Ocean REFuel Stakeholder Meeting - Agenda

- **09:30 – 10:00** Registration, refreshments
- **10:00 – 10:15** Ocean REFuel intro/overview
- **10:15 – 10:30** Work Stream 1 Update (Offshore structures, logistics and power generation)
- **10:30 – 10:45** Work Stream 2 Update (Power to Carbon Free Fuel)
- **10:45 – 11:05** Q&A/Discussion/Feedback
- **11:05 – 11:20** Work Stream 3 Update (Carbon Free Fuel Transportation & Storage)
- **11:20 – 11:35** Work Stream 4 Update (Networks, Capability and Demand)
- **11:35 – 11:50** Comfort/Coffee break
- **11:50 – 12:05** Work Stream 5 Update (Policy framework/Economic modelling)
- **12:05 – 13:00** Q&A/Discussion/Feedback
- **13:00** Close
- **13:00 – 13:30** Lunch
- **13:30 – ??** Nottingham University Facilities tour (TBC)

X THE PLACE OF USEFUL LEARNING

University of Strathclyde Engineering

Ocean REFuel

Workstream 1
Offshore structures, logistics, and power generation

www.strath.ac.uk/engineering

Workstream 1: the team

Prof Feargal Brennan, PI

Prof Maurizio Collu, WS1 lead

Dr Claudio Rodriguez-Castillo, Postdoc res.

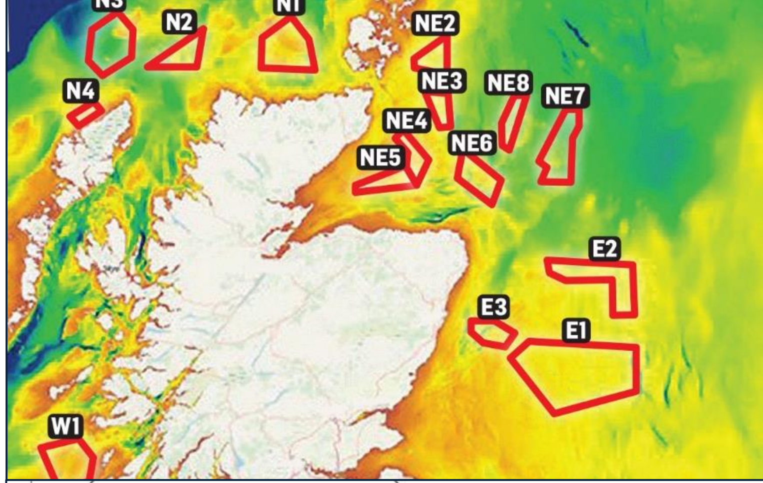
Dr Baran Yeter, Postdoc res.

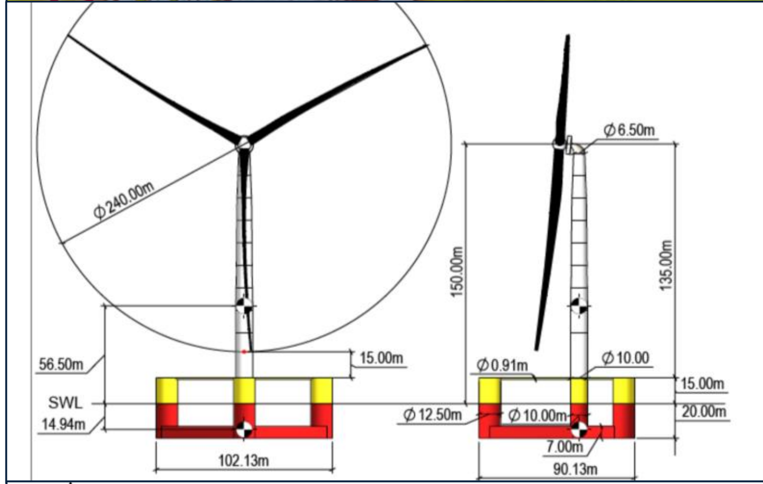
Dr Shen Li, Postdoc res.

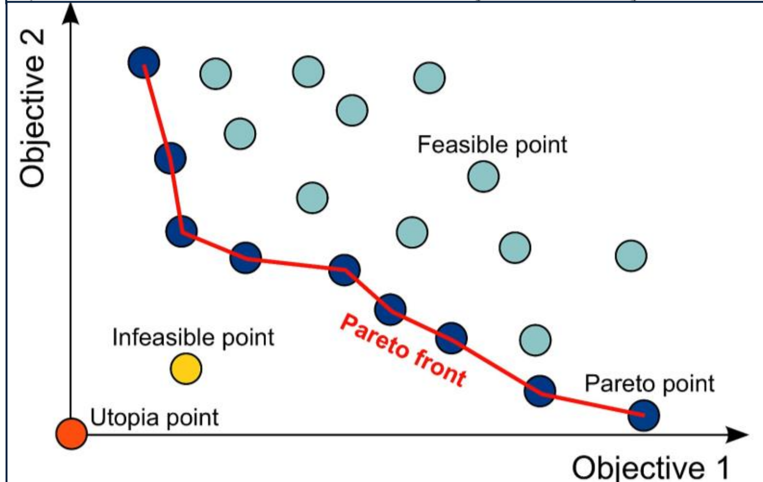
Research Workstreams / Cross cutting Themes	Materials	Safety	Socio Economics	Process Engineering	Environmental Impact
Offshore structures, logistics and power generation	●	●	●		●
Power to Carbon Free Fuel	●	●		●	●
Carbon Free Fuel transportation and storage	●	●	●	●	●
Networks, Compatibility and Demand		●			

