Hydrogen and CCS – could it be the decarbonisation game changer?

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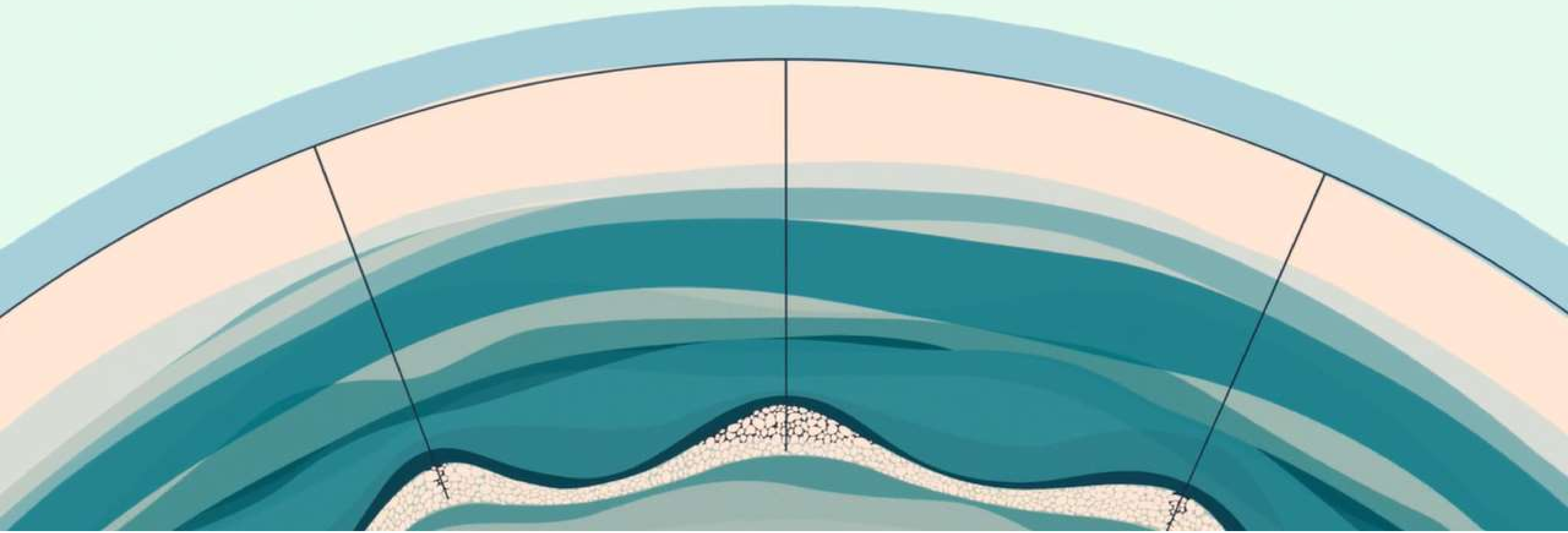
Scottish Energy Forum 28th Jan 2021



Motivation – Understanding the Energy Transition

Energy transformations so far:

- The industrial age
- The petroleum age

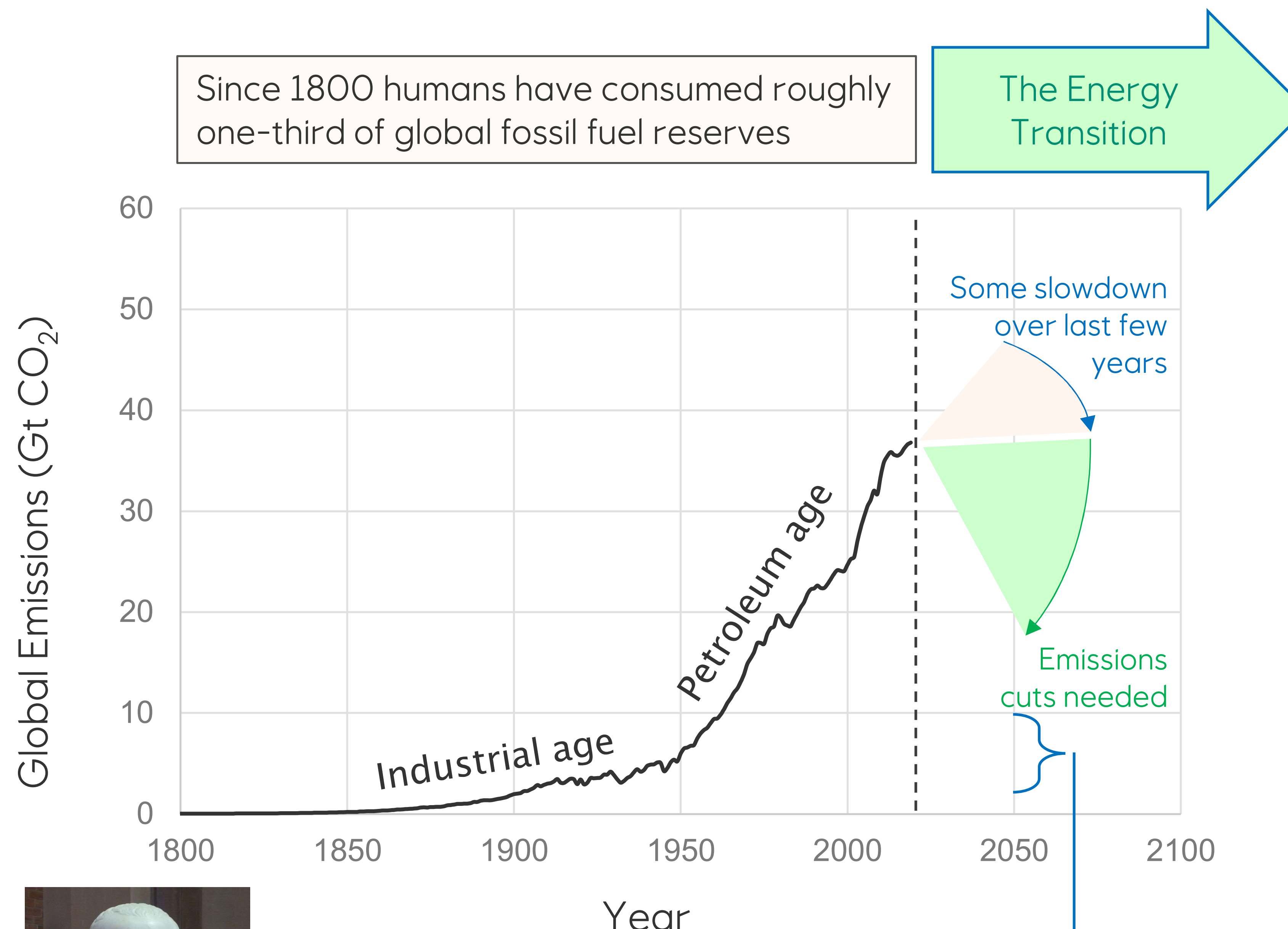
However, the emerging **energy transition** will be more dramatic than anything seen before

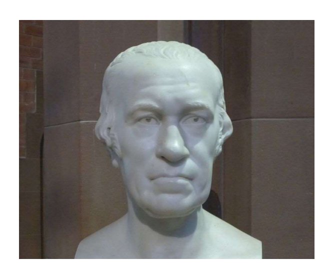
The challenge is huge:

- Global emissions from fossil fuel and industry in 2019 were 36.8 Gt CO_2
- They dropped a bit in 2020 (due to the pandemic and economic slowdown)

We need **emissions fall dramatically** in the next decades if we are to achieve the goals of the Paris agreement:

- https://unfccc.int/

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Motivation – Understanding the Energy Transition

How could rapid global decarbonisation be achieved?

There are many opinions on this, but the following are the dominant routes:

1. **Rapid growth in Renewable Energy supply**
   "Electricity projected to be main global energy carrier by 2050
   with RE giving up to 80% of this (IRENA 2019)
2. **Switching from coal power to gas & renewables (or nuclear?)**
   "UK achieved a historic milestone in 2019, with more electricity generated from zero carbon sources than fossil fuels (www.nationalgrid.com/stories)
3. **Decarbonisation of industry using CCS**
   Norway to focus on reducing emissions from industry using CCS
   (cement and waste incineration) - https://ccsnorway.com/
4. **Using energy more efficiently**
   Energy efficiency improved by 30% in the EU-28 from 1990-2016
   (average of 1.4 %/year) https://www.eea.europa.eu/
5. **Sustainable land use – reforestation and soils**
   UN-led 'Billion trees project' could sequester 100 Gt Carbon in the
   next 40 years (Thomas Crowther; Nature 569, 404–408; 2019)

Not either/or!

