SCOTTISH Hydrogen & Fuel Cell ASSOCIATION

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Hydrogen Storage for the Clean Energy Transition

Realising Scotland's Potential

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www.shfca.org.uk

HyStorPor Final Conference

ECCI, Edinburgh 12th July 2023

Hydrogen Storage for the Energy Transition

Hydrogen will support delivery of Net Zero targets. Scotland can help to decarbonise the UK and the wider North Sea region with green hydrogen. The Scottish Government hydrogen has set out clear ambitions:

- 5GW low carbon hydrogen capacity by 2030
- 25GW low carbon hydrogen capacity by 2045
- Up to 2.5 M tonnes p.a. of low carbon hydrogen for export by 2045

Experience gained by SHFCA members together with offshore expertise will help scale up hydrogen production. Large scale hydrogen gas storage will enable better integration of offshore wind and hydrogen into the wider energy system and meet future peak seasonal demands for winter heating.

THE SCOTTISH ENERGY SYSTEM 2020
AN INFRASTRUCTURE MAP

Scottish Government
Riaghaltas na h-Alba
gov.scot

Annual Energy in 2017

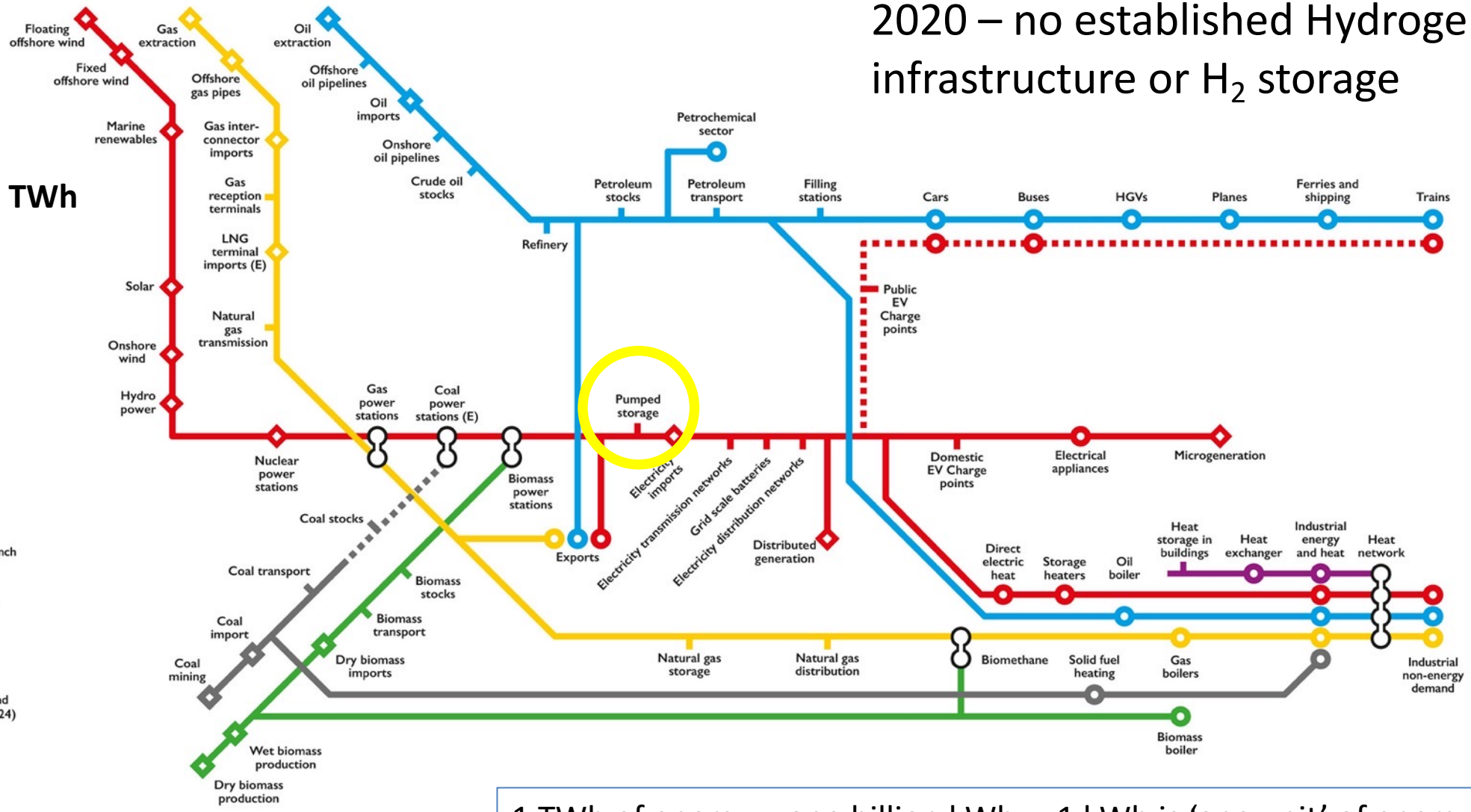
Heat = 82 TWh

Power = 38 TWh

Transport = 40 TWh

Scotland total = **160 TWh**

2020 – no established Hydrogen infrastructure or H_2 storage



1 TWh of energy = one billion kWh 1 kWh is 'one unit' of energy

Building Scotland's Hydrogen Economy: Ambition & Impact

Scottish Government Hydrogen Policy Statement (Dec 2020) set targets for:

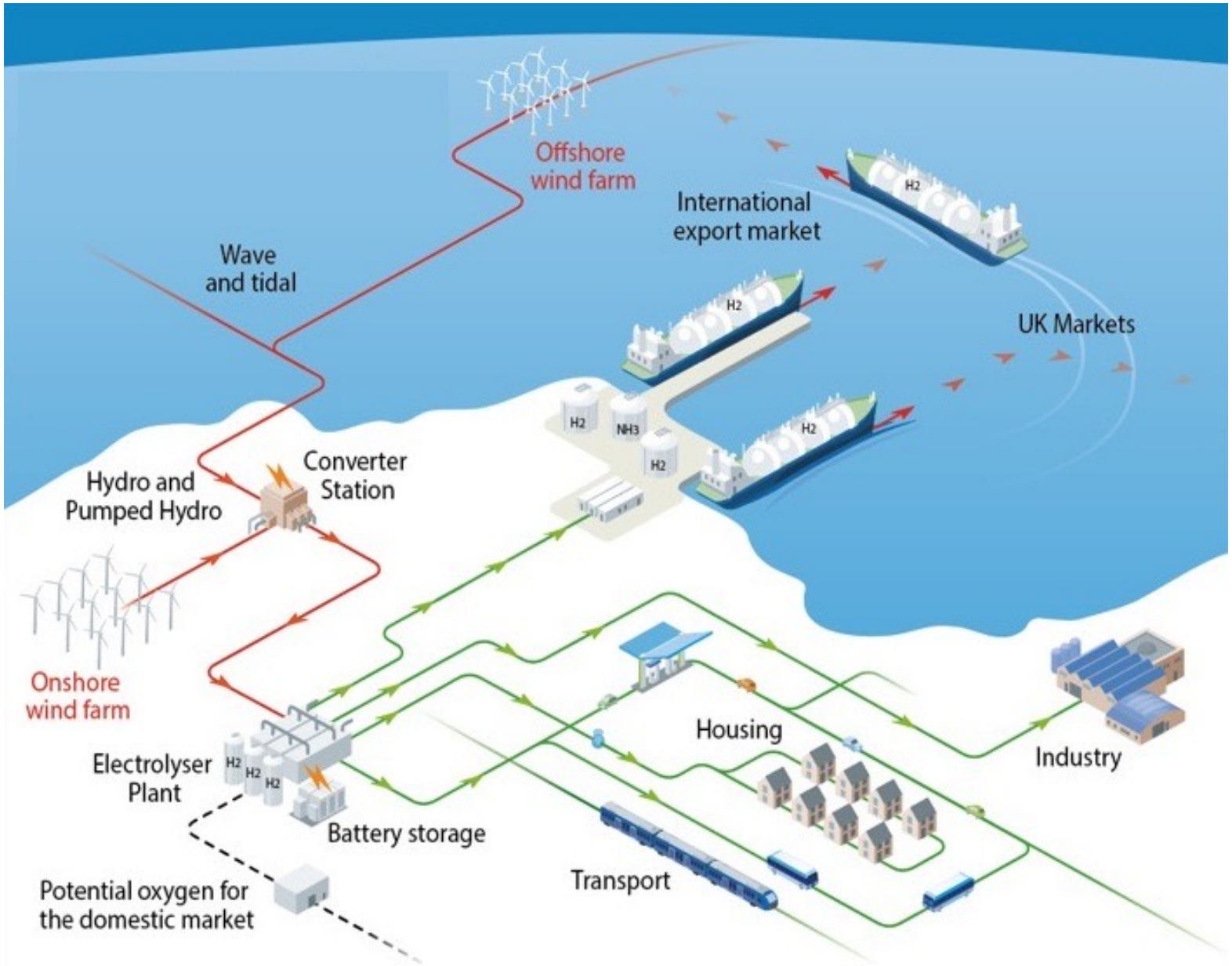
- 5GW of low carbon hydrogen production capacity by 2030
- Increasing to 25GW by 2045

Key enablers include:

- Abundant natural resources
- Experienced energy exporter
- Skilled energy supply chain
- Research and innovation expertise
- Supportive policy environment

Potential H2 economy impacts by 2045:

