouzband, A., Thaysen, E.M., Strobel, G.J., Schmidt-Hattenberger, C., Edlmann, K., Wilkinson, M., Bentham, M., Haszeldine,R.S., Carbonell, R., Rudloff, A., 2021. Enabling large-scale hydrogen storage in porous media – the scientific challenges. Energy and Environmental Science, 14, 853-864. https://doi.org/10.1039/d0ee03536j

Hassanpouryouzband, A., Joonaki, E., Edlmann, K., Heinemann, N. and Yang, J., 2020. Thermodynamic and transport properties of hydrogen containing streams. Scientific Data, 7(1), pp.1-14. https://doi.org/10.1038/s41597-020-0568-6

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Heinemann N., Booth M., Haszeldine S., Wilkinson M., Edlmann, K., Scafidi J. 2018. Hydrogen storage in porous geological formations - Onshore play opportunities in the Midland Valley (Scotland, UK). International Journal of Hydrogen Energy. *43*(45), pp.20861-20874.https://www.sciencedirect.com/science/article/pii/S0360319918330404

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Adnan Aftab, Aliakbar Hassanpouryouzband, Abby Martin, Jackie E. Kendrick, Eike M. Thaysen, Niklas Heinemann, James Utley, Mark Wilkinson, R. Stuart Haszeldine, and Katriona Edlmann. Geochemical Integrity of Wellbore Cements during Geological Hydrogen Storage Environmental Science & Technology Letters Article DOI: 10.1021/acs.estlett.3c00303

Eike M. Thaysen, Timothy Armitage, Lubica Slabon, Aliakbar Hassanpouryouzband, Katriona Edlmann, Microbial risk assessment for underground hydrogen storage in porous rocks, Fuel, Volume 352, 2023, https://doi.org/10.1016/j.fuel.2023.128852.

Craig Allsop, Georgios Yfantis, Evan Passaris and Katriona Edlmann (2022). Utilising publicly available datasets for identifying offshore salt strata and developing salt caverns for hydrogen storage Geological Society, London, Special Publications Volume 528. https://doi.org/10.1144/SP528-2022-82

Richard A Schultz, Niklas Heinemann, Birgit Horváth, John Wickens, Johannes M Miocic, Oladipupo Oluwatoyin Babarinde, Wenzhuo Cao, Paolo Capuano, Thomas A Dewers, Maurice Dusseault, Katriona Edlmann … (2022) An overview of underground energy-related product storage and sequestration. Geological Society, London, Special Publications, Volume 528 https://doi.org/10.1144/SP528-2022-160

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Niklas Heinemann, Mark Wilkinson, Kate Adie, Katriona Edlmann, Eike Marie Thaysen, Aliakbar Hassanpouryouzband, Robert Stuart Haszeldine (2022) Cushion Gas in Hydrogen Storage—A Costly CAPEX or a Valuable Resource for Energy Crises? Hydrogen 3 (4), 550-563. https://doi.org/10.3390/hydrogen3040035

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Eike M Thaysen, Ian B Butler, Aliakbar Hassanpouryouzband, Damien Freitas, Fernando Alvarez-Borges, Samuel Krevor, Niklas Heinemann, Robert Atwood and Katriona Edlmann (2022). Pore-scale imaging of hydrogen displacement and trapping in porous media, International Journal of Hydrogen Energy, https://doi.org/10.1016/j.ijhydene.2022.10.153

Bin Pan, Kai Liu, Bo Ren, Mingshan Zhang, Yang Ju, Jianwei Gu, Xueying Zhang, Christopher R. Clarkson, Katriona Edlmann, Weiyao Zhu, Stefan Iglauer, Impacts of relative permeability hysteresis, wettability, and injection/withdrawal schemes on underground hydrogen storage in saline aquifers, Fuel, Volume 333, Part 2, 2023 https://doi.org/10.1016/j.fuel.2022.126516

Anna Peecock, Katriona Edlmann, Julien Mouli-Castillo, Alfonso Martinez-Felipe and Russell McKenna. (2022) Mapping hydrogen storage capacities of UK offshore hydrocarbon fields and investigating potential synergies with offshore wind. Geological Society, London, Special Publications Volume 528 https://doi.org/10.1144/SP528-2022-40