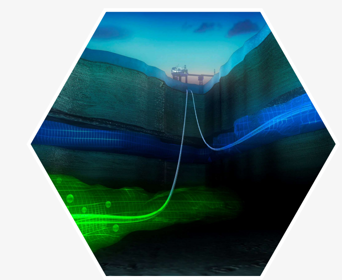
RE

and

Gas

and

CCS



and

Efficiency

and

Land-use

All of the above are needed

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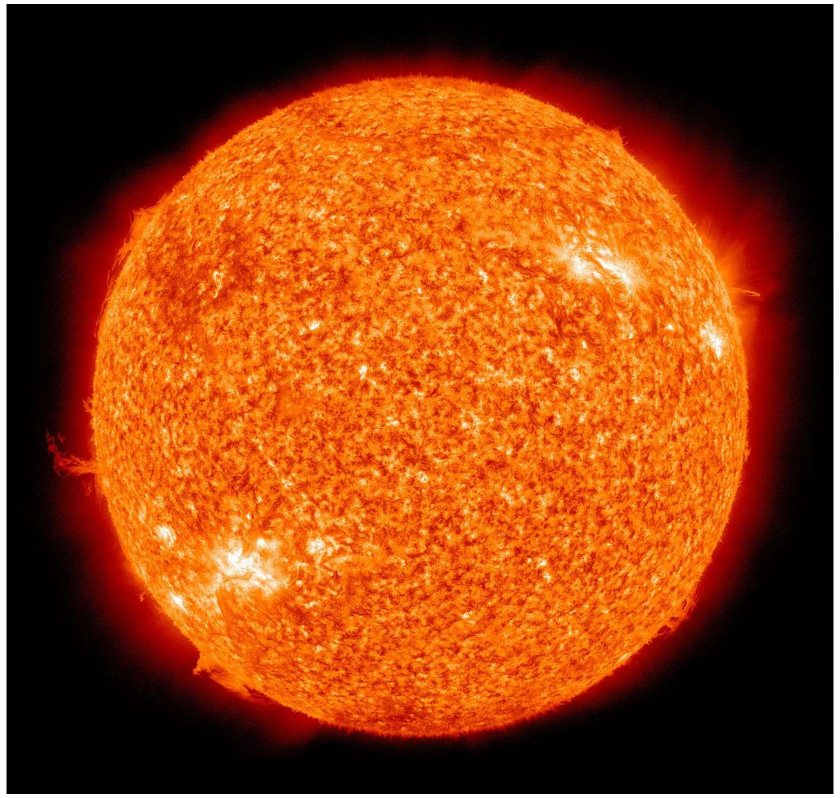
Why Hydrogen?

Some basic facts about hydrogen

- Hydrogen is the most abundant chemical substance in the universe, and the source of energy for our solar system
- Hydrogen is a naturally occurring and abundant molecule on planet earth, but it rapidly bonds with oxygen, carbon, nitrogen, aluminium, etc.
  - Many natural seeps of H_2 are found - mainly sourced from the serpentinization ultramafic rocks (Zgonnik, 2020)
- The main sources of H_2 for industry and energy are manufacture of H_2 from water (H_2O) or methane (CH_4)
  - Ammonia (NH_3) is an important energy carrier for hydrogen (and a fuel)
- Current global production of H_2 is about 69 Mt/yr (IEA, 2019):
  - Mainly used for hydrocarbon refining and fertilizer production
  - 71% of production is from CH_4 reforming, 27% from coal, 1% from EL
- Town gas: from 1940's to 1970's (in US, UK & Aus) coal gas was used as a district gas supply for fuel and lighting:
  - Coal gas contains 50% H_2



The Sun generates energy by nuclear fusion of hydrogen into helium

The natural gas seeps of Chimaera in Turkey contain 7-11% H_2
Photo from https://www.amusingplanet.com/

Hydrogen production (at industrial scale)

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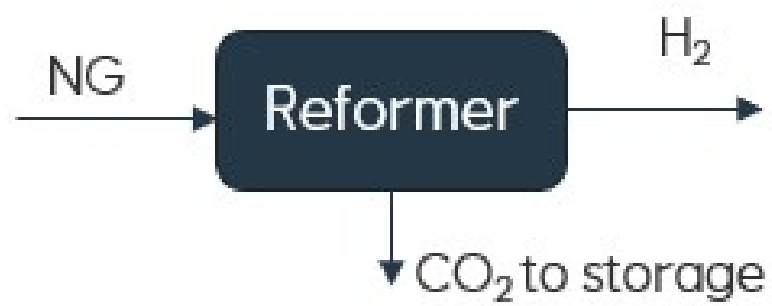
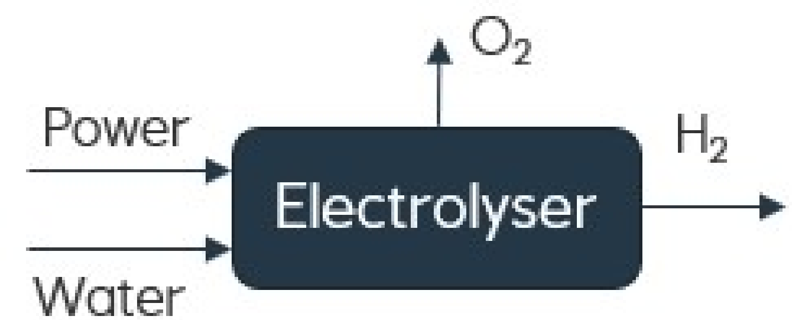
H_2 from methane reforming:

- Can be produced at large scales
- Uses less energy than H_2 generated by electrolysis
- Lower overall cost (including CCS)



$CH_4 + 2H_2O = 4H_2 + CO_2$
(ATR process)



$H_2O = H_2 + ½O_2$

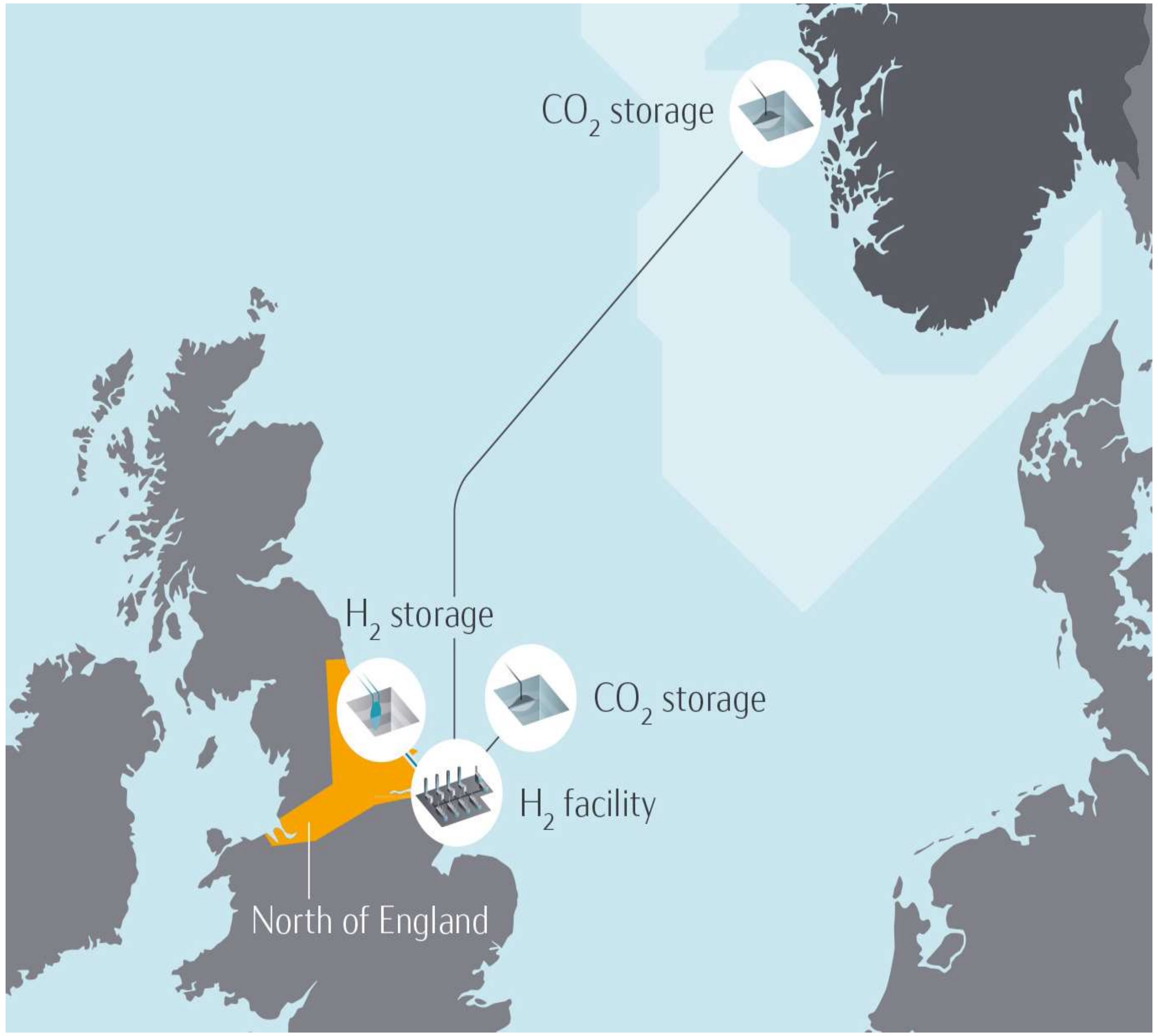
Guideline Dimensions	Methane Reforming	Electrolysis
Largest Installed Plant Capacity	2 100 MW (Qatar)	100 MW (alkaline), 20 MW (PEM)
Energy demand (Heat of reaction in kW/kg H_2)	6	40
CO_2 footprint of produced hydrogen (kg CO_2-eq per kg H_2)	1 – 2 (95+ % CO_2 capture)	0 – 30 (Depending on grid CO_2 footprint)
Fresh Water consumption (liter per Nm^3 H_2)	0.4-0.5	1
Capital Cost (USD / kW_{HHV})	800 – 1 100	800-1600 (alkaline) 1500 - 3 000 (PEM)

Summary of published data from various sources, courtesy of Jostein Pettersen, Equinor

H21 North of England

- System approach to decarbonise residential heating and distributed gas use (fuel switch from NG to H_2)
- Large-Scale: 12.5% of UK population, ~85 TWh
- Conversion starts 2028 with stepwise expansion to 2035 replacing more than 3.7 million appliances
- 17-18 Mt CO_2 reduction per year
- Security of supply - copes with seasonal demand
- Hydrogen produced from natural gas (Autothermal reformer with CCS).
- Offshore CO_2 storage in UK (with Norway option)
- A six-phase UK rollout could cover over 80% of UK's remaining emissions reduction target

Hydrogen to Humber (H2H) Saltend is a first step on the pathway towards realising this vision https://www.zerocarbonhumber.co.uk/



Full report at https://www.h21.green/projects/h21-north-of-england/

Scottish H_2 in the News

Scottish Government
Riaghaltas na h-Alba
gov.scot

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PUBLICATION - SPEECH/STATEMENT

Scottish Government Hydrogen Policy Statement

Published: **21 Dec 2020**

From: Minister for Energy, Connectivity and the Islands

Directorate: Energy and Climate Change Directorate

Part of: Economy, Energy, Environment and climate change

ISBN: 9781800045033

We set out our vision for Scotland to become a leading hydrogen nation in the production of reliable, competitive sustainable hydrogen, securing Scotland's future as a centre of international excellence as we establish the innovation, skills and and supply chain to underpin our energy transition.