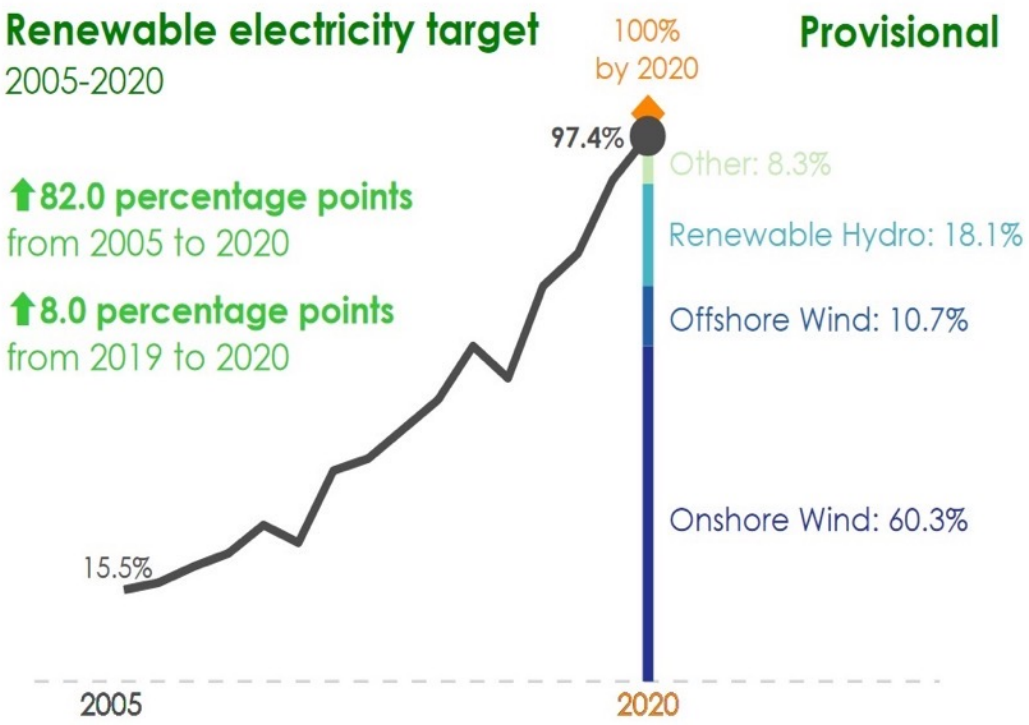
- from 70,000 to over 300,000 jobs
- GVA of between £5 - £25 billion



AN INCLUSIVE ENERGY TRANSITION

Scotland's Transition to Low Carbon Electricity

Onshore & Offshore Wind Capacity by 2035



Energy Statistics for Scotland: Q4 2020
9GW onshore wind & 1MW offshore wind

Wind Generation	GW	Timing
Existing onshore	9	2023
Existing offshore	2	2023
Additional onshore	8 - 12	2030
Additional offshore	9	2030
ScotWind offshore	27.6	2028-35
INTOG offshore	5.5	2025-30
Total Wind Potential	**55 - 60**	**2035 onwards**

Estimated Scottish onshore & offshore wind generation potential by mid 2030's

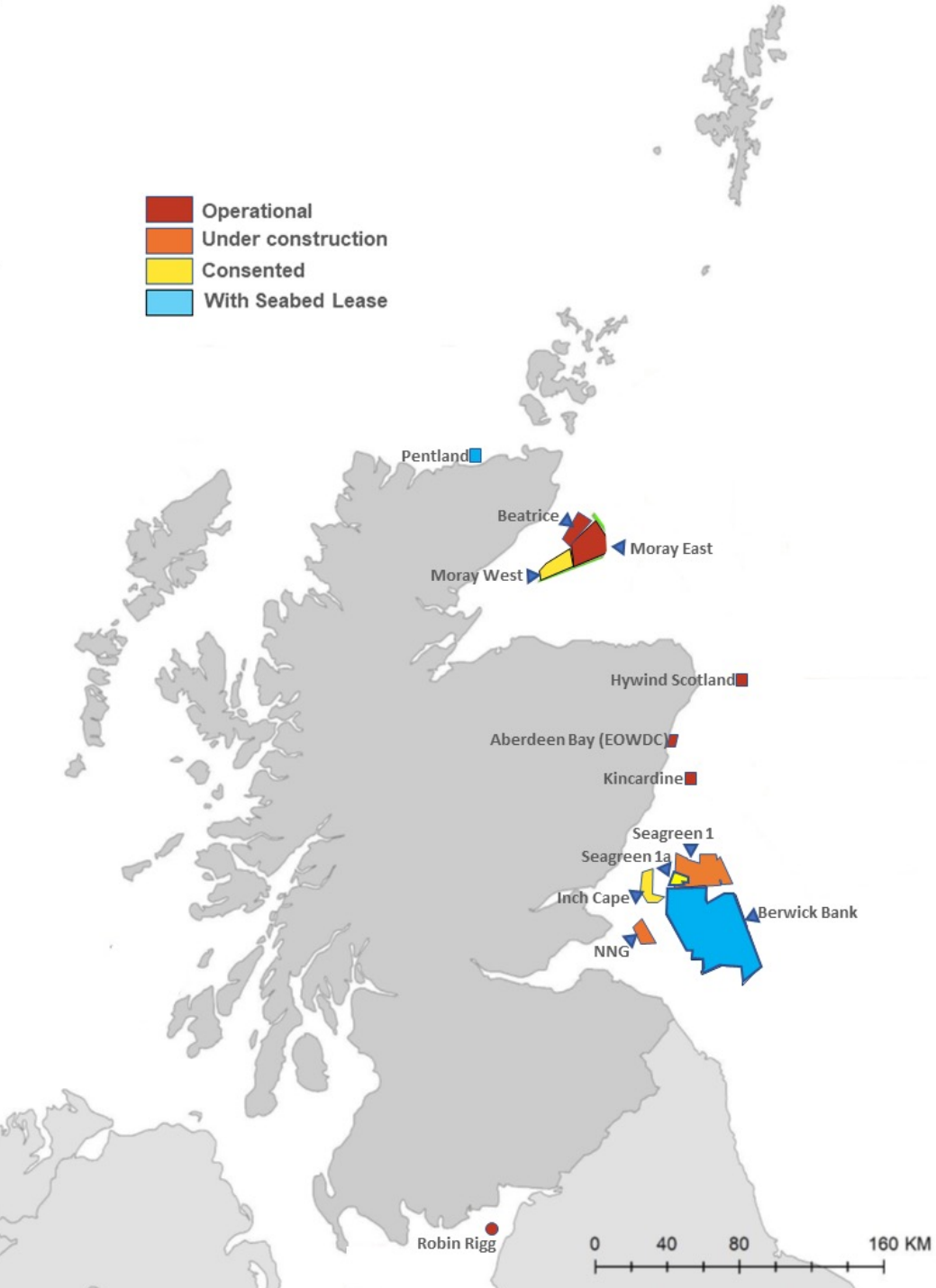
(1 GW offshore wind = about 4 TWh per year)

Scottish current projects

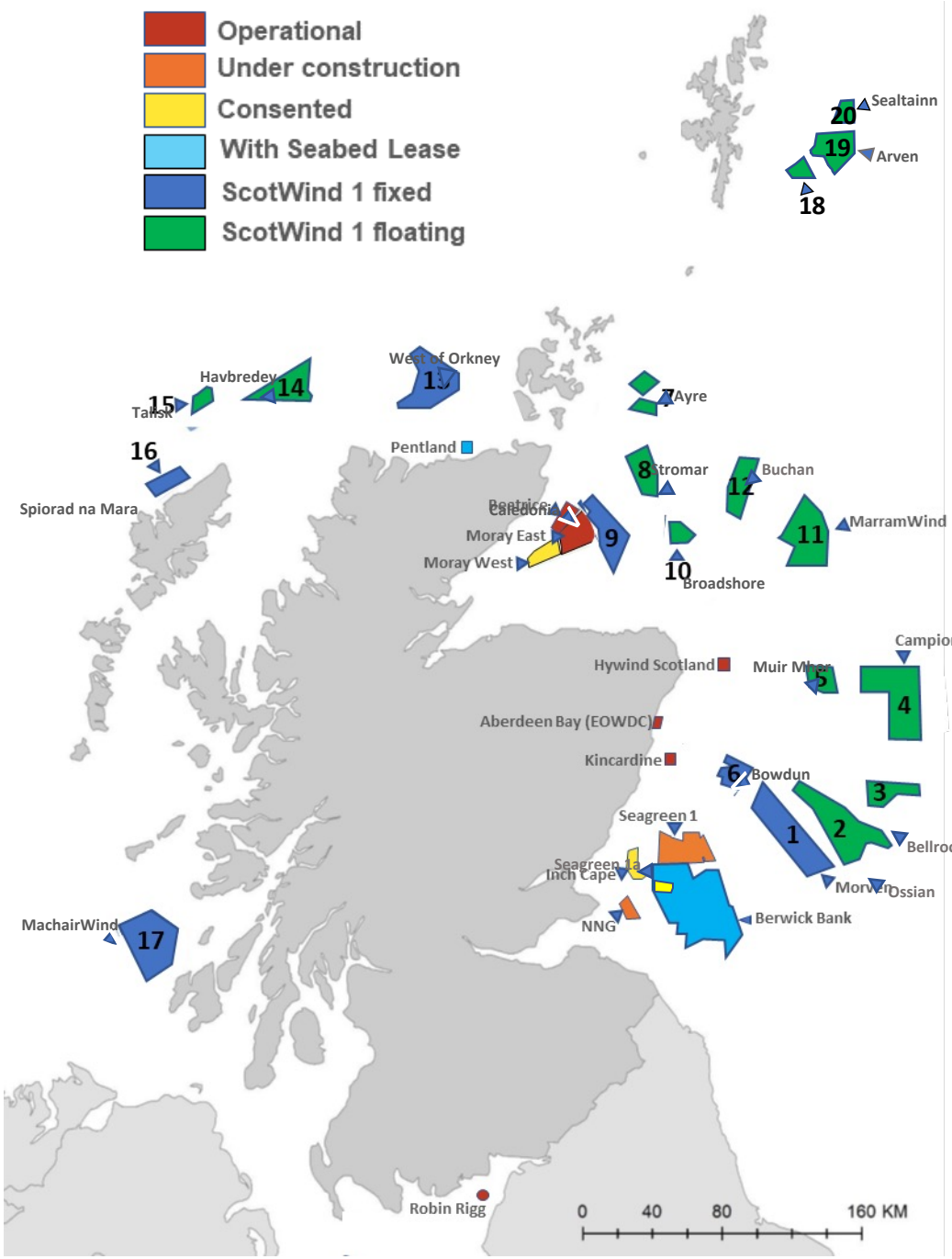
Total = 10 GW

Floating Wind = 0.18 GW (1.8%)