Christopher J. McMahon, Jennifer J. Roberts, Gareth Johnson, Katriona Edlmann, Stephanie Flude, and Zoe K. Shipton. (2022) Natural hydrogen seeps as analogues to inform monitoring of engineered geological hydrogen storage. Geological Society, London, Special Publications. Volume 528 https://doi.org/10.1144/SP528-2022-59

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Aliakbar Hassanpouryouzband, Kate Adie, Trystan Cowen, Eike M. Thaysen, Niklas Heinemann, Ian B. Butler, Mark Wilkinson, and Katriona Edlmann. (2022). Geological Hydrogen Storage: Geochemical Reactivity of Hydrogen with Sandstone Reservoirs. ACS Energy Lett. 2022, 7, 2203–2210. https://doi.org/10.1021/acsenergylett.2c01024

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N.Heinemann, J.Scafidi, G.Pickup, E.M.Thaysen, A.Hassanpouryouzband, M.Wilkinson, A.K.Satterley, M.G.Booth, K.Edlmann, and R.S.Haszeldine. (2021). Hydrogen Storage in Saline Aquifers: The Role of Cushion Gas for Injection and Production. International Journal of Hydrogen Energy. https://doi.org/10.1016/j.ijhydene.2021.09.174

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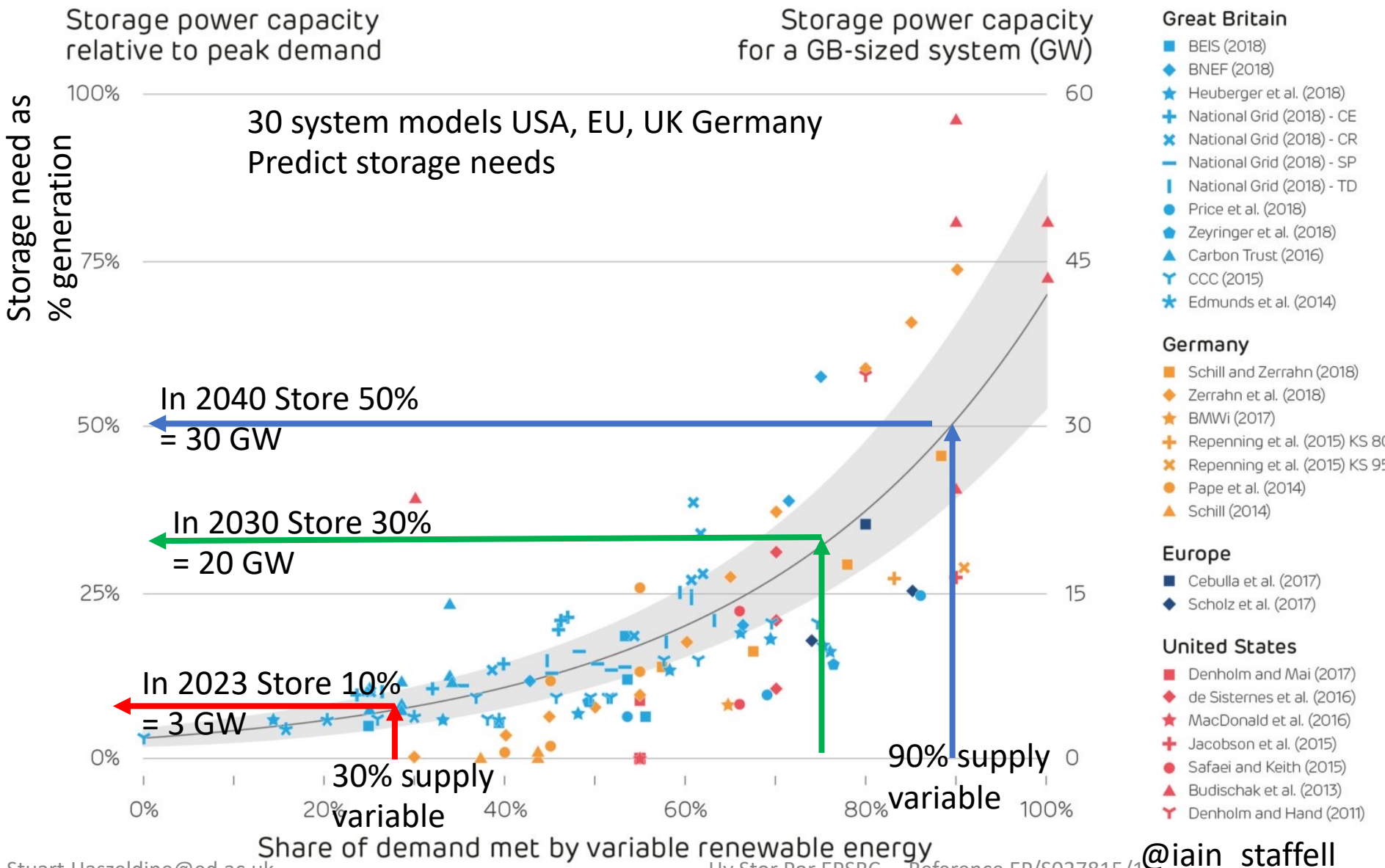
Mouli-Castillo, J., Heinemann N, Edlmann K. (2021). Mapping geological hydrogen storage capacity and regional heating demands: An applied UK case study, Applied Energy, https://doi.org/10.1016/j.apenergy.2020.116348