Acorn CCS and hydrogen project drives clean energy player's growth plan

UK-based independent Storegga Geotechnologies sets scene for rapid rise in energy transition projects, building on its sub-surface knowledge

https://www.upstreamonline.com/energy-transition

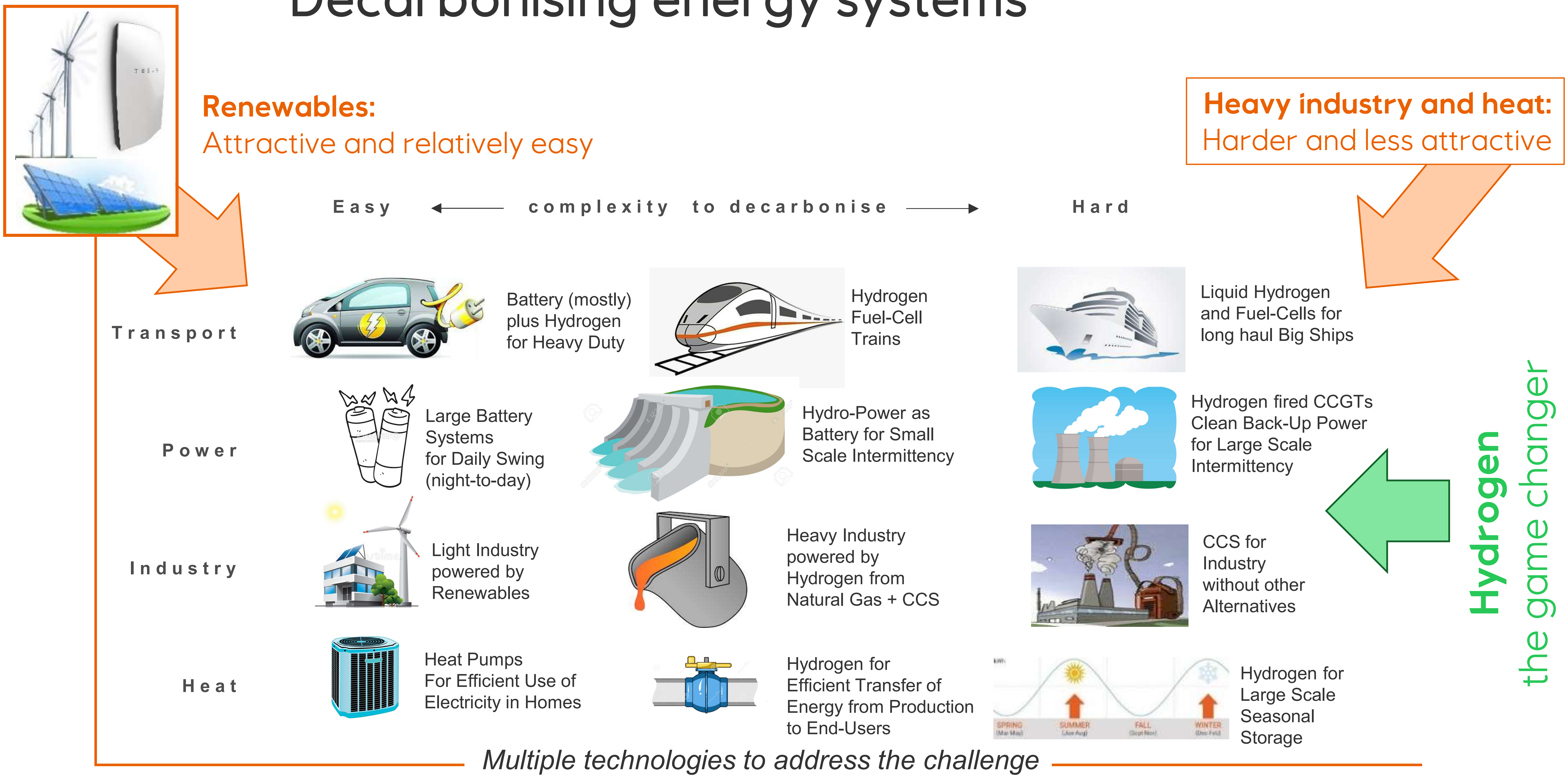
Scottish team to explore underground Hydrogen storage

By Jon Excell 2nd October 2019 11:12 am

https://www.theengineer.co.uk/

Geoscientists from the University of Edinburgh have received £1.4m funding from the Engineering and Physical Science Research Council (EPSRC) to investigate the underground storage of hydrogen in porous rocks.

Decarbonising energy systems

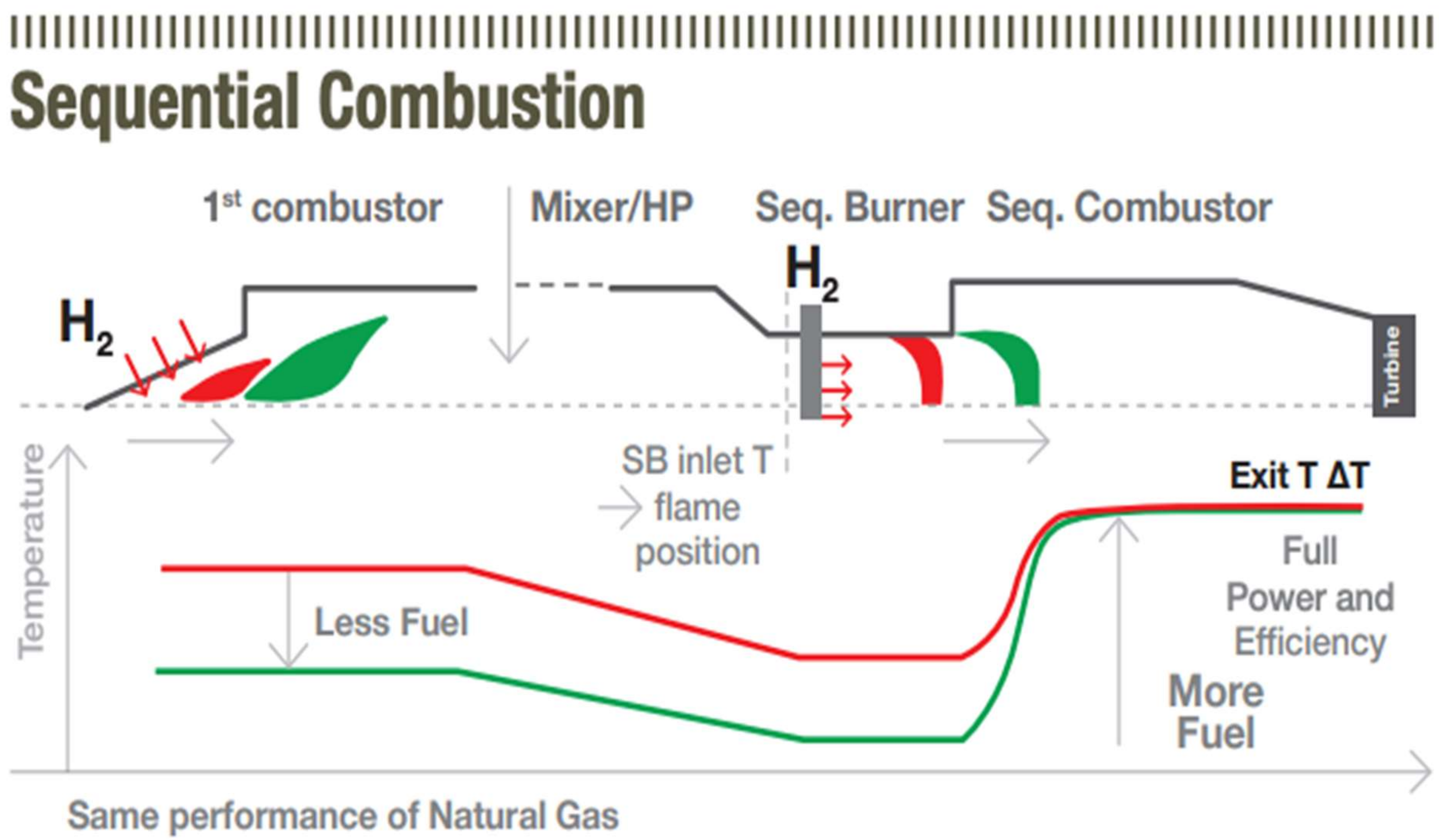


Turning Hydrogen into energy

- Power industry already has hydrogen-fueled turbines in operation (many suppliers)
- Getting from 30% H_2 blend towards 100% H_2 for turbines at industrial scales is an important ongoing challenge, but has been demonstrated at pilot/lab scales