DeepWind
North of Scotland Offshore Wind Cluster



SITE	DEVELOPER	CAPACITY	
Robin Rigg	RWE Renewables	174MW	1890MW
Hywind Scotland	Equinor	30MW	
Aberdeen Bay	Vattenfall	93MW	
Levenmouth	ORE Catapult	7MW	
Beatrice	SSE/Red Rock Power	588MW	
Kincardine FOW	Cobra/Pilot Offshore	48MW	
Moray East	Ocean Winds	950MW	
Seagreen 1	SSE Renewables/TotalEnergies	1075MW	1523MW
NnG	EDF Renewables/ESB	448MW	
Seagreen 1a	SSE Renewables/TotalEnergies	425MW	2367MW
Inch Cape	Red Rock Power/ESB	1080MW	
Moray West	Ocean Winds	850MW	
ForthWind	Cierco	12MW	
Berwick Bank	SSE Renewables	4150MW	4250MW
Pentland FOW	Copenhagen Infrastructure Partners	100MW	



ScotWind Leasing Round

Total for Scotwind 1 = 27.6 GW

Floating wind = 18 GW

DeepWind
North of Scotland Offshore Wind Cluster

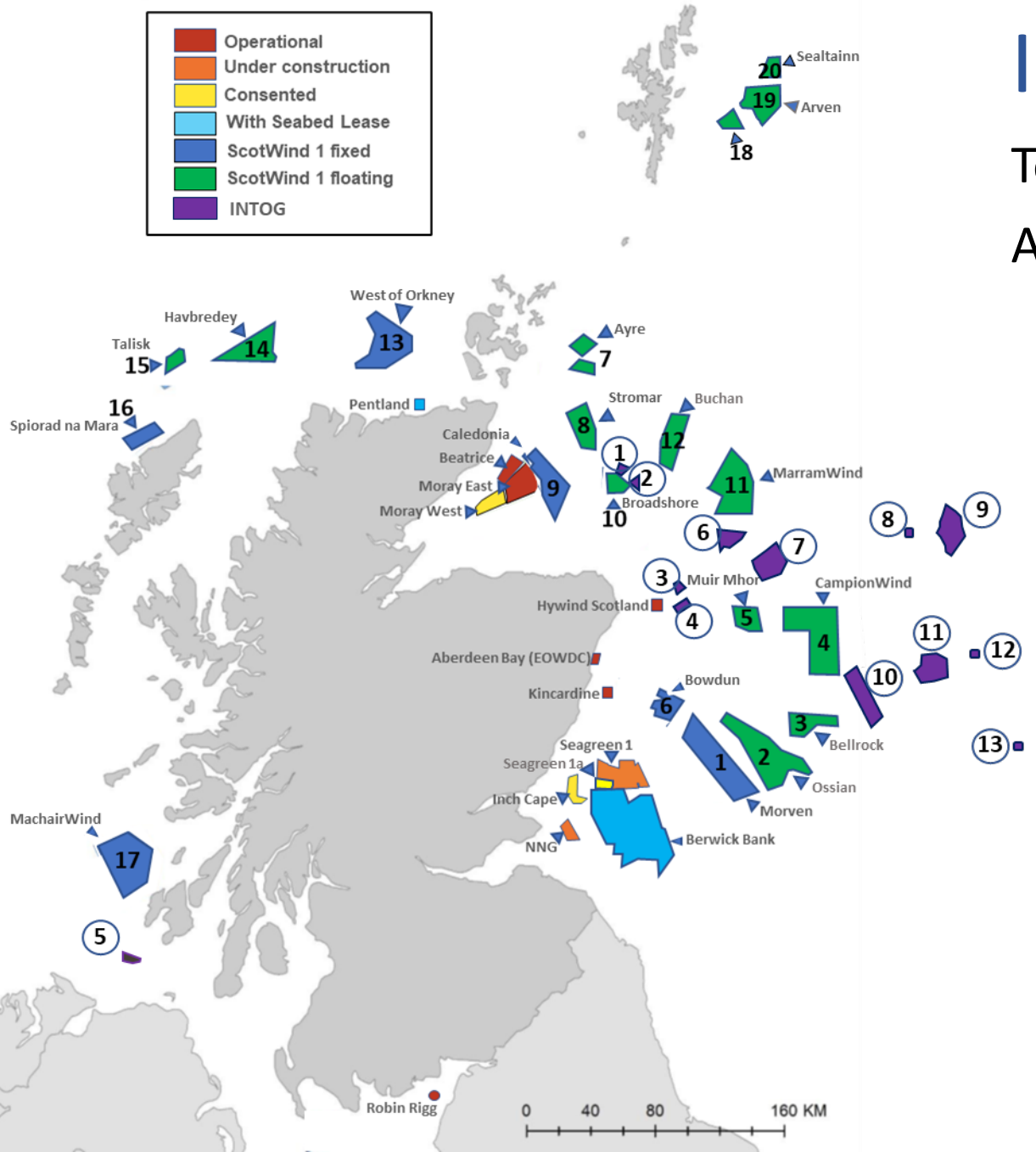
SITE	PROJECT NAME	DEVELOPERS	CAPACITY
1	Morven	BP and EnBW	2,907MW
2	Ossian	SSE Renewables, CIP and Marubeni	3,610MW
3	Bellrock	Renantis and BlueFloat Energy	1,200MW
4	CampionWind	ScottishPower Renewables and Shell	2,000MW
5	Muir Mhor	Vattenfall and Fred Olsen Seawind	798MW
6	Bowdun	Thistle Wind Partners	1,008MW
7	Ayre	Thistle Wind Partners	1,008MW
8	Stromar	Renantis, Orsted and BlueFloat Energy	1,000MW
9	Caledonia	Ocean Winds	2,000MW
10	Broadshore	Renantis and BlueFloat Energy	900MW
11	MarramWind	ScottishPower Renewables and Shell	3,000MW
12	Buchan	Floating Energy Allyance	960MW
13	West of Orkney	RIDG, Corio Generation and TotalEnergies	2,000MW
14	Havbredey	Northland Power/ESB	1,500MW
15	Talisk	Magnora Offshore Wind	495MW
16	Spiorad na Mara	Northland Power/ESB	840MW
17	MachairWind	ScottishPower Renewables	2,000MW
18	n/a	Ocean Winds	500MW
19	Arven	Mainstream RP and Ocean Winds	1,800MW
20	Sealtainn	ESB Asset Management	500MW