Niklas Heinemann, Juan Alcalde, Johannes M. Miocic, Suzanne J. T. Hangx, Jens Kallmeyer, Christian Ostertag-Henning, Aliakbar Hassanpouryouzband, Eike M. Thaysen, Gion J. Strobel, Mark Wilkinson, Cornelia Schmidt-Hattenberger, Katriona Edlmann, Michelle Bentham, R. Stuart Haszeldine, Ramon Carbonell and Alexander Rudloff. (2021). Enabling large-scale hydrogen storage in porous media – the scientific challenges. Energy Environ. Sci. https://doi.org/10.1039/D0EE03536J

Hydrogen – as interseasonal storage – more to do



Great Britain
- BEIS (2018)
- BNEF (2018)
- Heuberger et al. (2018)
- National Grid (2018) - CE
- National Grid (2018) - CR
- National Grid (2018) - SP
- National Grid (2018) - TD
- Price et al. (2018)
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- Carbon Trust (2016)
- CCC (2015)
- Edmunds et al. (2014)

Germany
- Schill and Zerrahn (2018)
- Zerrahn et al. (2018)
- BMWi (2017)
- Repenning et al. (2015) KS 80
- Repenning et al. (2015) KS 95
- Pape et al. (2014)
- Schill (2014)

Europe
- Cebulla et al. (2017)
- Scholz et al. (2017)

United States
- Denholm and Mai (2017)
- de Sisternes et al. (2016)
- MacDonald et al. (2016)
- Jacobson et al. (2015)
- Safaei and Keith (2015)
- Budischak et al. (2013)
- Denholm and Hand (2011)

ENERGY storage (TWhr)

Relative to peak POWER (GW)