An exciting and active research field:

- ➢ Research on auto-ignition and H_2 flame stabilization (Reheat2H2 Project, Sintef, NTNU, Ansaldo)
- ➢ Ansaldo's reheat scheme turbine: firing temperature of 1st stage controls ignition time and flame stabilization in 2nd stage
- ➢ Other suppliers are looking at "multi-cluster" H_2 combustors



Courtesy of Ansaldo Energia

The rainbow of Hydrogen generation

a brief narrative

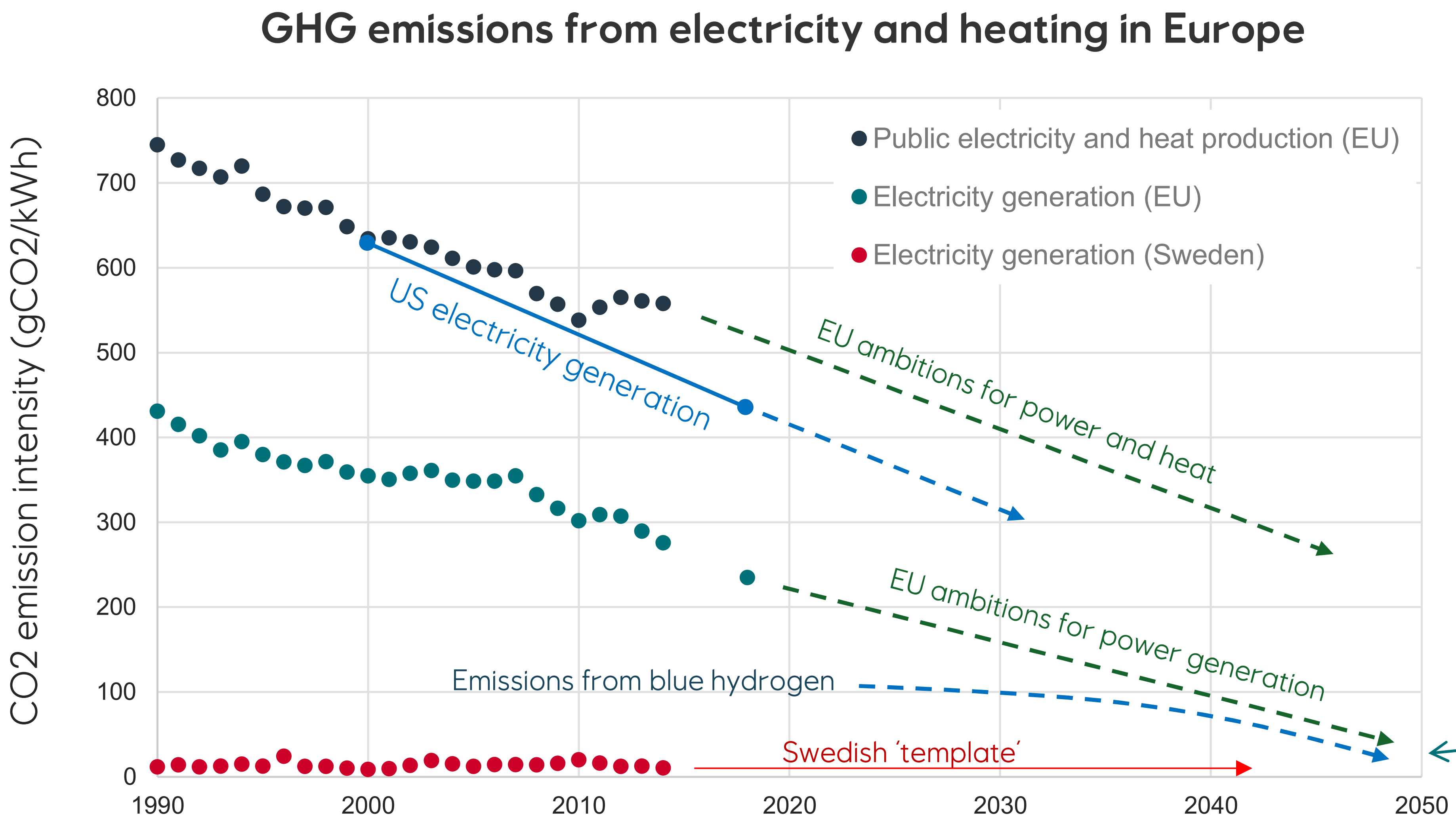
- Grey hydrogen is H_2 produced by steam reforming of natural gas
- Pink hydrogen is H_2 produced by using Nuclear energy
- Turquoise hydrogen is from pyrolysis/cracking of natural gas
- Green hydrogen is H_2 produced by electrolysis and renewable electricity
- Blue Hydrogen is H_2 produced by steam reforming of natural gas along with CCS.

Since green hydrogen uses RE why not just focus on that? Green must be good?

- Unfortunately, the current electrical power supply is far from green – so for the next few decades blue hydrogen will have lower overall emissions profile than green hydrogen
- To develop a hydrogen-based energy system we need both blue and green hydrogen as part of the pathway to a **fully decarbonised economy**

GHG emissions from electricity and heating in Europe

The EU is making good progress in decarbonising electrical power generation, but won´t reach the ´Swedish target level´ before 2050



Blue hydrogen is better for decarbonising Europe than green hydrogen
(for the next 2-3 decades)

The long term target for GHG emissions from production of hydrogen could be <50 gCO_2/kWh

Data Source https://www.eea.europa.eu

CCS – How, why, what if?

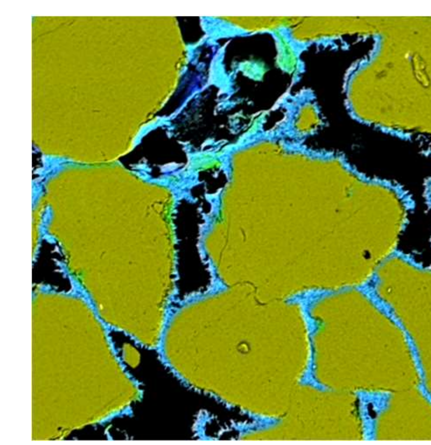
Carbon capture and storage (CCS) is set of technical solutions to remove CO_2 from industrial processes and inject the CO_2 into the subsurface in order to isolate it from the atmosphere

CO_2 Capture refers to the removal carbon dioxide from point sources of emissions

CO_2 Storage means long-term geological storage

Greenhouse Gas Removal: a related set of direct and indirect ways for removing CO_2 from the atmosphere (BECCS, DAC, forestry, land use)

The point is decarbonisation of our society!



Rock pores

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But how do we know if storage is safe in the long term?

1. There are many natural stores of CO_2 in volcanically active regions of the world:
   - Bravo Dome in New Mexico contains 1.6 Gigatons of CO_2 which has been there for approximately 1.3 million years (Sathaye et al. 2014. PNAS)
2. Humans (especially the Romans!) have been living alongside natural CO_2 vents for 1000's of years
3. Study of a 400-thousand-year-old leaky fault in a CO_2 volcanic region (Paradox Basin Utah) shows a maximum leakage rate of around 870 tonnes/yr - at the Crystal Geyser tourist spot! (Burnside et al. 2013; Geology, 41, 471-474)

So the most leaky fault on earth (in a volcanic region) is equivalent to annual emission of 100 Norwegians!

Natural CO_2 vent at Mefitiniella Polla, Italy. The seep has claimed animal lives but no human fatalities have occurred.
Photo from SCCS
http://www.sccs.org.uk/features/italyseeps.html

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Is large-scale CCS realistic? What would it take?