INTOG Leasing Round

Total Capacity = 5.4 GW

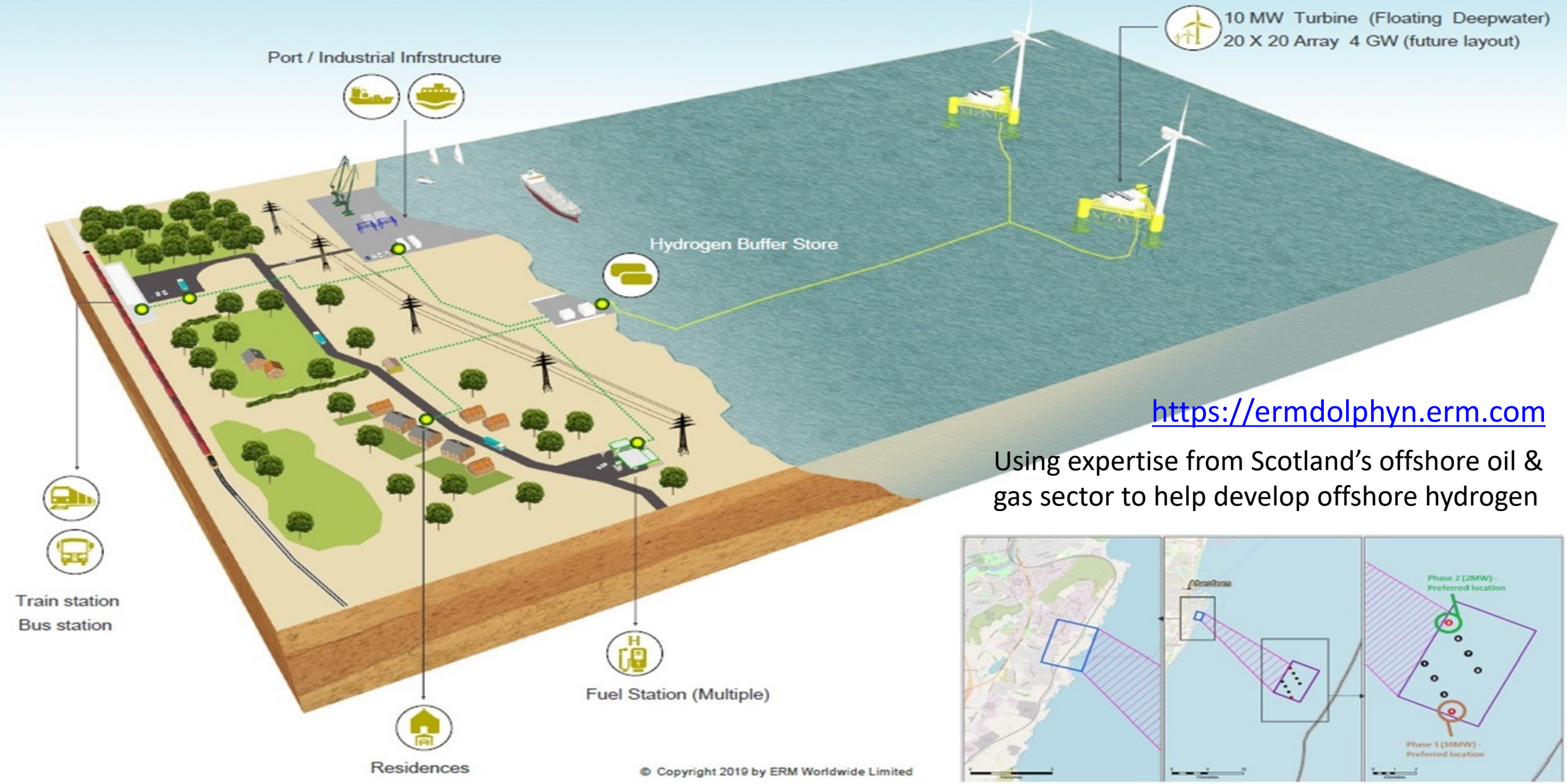
All as Floating Wind

DeepWind
North of Scotland Offshore Wind Cluster



SITE	DEVELOPERS	NAME	CAPACITY
1	BlueFloat Energy/Renantis Partnership	Sinclair	100MW
2	BlueFloat Energy/Renantis Partnership	Scaraben	100MW
3	Ørsted/Simply Blue Group	Salamander	100MW
4	BP Alternative Energy Investments	n/a	50MW
5	ESB Asset Development	Malin Sea Wind	100MW
6	Flotation Energy/Vargrønn	Green Volt	560MW
7	Cerulean Winds	Aspen	1008MW
8	Harbour Energy	HE North	15MW
9	Cerulean Winds	Beech	1,008MW
10	Cerulean Winds	Cedar	1,008MW
11	Flotation Energy/Vargrønn	Cenos	1,350MW
12	TotalEnergies	Culzean Demo	3MW
13	Harbour Energy	HE South	15MW

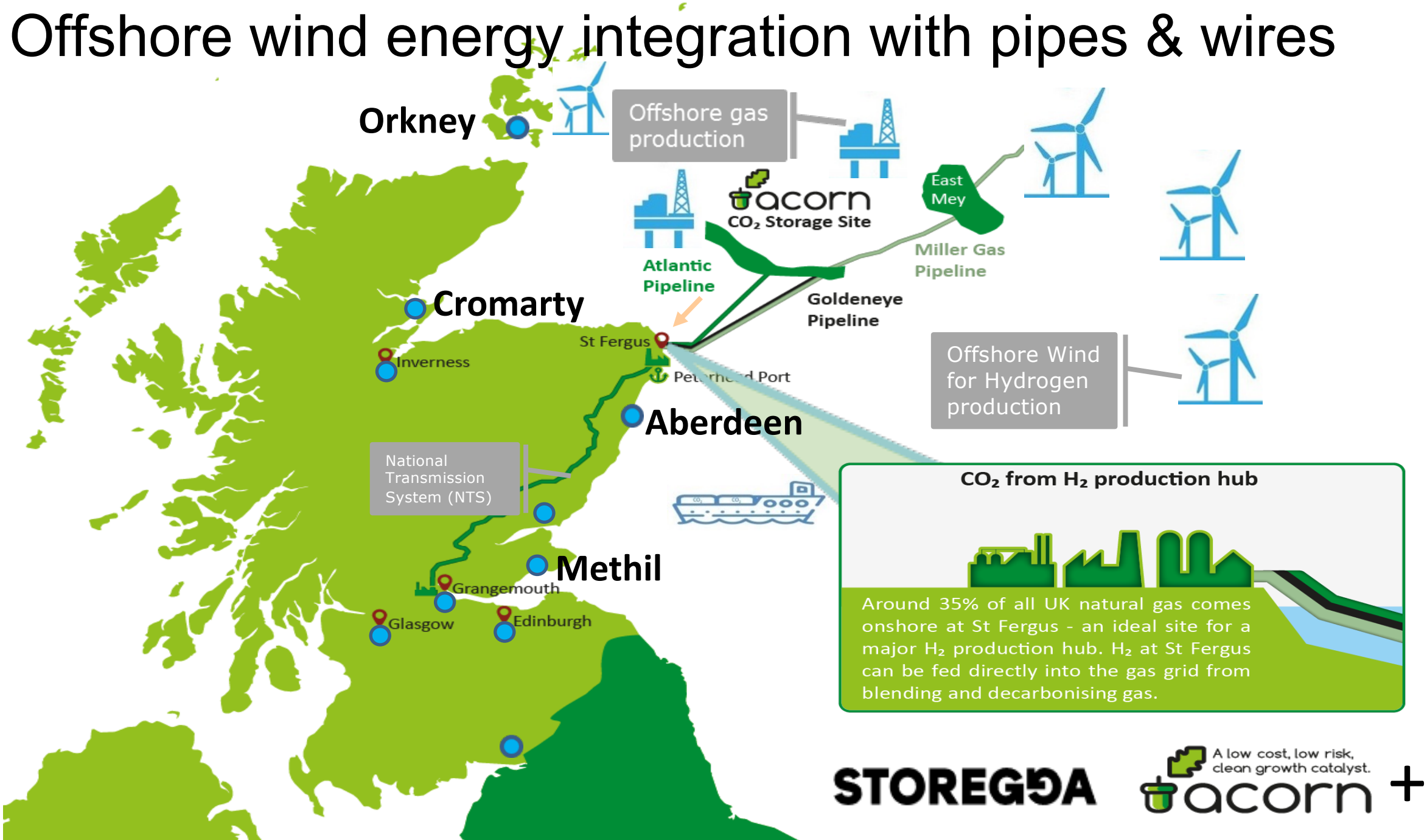
ERM DolpHyn 10MW Floating Offshore Wind & Hydrogen



https://ermdolphyn.erm.com

Using expertise from Scotland's offshore oil & gas sector to help develop offshore hydrogen