Storage need rises exponentially with variable renewables

2023 30 % variable demand needs 2-5 GW storage

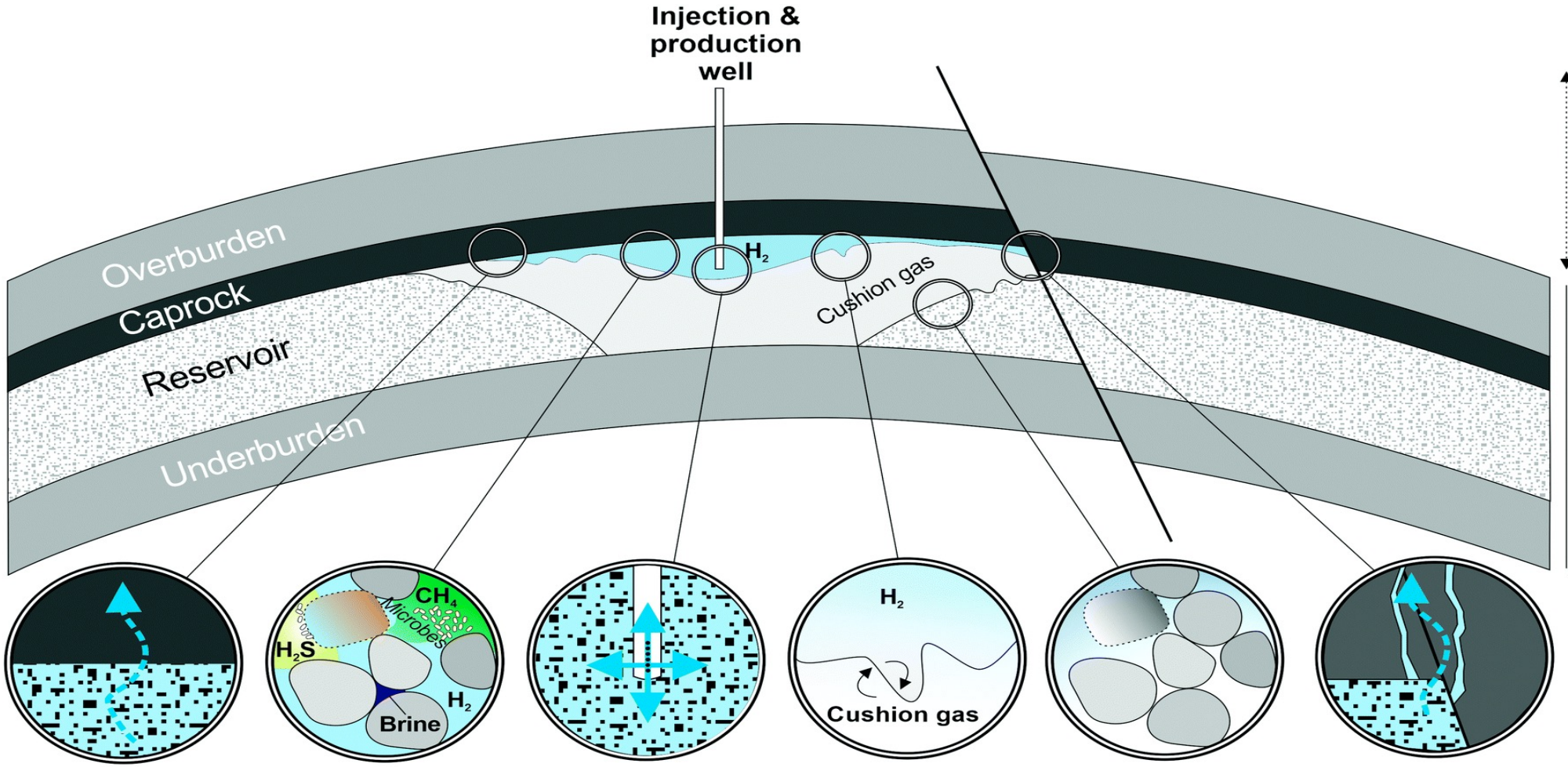
2027 50% variable peak demand, means total of 5-10 GW of storage

2030 75% variable supply, needs 11-21 GW storage

2040 90% variable needs
50% store = 30GW
3 months = 65 TWhr

@iain_staffell

Geological storage ; subsurface factors



Caprock:

- Diffusion
- Capillary leakage
- Fracturing
- Buoyancy pressure

Hydrogen plume

- Fluid-rock interaction
- Microbial activity
- Dissolution & residual trapping

Injection/production:

- P/T change
- Multiphase processes
- Stress/strain changes

H_2 - cushion gas:

- Unstable displacement & uncrontrolled lateral spreading
- Gas mixing

Cushion gas- brine

- Fluid-rock interaction
- Unstable displacement
- Dissolution & residual trapping

Structural geology:

- Fault leakage
- Far and near field stress changes
- Reactivation
- Overpressure