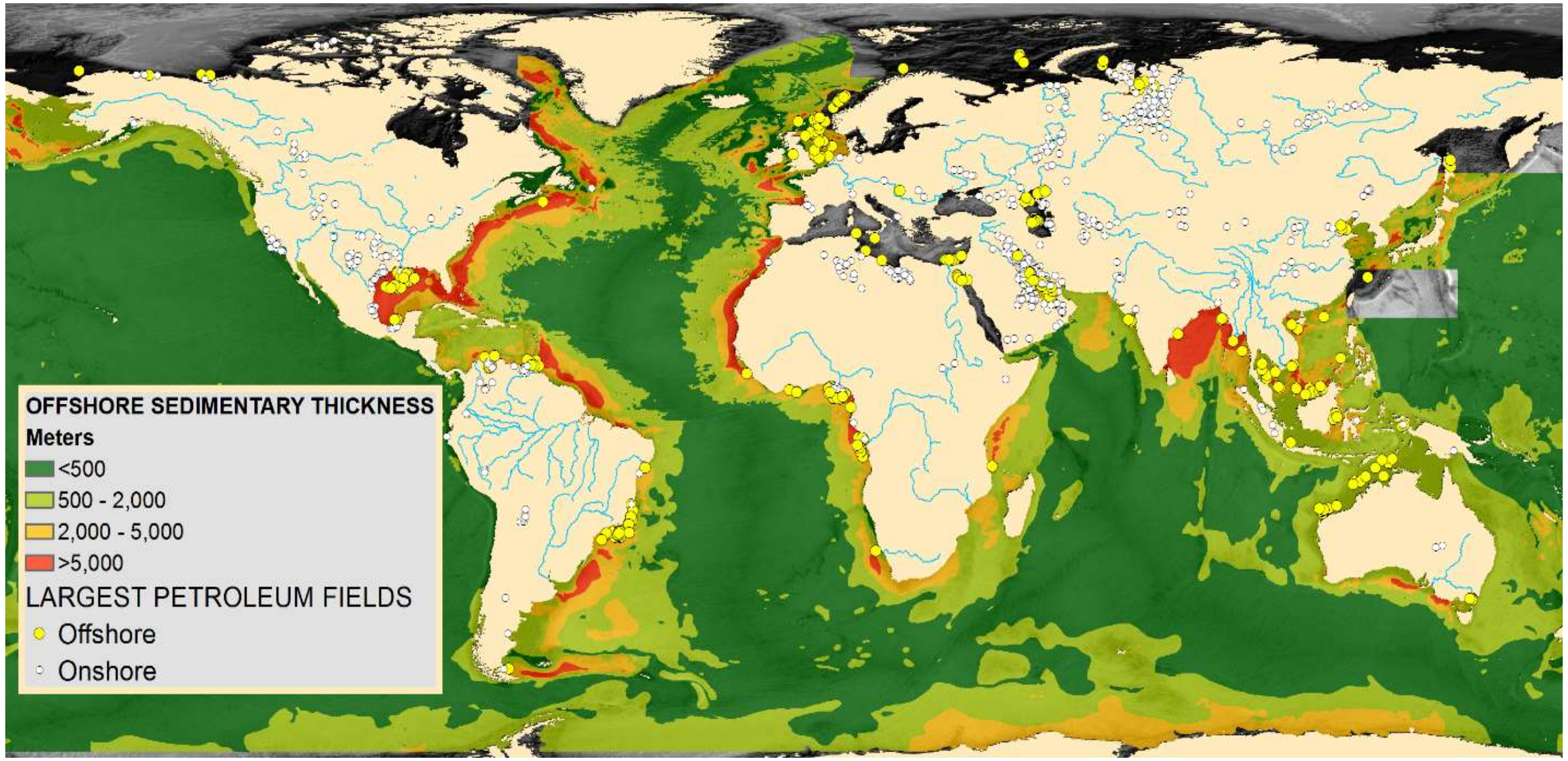
Recent study by Ringrose & Meckel, Scientific Reports (2019) on offshore global CO_2 storage resources
https://www.nature.com/articles/s41598-019-54363-z

- Uses basin geo-pressure approach
- Projected growth of CO_2 injection wells from historical hydrocarbon well developments
- Captures 'industrial maturation' phases for global CO_2 storage

Main Conclusion:

- We will need ~12,000 CO_2 injection wells by 2050 to achieve 2DS goal

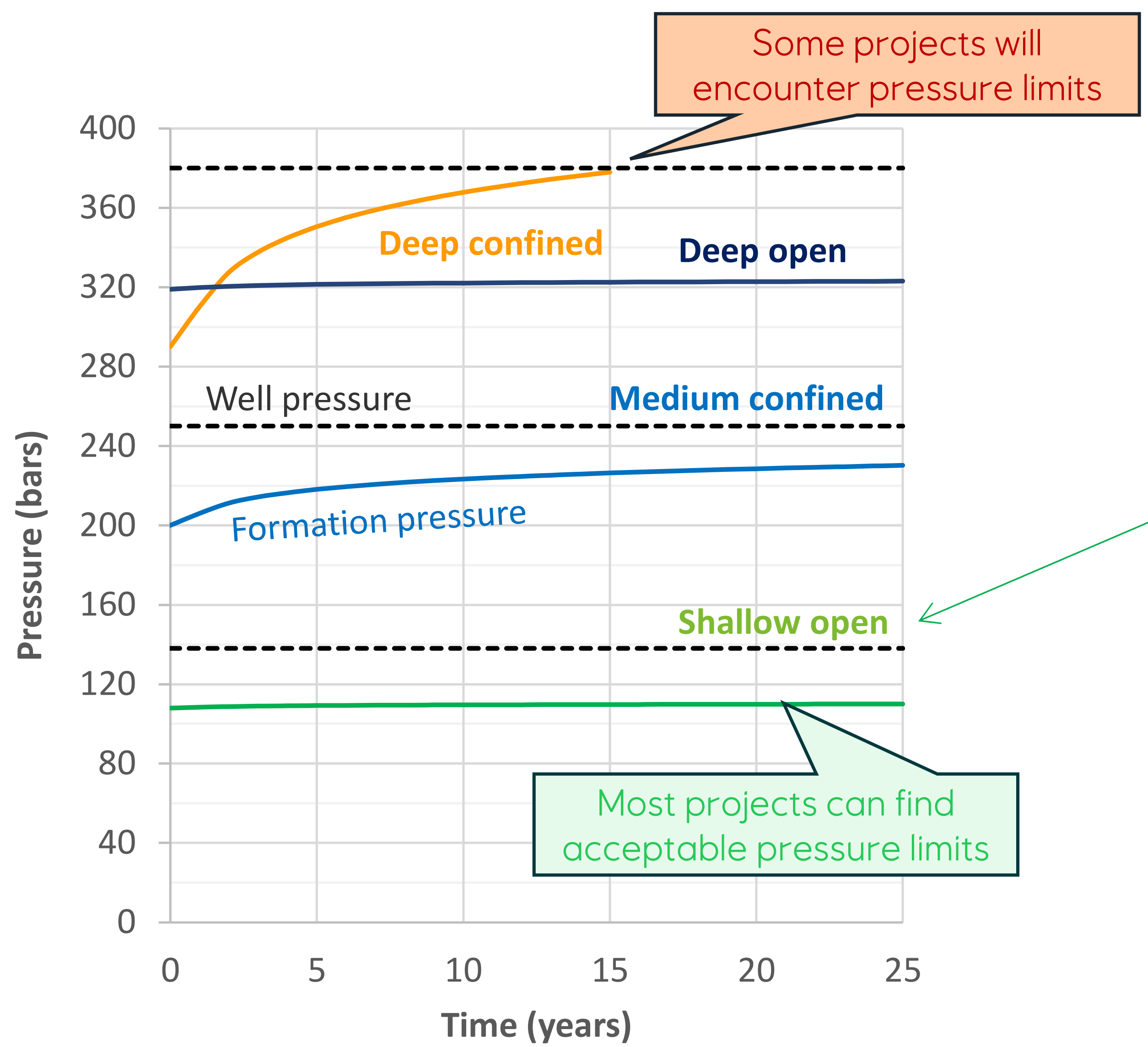
Each continental 'CCS hub' will need 100-200 wells in the next decade

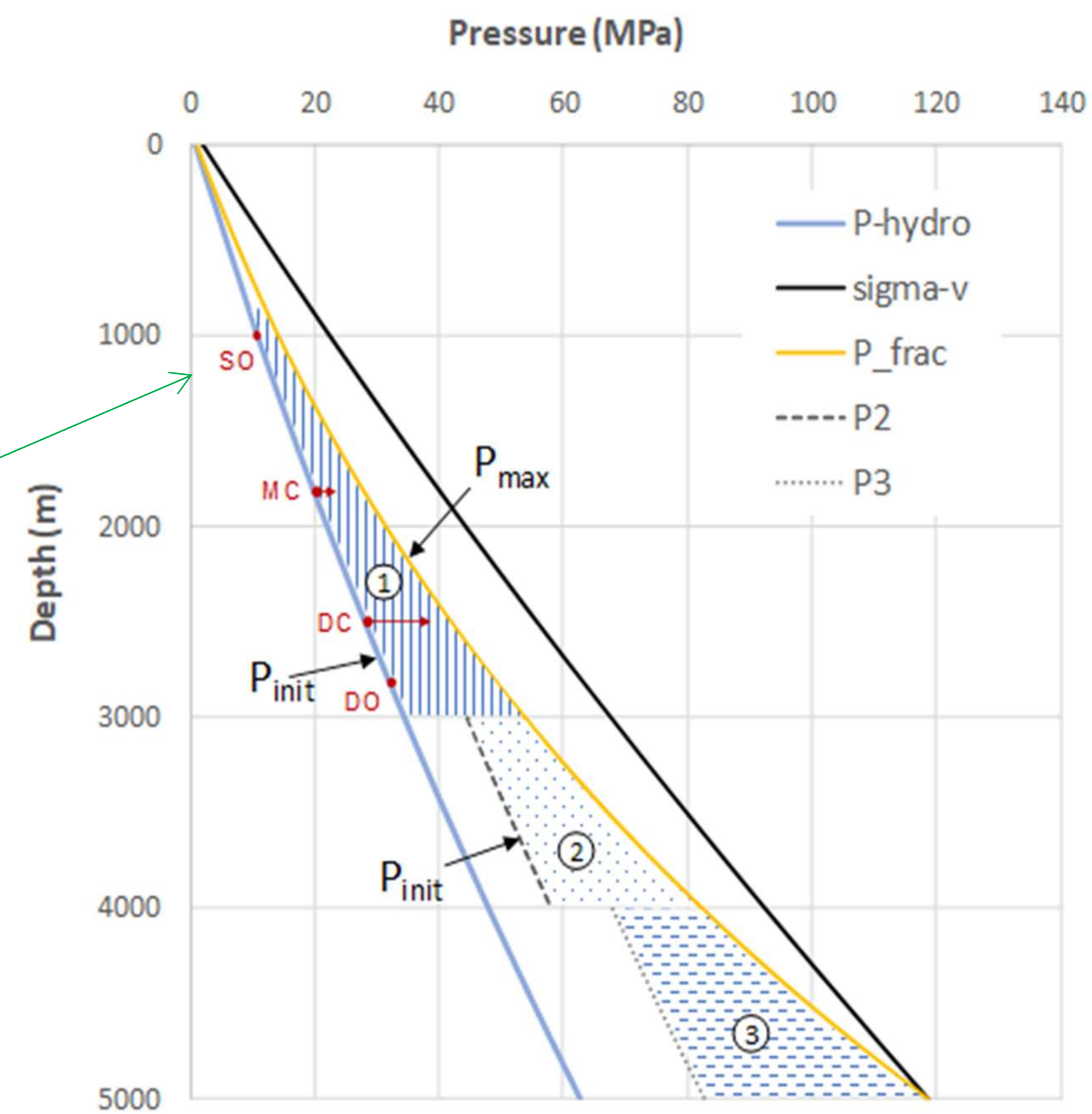


Global distribution and thickness of sediment accumulations on continental margins, with largest oilfields and main river systems (Ringrose & Meckel, 2019)