Offshore wind energy integration with pipes & wires

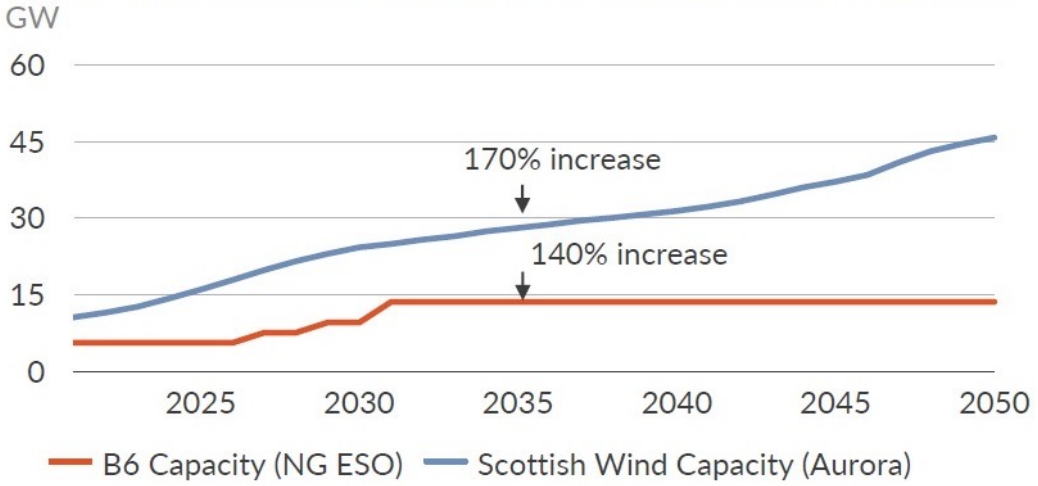


Integrating Wind: UK Constraints by 2035 & 2050

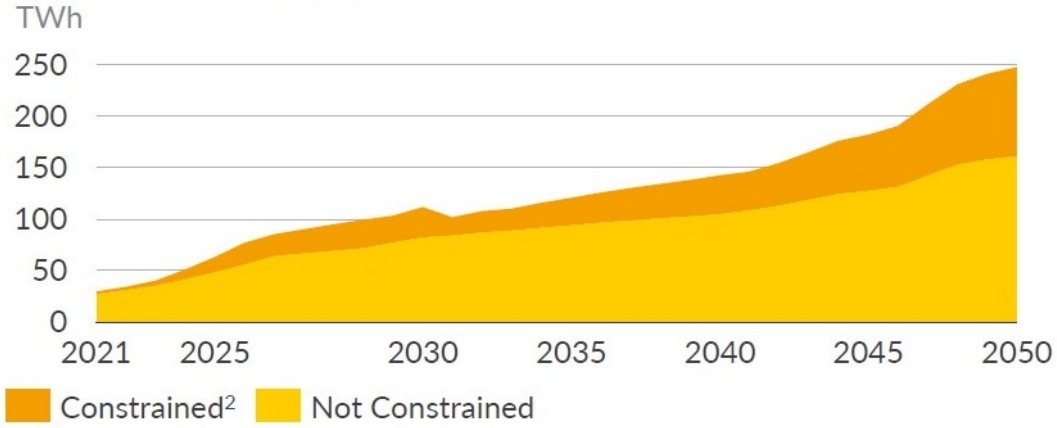
AURORA

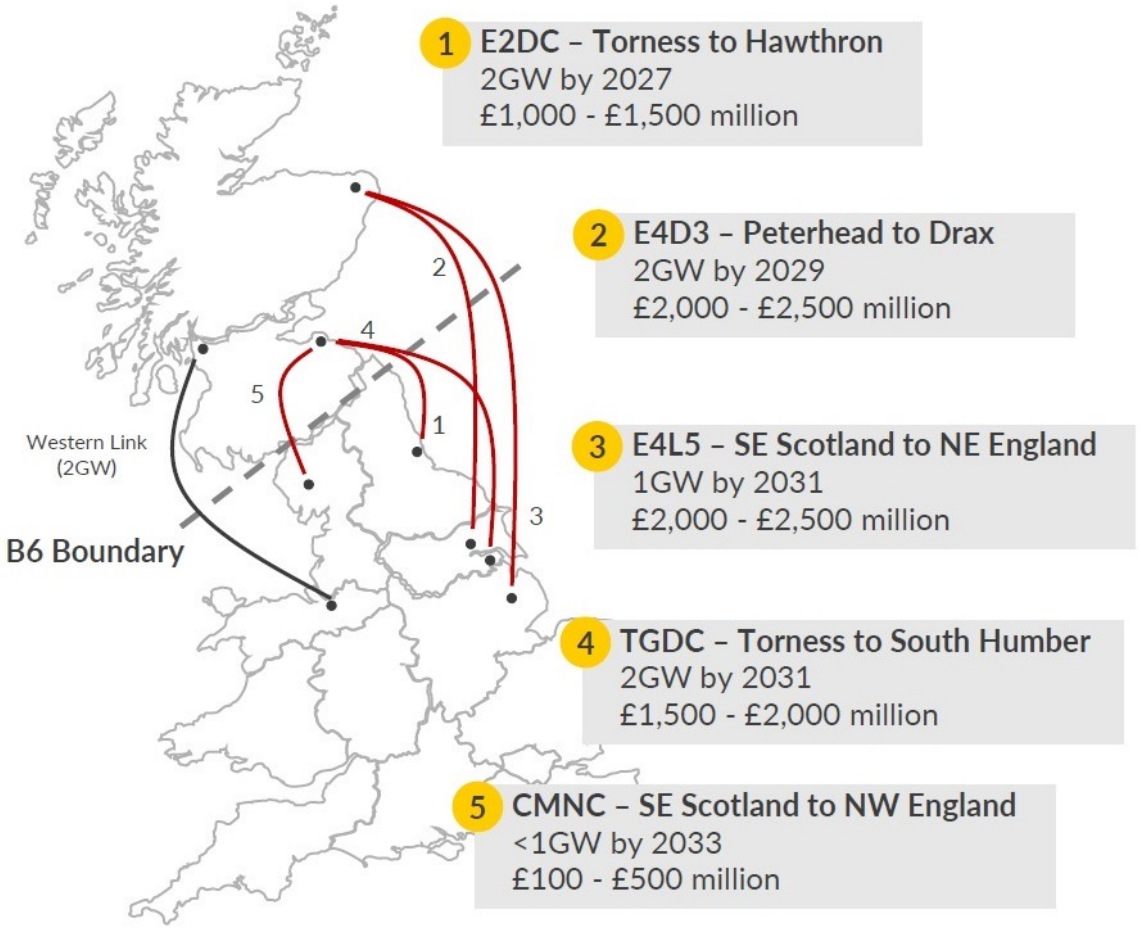
Source: Aurora Energy Research, National Grid ESO

Changes in Scottish wind capacity compared to B6 transmission capacity[1]



Scottish wind generation





NG is planning 7 GW build out of transmission capacity across the B6 boundary by 2035, however this will not keep pace with the expected build-out of Scottish wind capacity in a net zero world, which could result in further curtailment of RES resources

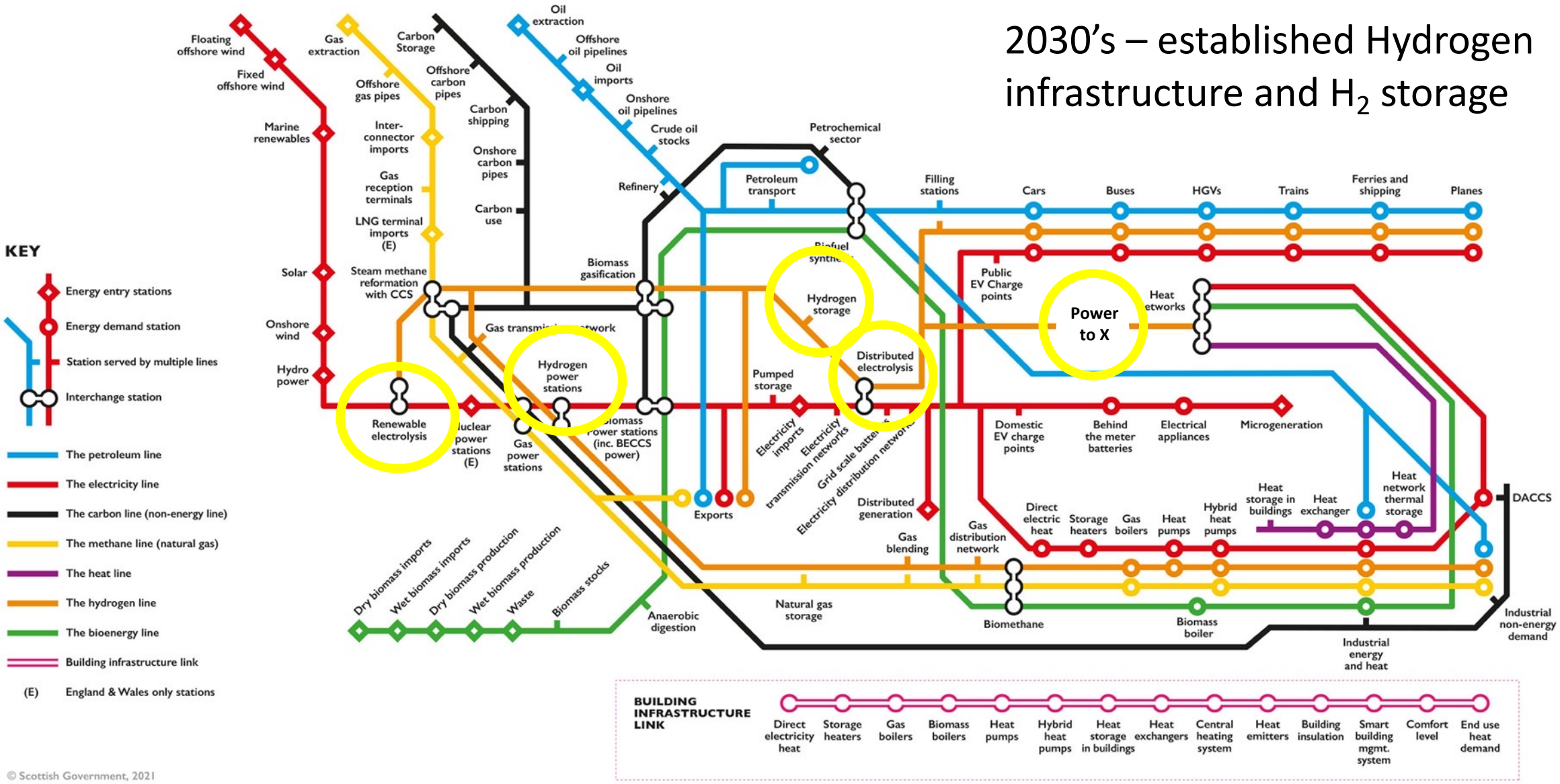
1) Assumes build out of transmission capacity in line with NOA6 targets, and build out of Scottish wind capacity in line with net zero targets laid out by UK & Scottish governments. 2) Constrained generation is equal to 8% in 2021 and rises to 35% in 2050.

Feb 2022 report: https://auroraer.com/wp-content/uploads/2022/02/Aurora-Report-Long-Duration-Electricity-Storage-in-GB.pdf

AN ENERGY SYSTEM FOR SCOTLAND – 2030s
AN INFRASTRUCTURE MAP

Scottish Government
Riaghaltas na h-Alba
gov.scot

2030's – established Hydrogen infrastructure and H_2 storage



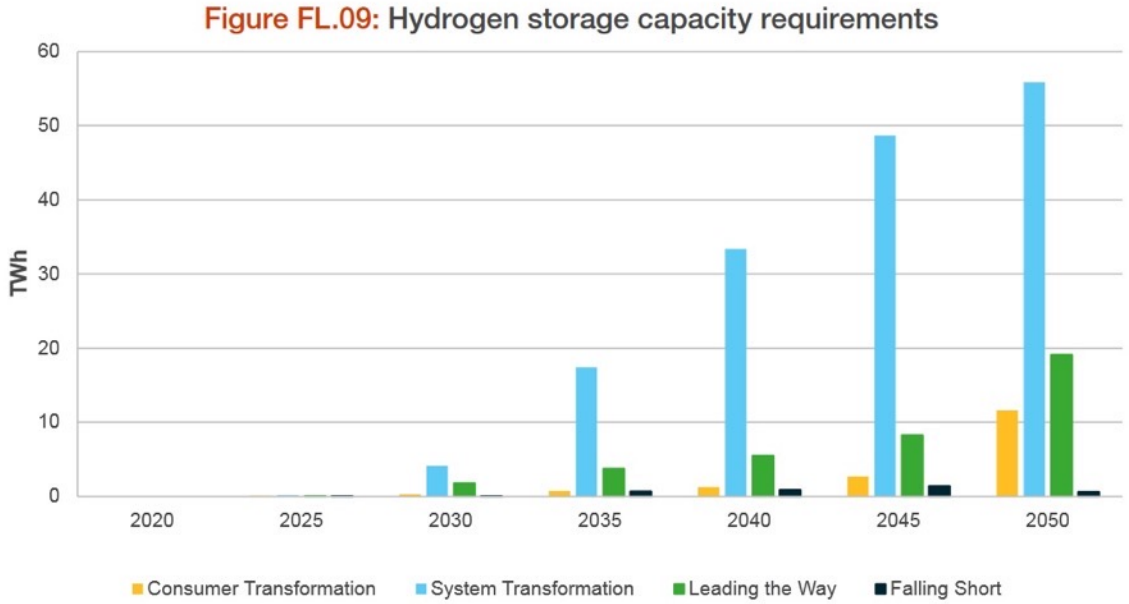
FES2023: Hydrogen storage scenarios to 2050

Hydrogen can provide significant flexibility benefits across the whole energy system. It is needed to replace some of the flexibility currently provided by natural gas but this relies on the development of hydrogen transportation and storage.