Fundamental petrophysical properties

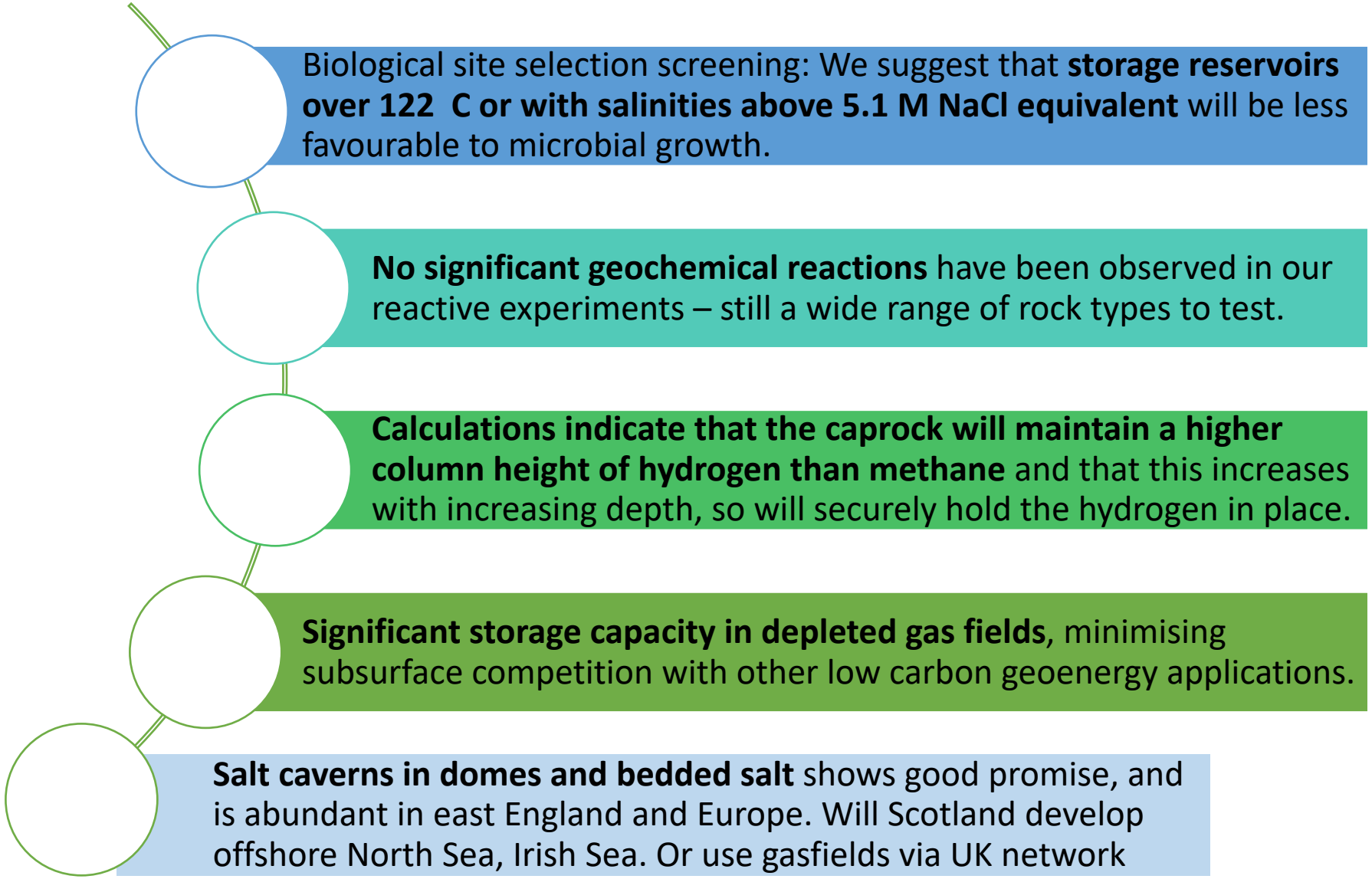
Geological features – reservoir, cap rock, overpressure, stress

Subsurface fluid engineering

Fluid displacement Hydrogen plume, cushion gas

Heinemann 2022 Energy Envir Sci https://doi.org/10.1039/D0EE03536J

Site selection much more clearly understood



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