Basin geo-pressure framework for CO_2 storage scale-up

Review of basin pressure data from Norway and Gulf of Mexico applied to offshore CO_2 storage concepts (Ringrose & Meckel, 2019)





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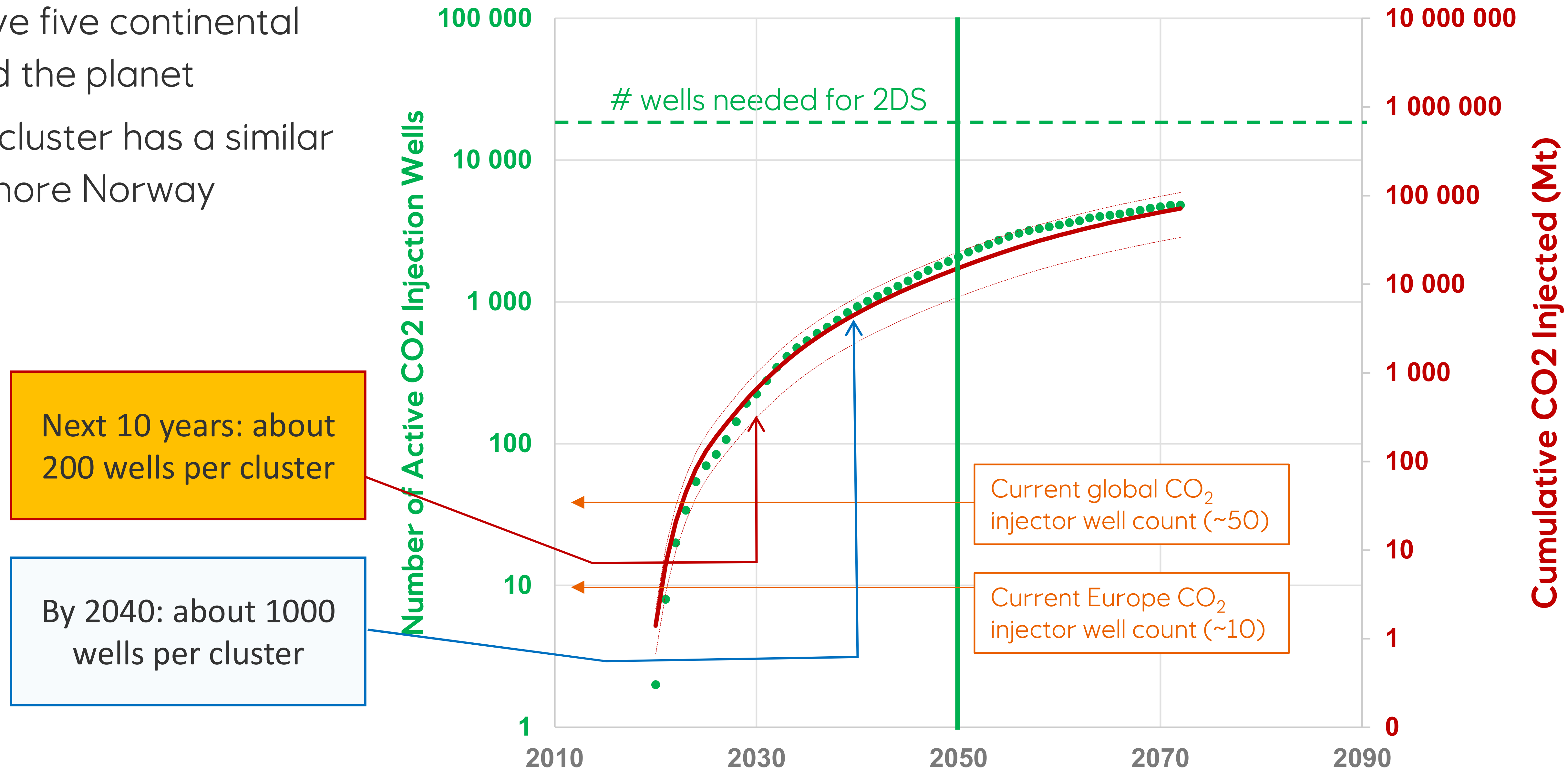
Characteristics of a continental CCS cluster

- Let´s assume we have five continental CCS clusters around the planet
- And that each CCS cluster has a similar well drill rate to offshore Norway
- What would the storage build-out rate look like?



H21: Facilities concept

Facilities concept is focused on a sub-sea development (with shipping options)

- 12 sub-sea wells drilled from 4 templates / 120 km pipe (26")
- Delivering 17-18 Mt CO_2 reduction per year

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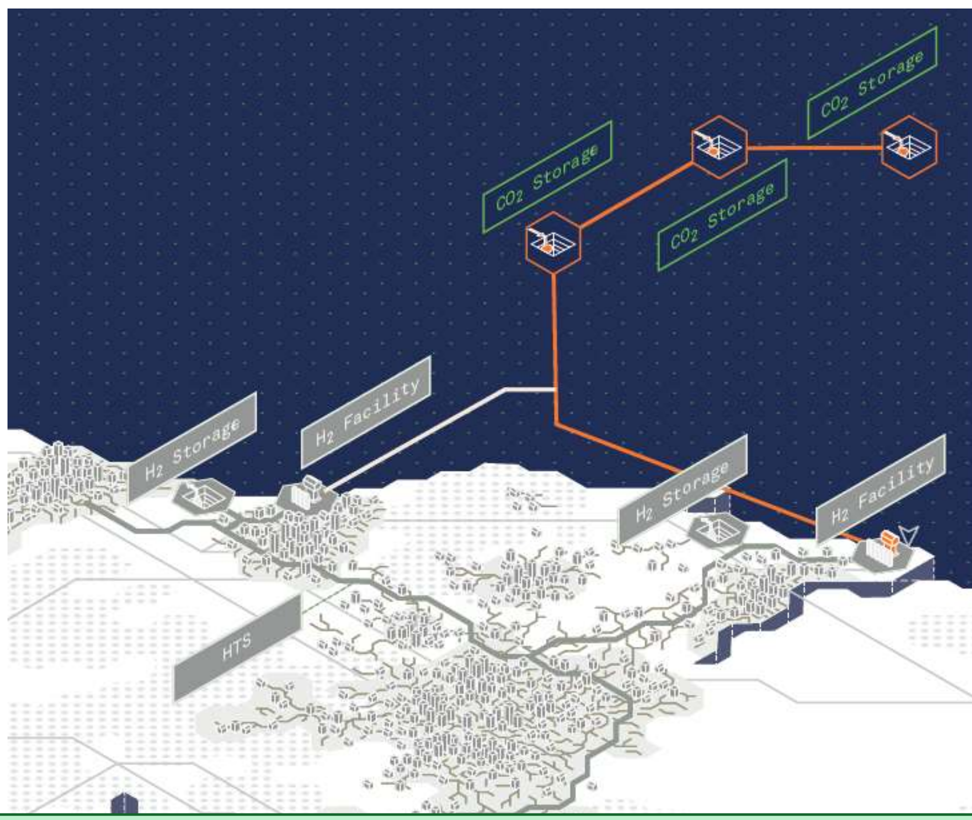
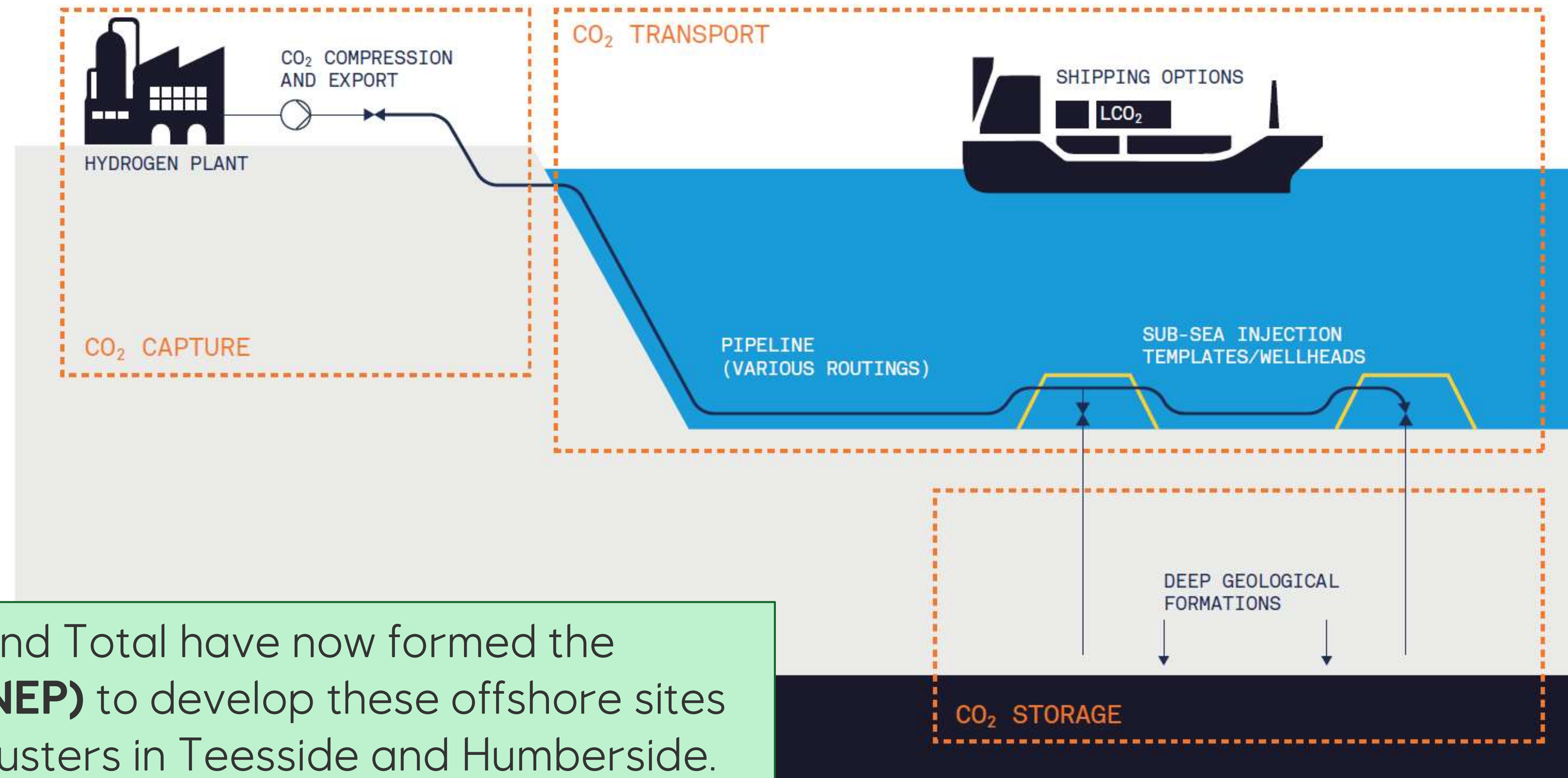
Northern Gas Networks