In the net zero scenarios in 2050, whole energy system flexibility is provided primarily using electricity or gas to produce hydrogen, storing it, then using the hydrogen in the power sector or to meet end user demand directly.

Producing hydrogen through electrolysis offers demand side flexibility to the electricity system and converting it back to power offers supply side flexibility.

Hydrogen storage will be important to support security of supply and to accommodate electrolytic hydrogen at times of excess wind or solar. Given hydrogen's future importance to the energy system, urgent focus is needed to optimise the energy system infrastructure changes needed to support hydrogen storage and contribute to delivering zero carbon energy to consumers.



FES 2023 analysis and stakeholder engagement shows that most hydrogen storage projects in the UK are for underground caverns, currently under scoping phase and only a very small capacity is expected to be operational towards the end of 2028. Across all three net zero scenarios, hydrogen storage capacity begins to develop with between 0.6-3.5 TWh by 2030

Link to FES2023 report (July 2023): https://www.nationalgrideso.com/document/283101/download

Hydrogen storage for UK Net Zero Power by 2035

In line with CCC advice the UK Government has committed to decarbonise electricity supply by 2035, subject to security of supply.

The challenges of balancing the UK electricity system are poised to intensify with both more extreme residual demand positions to manage and greater volatility over time, and this CCC report from March 2023 shows that hydrogen demand for UK power generation could exceed 2 million tonnes of hydrogen by 2030.

The power sector is projected to be the primary driver of UK hydrogen demand in 2028 and 2030. By 2035, demand in the non-power sectors is expected to increase significantly while hydrogen demand in the power sector is predicted to decline.

Consequently, the overall demand for hydrogen becomes relatively even between the power and nonpower sectors by 2035, as shown in exhibit 4.18 opposite (top right).

Link: https://www.theccc.org.uk/publication/net-zero-power-and-hydrogen-capacity-requirements-for-flexibility-afry/

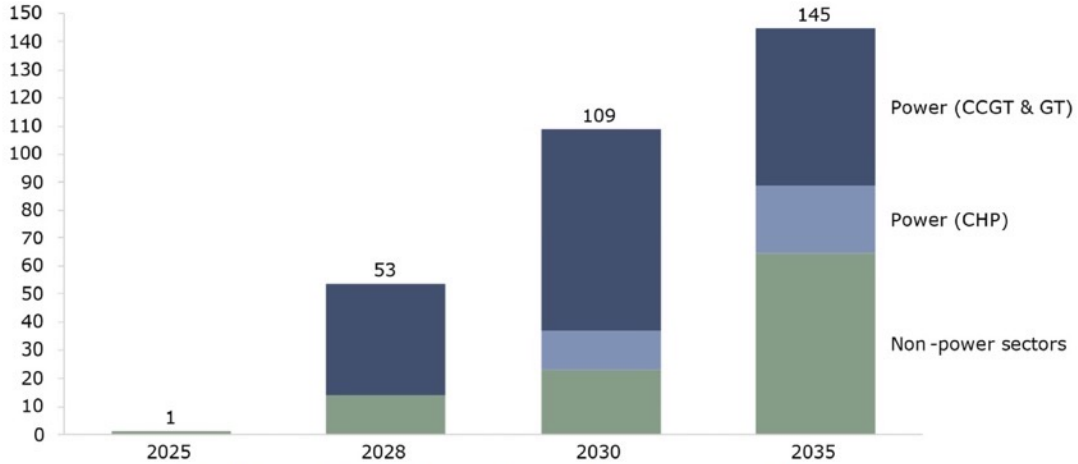
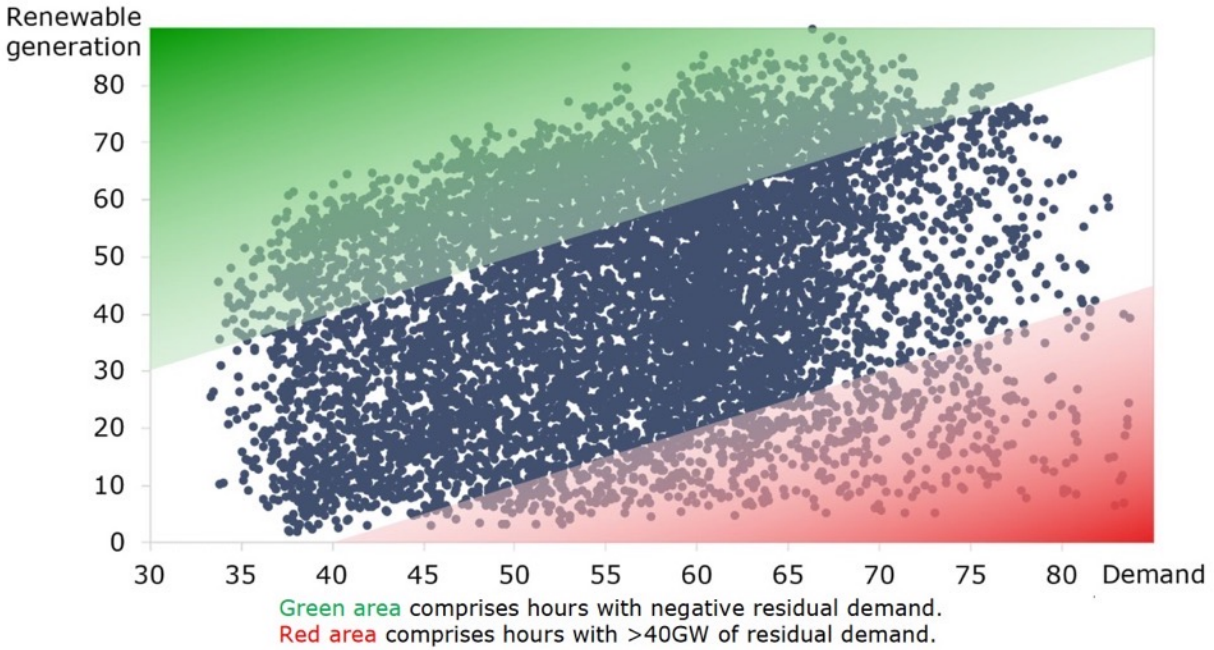
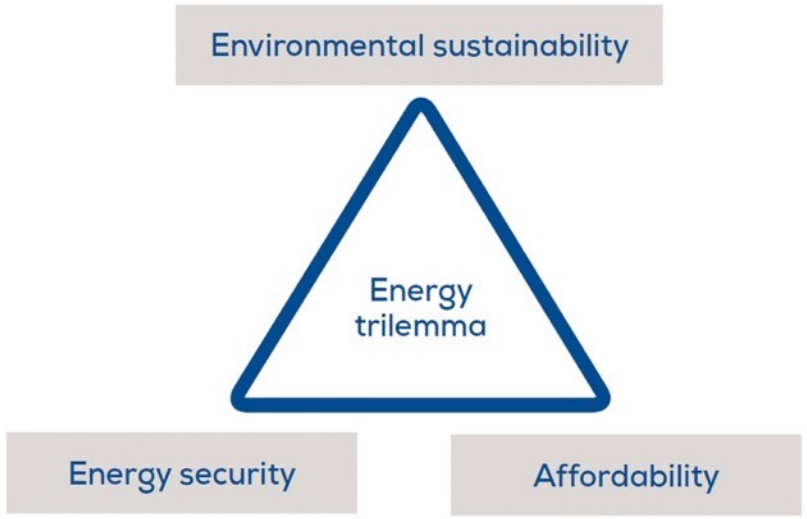


Exhibit 4.18 – Hydrogen demand by source (TWh)



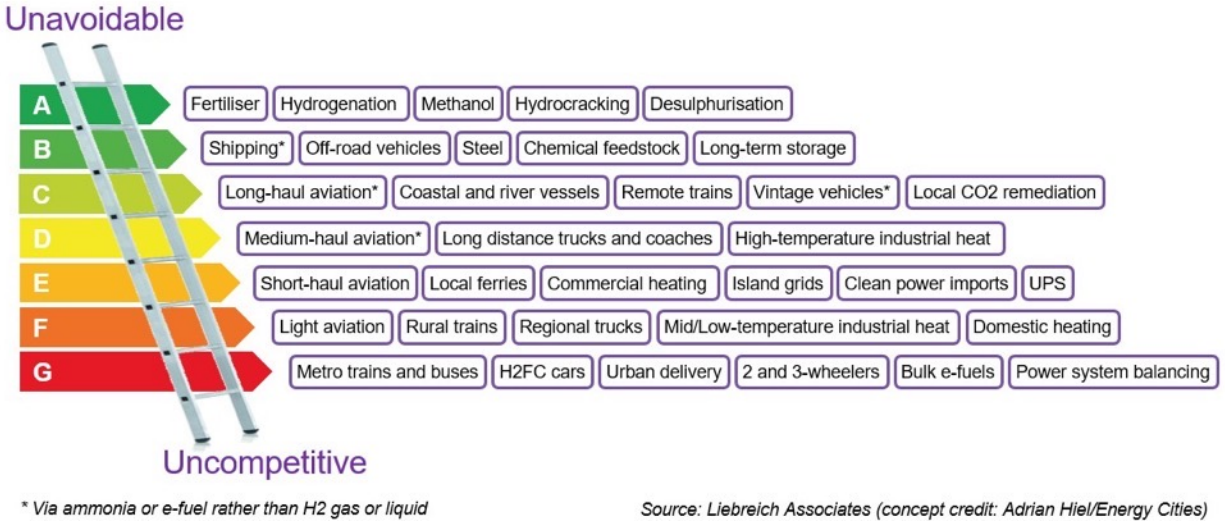
Hydrogen for Energy System Transformation

Uptake of hydrogen storage post-2030 will depend on the future potential revenue streams for energy system flexibility, using hydrogen to maximise renewable energy integration together with responsive power generation and security of energy supply.