Cadent





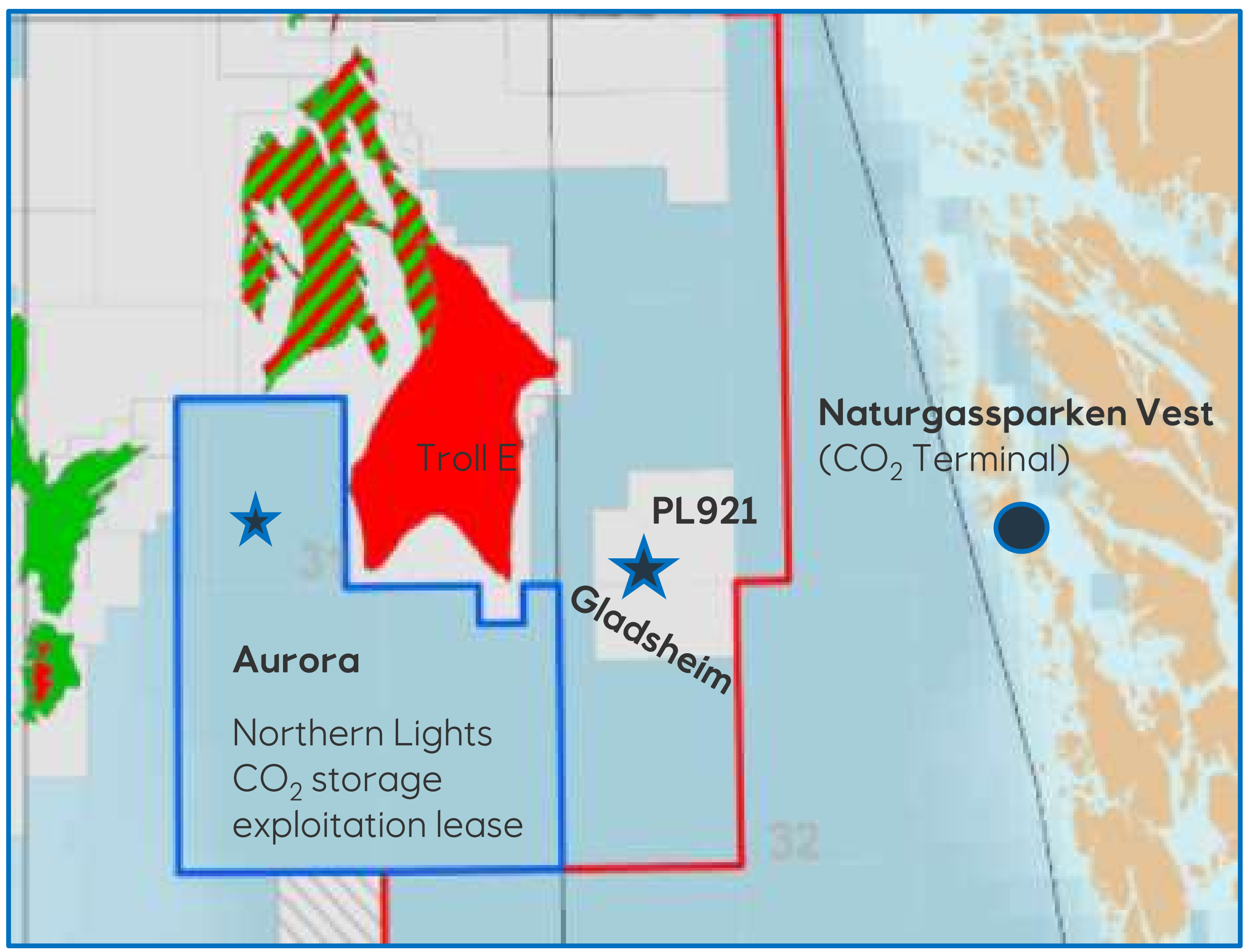
bp, Eni, Equinor, National Grid, Shell and Total have now formed the **Northern Endurance Partnership (NEP)** to develop these offshore sites to support decarbonized industrial clusters in Teesside and Humberside.

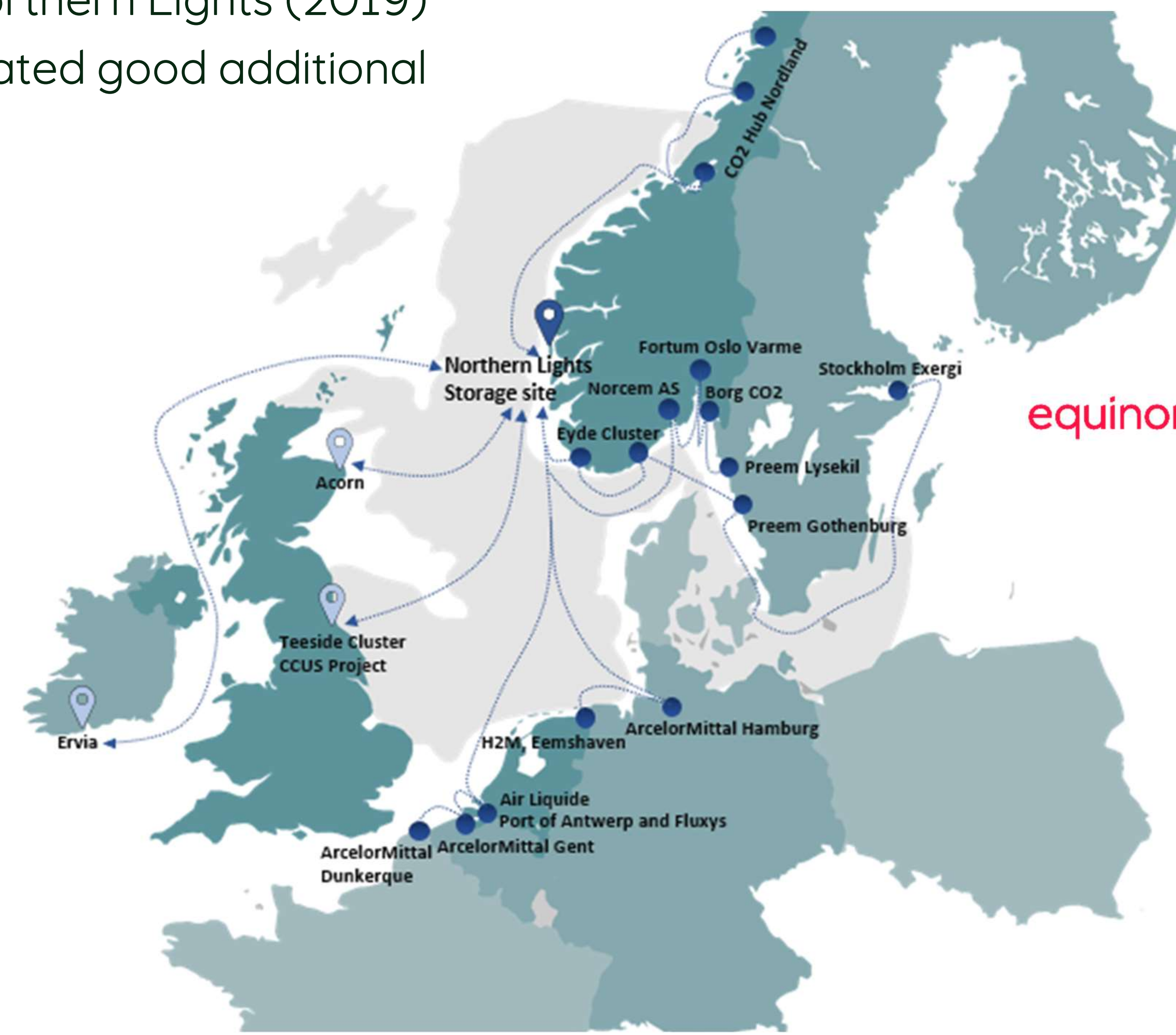
The Northern Lights "open storage" facility concept

Combining a "CO_2 capture market development" strategy with a smart and cost-effective exploration and development strategy:

- Aurora (EOS) well sanctioned for FID & development in Northern Lights (2019)
- Gladsheim exploration well (drilled in 2019) has demonstrated good additional storage potential in a nearby structure

The Longship CCS project
https://ccsnorway.com/

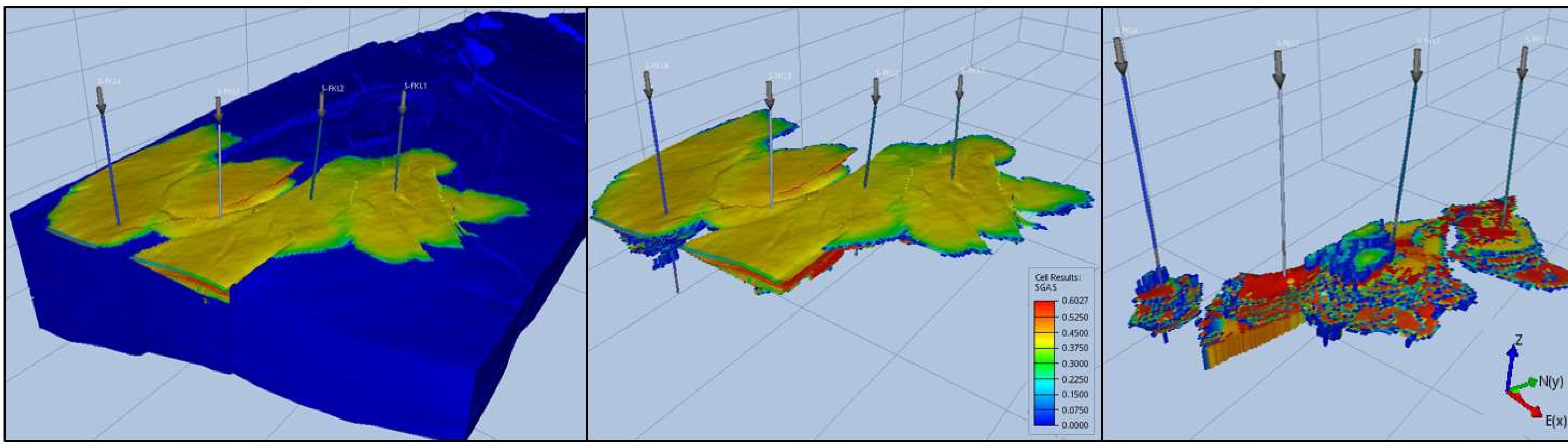




Planning for future CO_2 storage scale-up

Reservoir simulations of Giga-tonne scale storage

- Here 2.4 Gt of CO_2 is injected into the Smeaheia saline aquifer model
- CO_2 plume is shown 100 years after injection start
  - *Left:* Location of the 4 injectors at southern part of the aquifer
  - *Middle:* CO_2 plume in the Viking group (depleted pressures)
  - *Right:* Higher saturation plume in the lower (un-depleted) Dunlin and Lunde formations



Simulation results courtesy of Bamshad Nazarian (paper in review)

Is Hydrogen the decarbonisation game changer?

Partly:

- It is 'probably the best beer in the world' (for decarbonisation)
- It reaches the parts that other (renewable) beers cannot reach
- Both blue and green H_2 are needed (and potentially other forms)

The real game changer is moving to a zero-net-emissions world

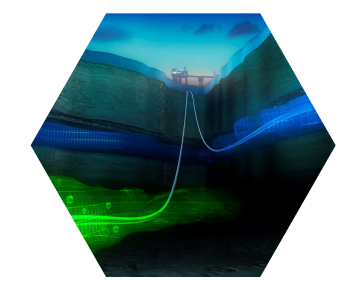
1. Gigatonnes of CO_2 need to be returned to the earth
   - from whence it came - 'geospheric return'
2. Large-scale geological disposal of CO_2 is clearly possible in terms of the available geological resources:
   - But it needs to become a routine business in the 21st Century in order to limit global warming to 2°C
3. Don't forget the 'all of the above' concept which is essential for the Energy Transition

RE

and

Gas

and **H_2**



CCS

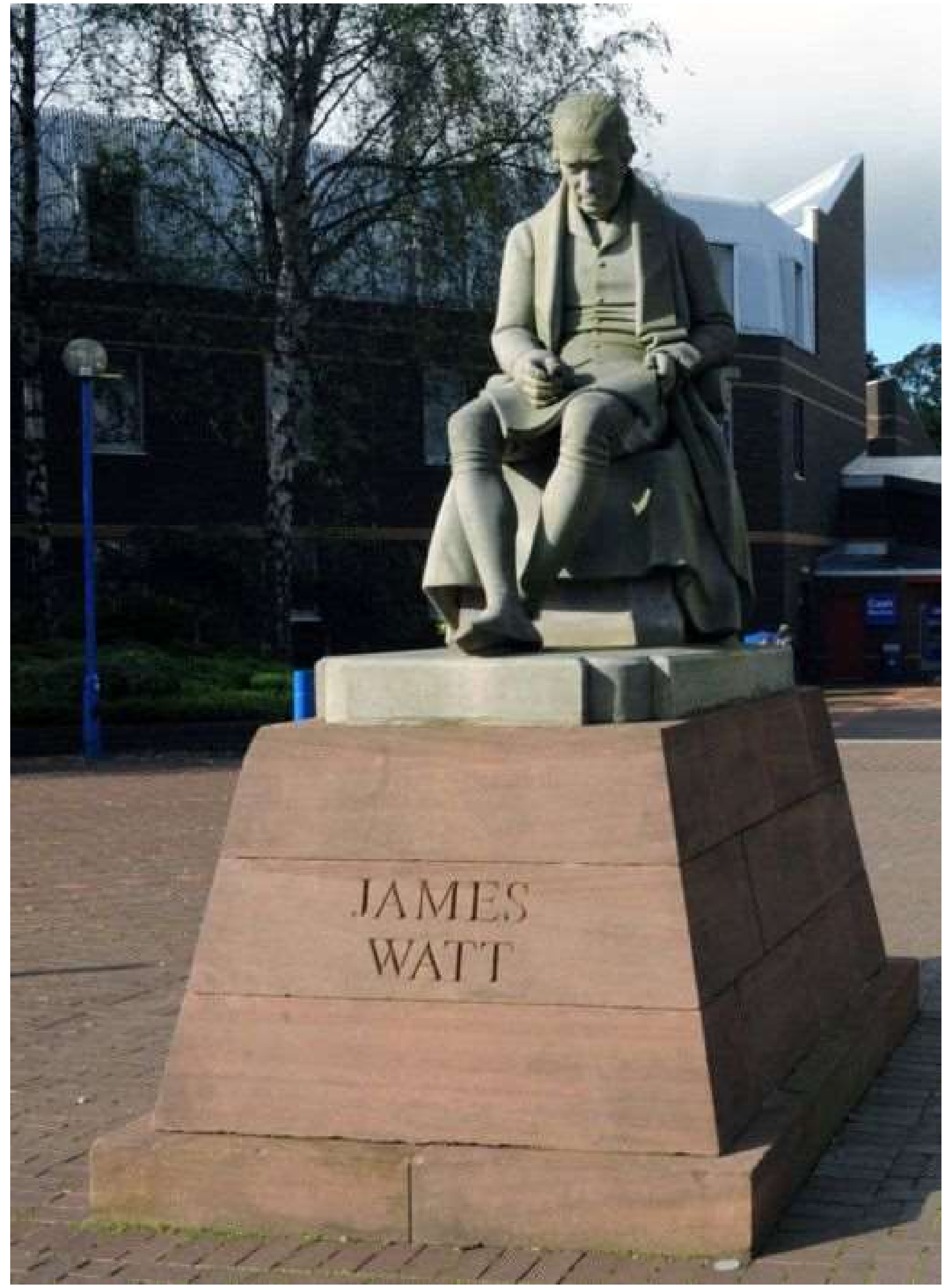
and

Efficiency

and

Land-use

All of the above are needed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