The Energy Trilemma

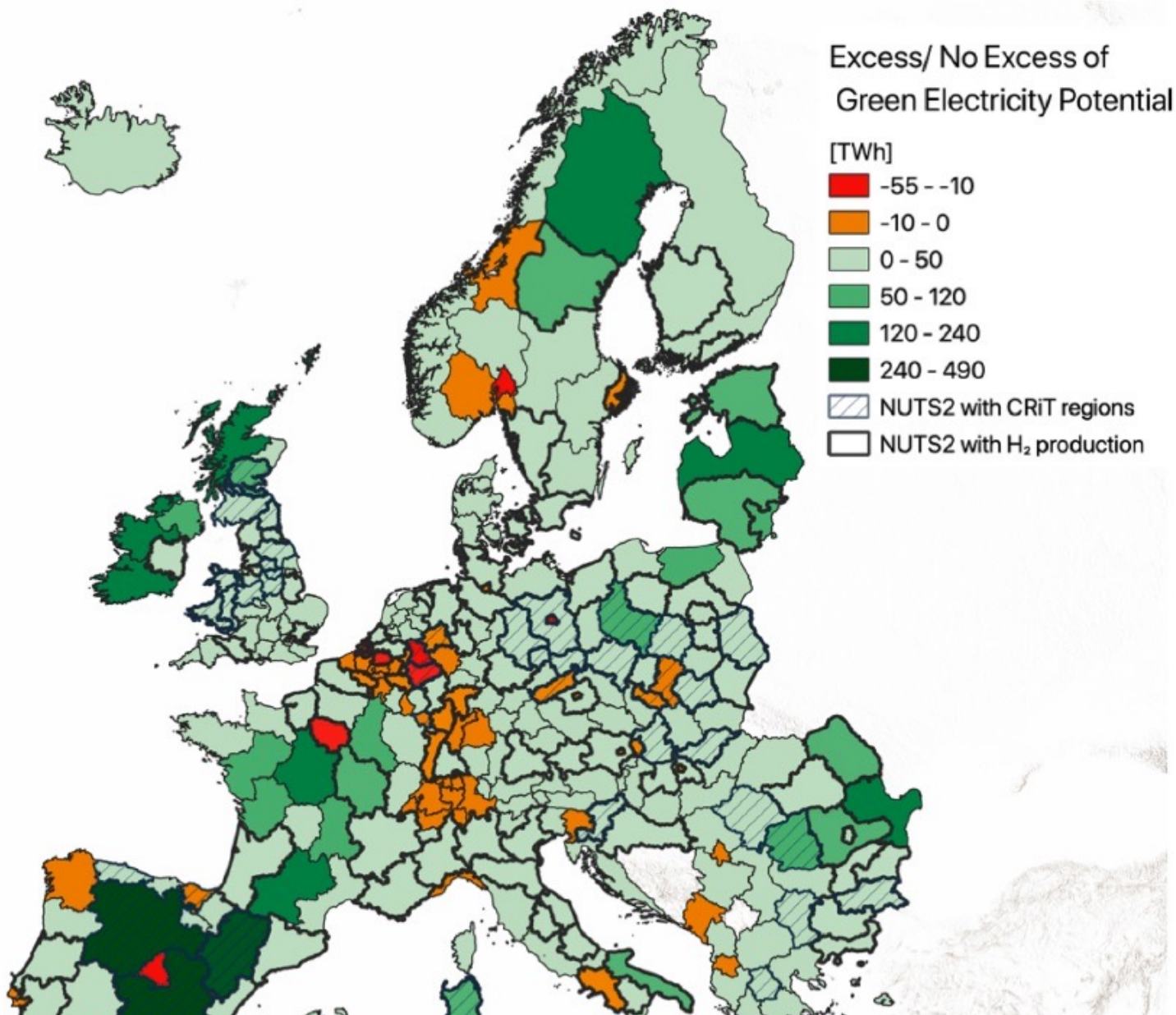
Energy Trilemma or Hydrogen Ladder?

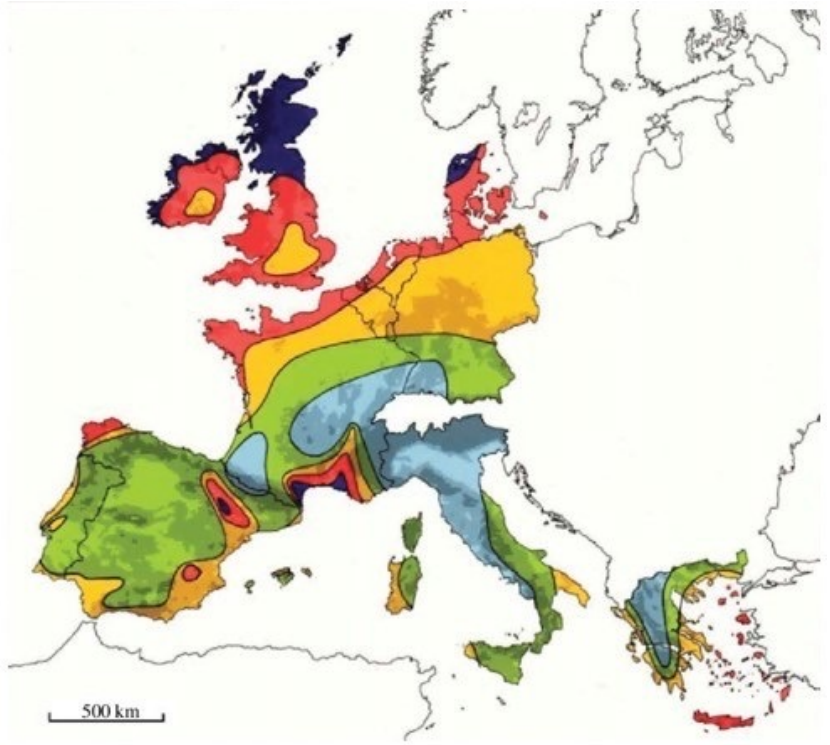


Michael Liebrich's Proposed Hierarchy for Hydrogen Use

Hydrogen storage for 'uncompetitive' applications such as power system balancing will be essential to meet future energy system peak seasonal demands for winter heating.

Make, Move & Use: Green H2 across North Sea Region





wind resources at 50m above ground level for five different topographic conditions

	sheltered terrain		open plain		at a sea coast		open sea		hills and ridges	
	ms^{-1}	Wm^{-2}	ms^{-1}	Wm^{-2}	ms^{-1}	Wm^{-2}	ms^{-1}	Wm^{-2}	ms^{-1}	Wm^{-2}
	>6.0	>250	>7.5	>500	>8.5	>700	>9.0	>800	>11.5	>1800
	5.0–6.0	150–250	6.5–7.5	300–500	7.0–8.5	400–700	8.0–9.0	600–800	10.0–11.5	1200–1800
	4.5–5.0	100–150	5.5–6.5	200–300	6.0–7.0	250–400	7.0–8.0	400–600	8.5–10.0	700–1200
	3.5–4.5	50–100	4.5–5.5	100–200	5.0–6.0	150–250	5.5–7.0	200–400	7.0 – 8.5	400 – 700
	<3.5	<50	<4.5	<100	<5.0	<150	<5.5	<200	<7.0	<400

European onshore wind potential (above):
https://www.hindawi.com/journals/jwe/2014/415898/

Green H2 in Europe – a regional assessment (left):
https://www.sciencedirect.com/science/article/pii/S0196890420311766

Co-operation across the North Sea Region

The Ostend Declaration of 24th April 2023 for the North Seas as Europe's Green Power Plant sets out ambitions for hydrogen:

- Denmark and the United Kingdom will cooperate on offshore wind development and infrastructure including energy islands and renewable hydrogen

- Germany will initiate the development of large-scale demonstration projects for offshore renewable hydrogen production with a total capacity of 1 GW

- The Netherlands will facilitate two hydrogen demonstration projects: one pilot of <100MW before 2030 and one demonstration project of +/- 500 MW around 2031

- The development of energy hubs will explore ways to promote onshore and offshore production of hydrogen including the necessary transmission and pipeline infrastructure

- Support the development of a well-functioning market and projects of common interest (PCIs) for hydrogen in order to scale up capacity nationally and regionally, and support the necessary regulation and standards.

- Support simplified regulatory framework to speed up the green transition and help facilitate the development of hydrogen solutions.

OSTEND DECLARATION OF ENERGY MINISTERS

ON

THE NORTH SEAS AS EUROPE'S GREEN POWER PLANT

DELIVERING CROSS-BORDER PROJECTS

AND ANCHORING THE RENEWABLE OFFSHORE INDUSTRY IN EUROPE

Recalling the declaration on the North Seas as a Green Power Plant of Europe in Esbjerg signed by the energy ministers of Belgium, Denmark, Germany and the Netherlands on 18 May 2022.

The energy ministers of France, Ireland, Luxembourg, Norway and the United Kingdom are joining this Ostend declaration.

Underlining that energy security and the fight against climate change are crucial to the future of Europe, we need to strengthen our cooperation to ensure affordable, secure and sustainable energy, while at the same time, continuing our efforts to protect the marine ecosystem. In response to Russia's aggression against Ukraine and attempts of energy blackmail against Europe we will accelerate our efforts to reduce fossil fuel consumption as well as dependence on fossil fuel imports and promote the rapid upscaling and deployment of renewable energy for an energy resilient Europe.

Further underlining that the goal of the development of infrastructure, production of offshore renewables and market design for the North Seas, is to accelerate the energy transition and maximise the benefits for households, industry and society as a whole.

Together, we have set ambitious combined targets for offshore wind of about 120 GW by 2030 in the North Seas. Based on the North Seas as a Green Power Plant of Europe, together we aim to more than double our total 2030-capacity of offshore wind to at least 300 GW by 2050.

We acknowledge the progress made since the last summit including through the conclusion of both bilateral agreements on offshore renewable generation and non-binding agreements to cooperate on goals for offshore renewable generation for the North Seas, under the revised framework for trans-European energy networks (TEN-E). We fully support the ongoing work to develop a high level strategic integrated offshore network development plan for the North Seas, including by enhanced cross-border coordination of grid and maritime spatial planning.

In that respect we also welcome the initiative that the Transmission System Operators (TSO's) from Belgium, Denmark, Germany and the Netherlands have undertaken to develop a meshed offshore grid and to identify the next steps for its realisation. We invite them to continue the work and extend the process to the TSO's of the five countries that have joined this declaration.

This will contribute to large-scale onshore and offshore production of renewable hydrogen. Germany, Denmark, The Netherlands and The United Kingdom have set combined targets of about 30 GW production capacity by 2030 and look to expand their production even further for 2050.

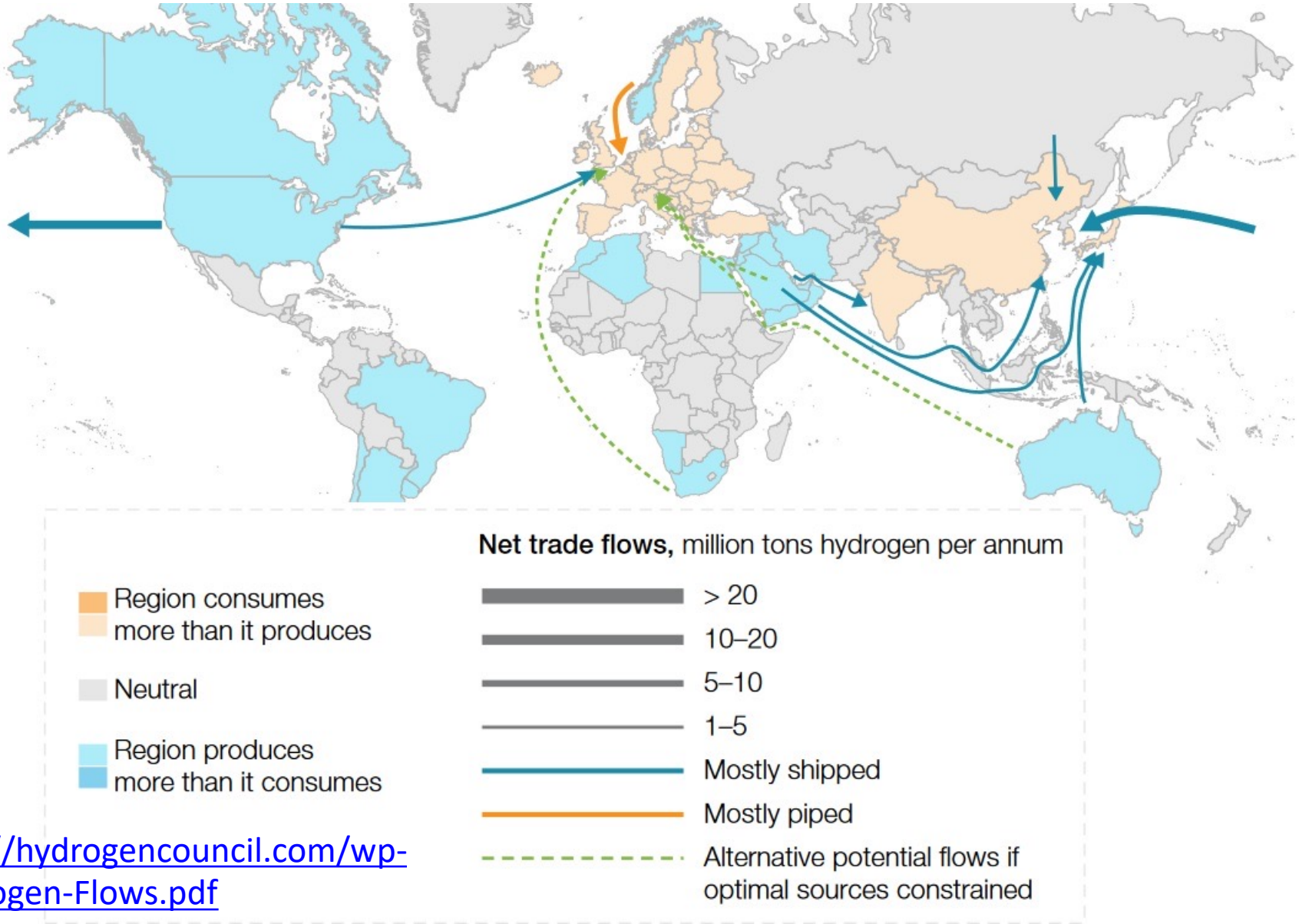
1

Major global flows of hydrogen and derivatives in 2030

The Hydrogen Council report on Global Hydrogen Flows finds that hydrogen trade with shipping and pipelines reaches scale by 2040, and a fully mature traded market by 2050.

This report finds that in a cost-optimal world around 50% of hydrogen trade uses pipelines.

Pure hydrogen is expected to be a 'regional' business and will be predominantly sourced domestically or piped from nearby regions.

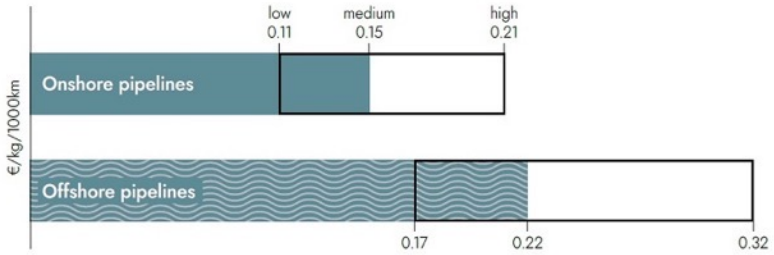


Link to Hydrogen Council report: https://hydrogencouncil.com/wp-content/uploads/2022/10/Global-Hydrogen-Flows.pdf

European Hydrogen Backbone = Regional H2 Pipelines

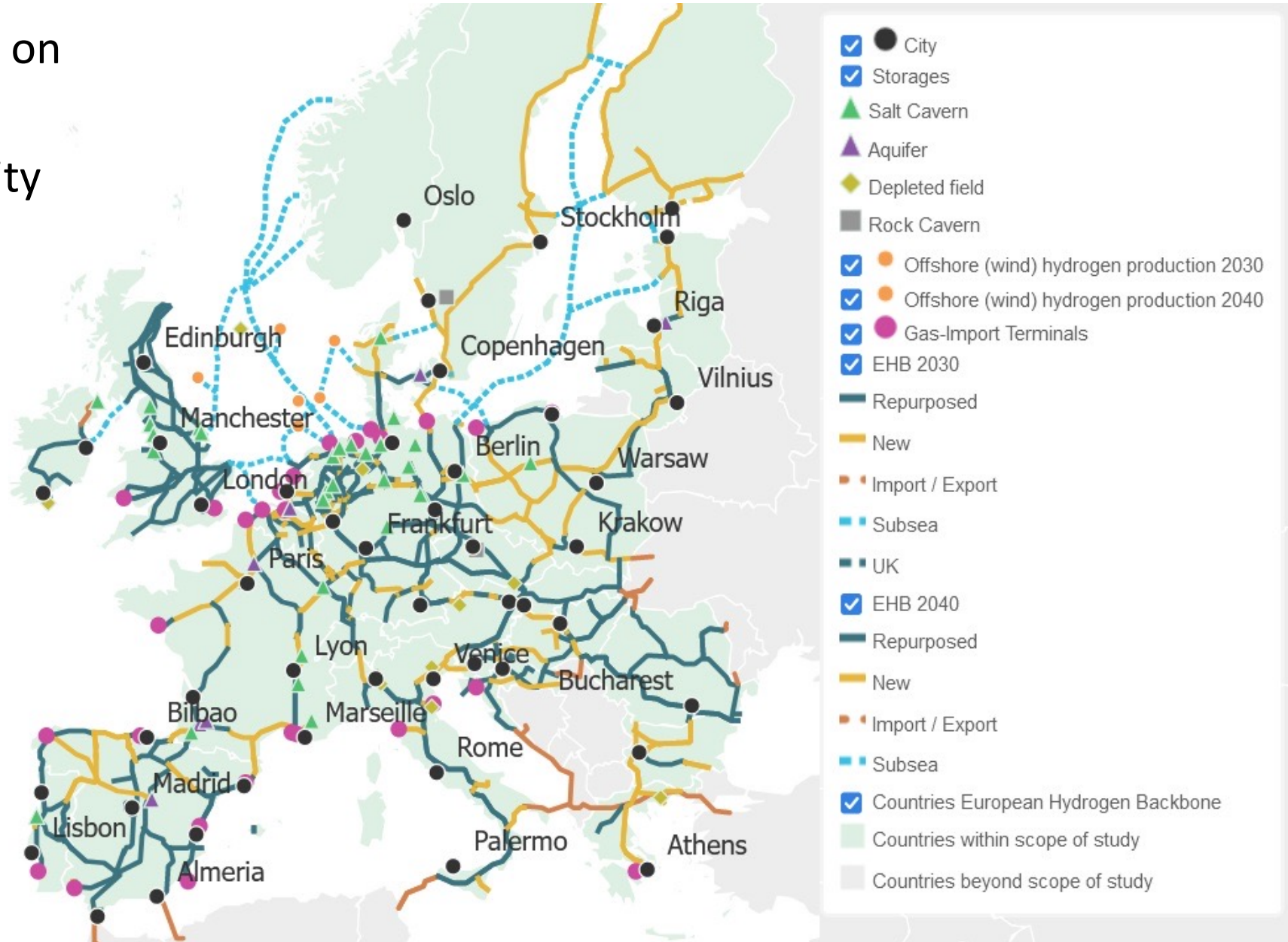
Reduce Europe's dependency on imported oil and gas

- increase renewables capacity
- Scale up H2 production
- Backbone of H2 pipelines
- Can integrate H2 storage



Cost of transporting hydrogen estimate €0.22/kg per 1000km for offshore pipeline.

EHB link: https://www.ehb.eu/



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