Introduction to Workstream 1

WS1.1 Scenarios definition	T1.1.1 Locations? Metocean conditions?
	T1.1.2 Which ORE technologies?
WS1.2 Production of H_2 in offshore conditions	T1.2.1 Support platform: objectives, constraints
	T1.2.2 Support platform: MDAO analysis
	T1.2.3 Impact of offshore conditions on H_2 production
	T1.2.4 Offshore platform for H_2 **production**: optimum configuration
WS1.3 Storage of H_2 in offshore conditions	T1.3.1 Optimum materials for H_2 storage
	T1.3.2 Impact of offshore conditions on H_2 storage system equipment
	T1.3.3 Offshore platform for H_2 **storage**: optimum configuration
WS1.4 H_2 transportation to shore	T1.4.1 Materials and technologies for H_2 transportation
	T1.4.2 Damage modelling and mitigation solutions

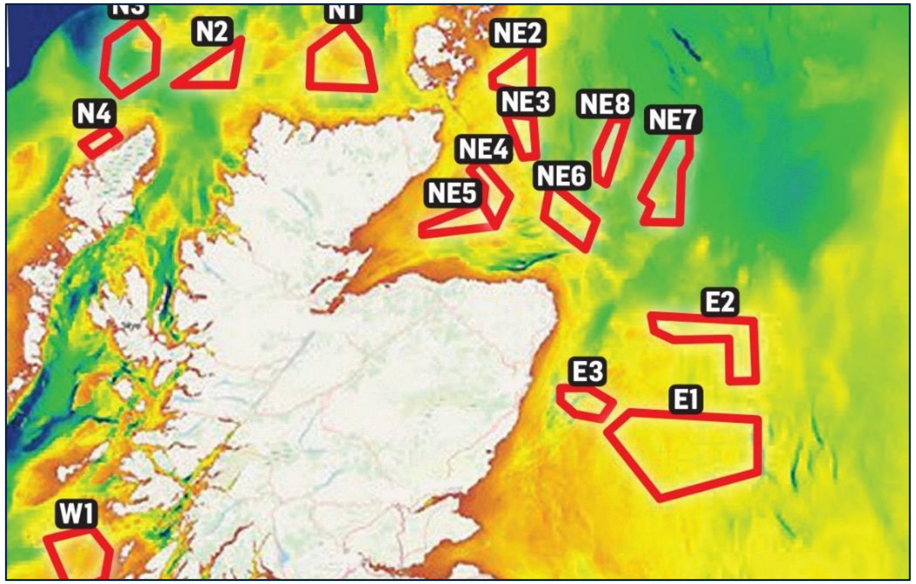






Recap of previous results

1. NE8 as location: metocean conditions obtained
2. Floating offshore wind – barge/semisubmersible type most suitable for H2 offshore production



Scenarios →	Baseline	Enhanced LCoE & Resource Potential	Enhanced Deck & Storage Availability	Enhanced Sea- & Station- keeping
Alternatives ↓	Closeness to ideal positive solution (1.00)			
Wave-OB (PA)	0.31	0.36	0.23	0.25
Wave-OB (ATE)	0.49	0.47	0.55	0.48
Wave-OWC	0.59	0.54	0.62	0.69
Wave-OVT	0.36	0.38	0.41	0.33
Marine current	0.37	0.36	0.27	0.29
Tidal stream	0.34	0.35	0.25	0.27
Salinity gradient	0.60	0.51	0.66	0.68
OTEC	0.72	0.64	**0.79**	**0.78**
Offshore solar	0.41	0.38	0.38	0.37
OWT-fixed monopile	0.63	0.71	0.52	0.71
OWT-spar	0.65	0.71	0.59	0.73
OWT-semi	**0.73**	**0.76**	0.75	**0.78**
OWT-barge	**0.75**	**0.77**	**0.82**	0.76
OWT-TLP	0.67	0.69	0.71	0.74

Platform design and dynamics
Knowledge gaps

Area ->	Platform design / dynamics	Example
Gaps	1. NEW objective / constraints for H_2-producing floating offshore wind turbines? *Innovative approach to design/analysis, leading to NOVEL configurations* *MDAO: Multidisciplinary Design and Analysis approach*	1.1 Current practice optimising LCoE may not apply → LCoH-optimised design analyses needed (lower power, more stable) 1.2 Platforms fully dedicated to H_2 production better than those using only surplus electricity. NO power connection?
	2. What is the impact of offshore conditions on H_2 production? H2 Storage?	2.1 Impact of inclination / velocity / accelerations imposed by the platform on the electrolyser / desalination plant? 2.2 Impact of oscillating power input on electrolyser / desalination plant

Platform design and dynamics
Plan

Definition of NOVEL, SPECIFIC critical objectives/constraints

Based on literature and feedback from industry

↓

"Illustrative example" platform numerical model, in realistic metocean conditions

Allow quantification of critical obj/const	Parametric design, allow optimisation

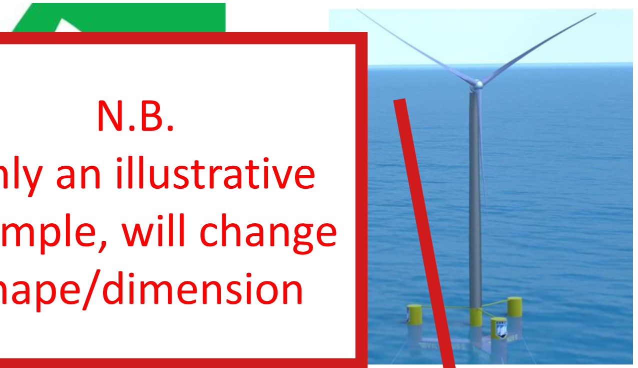
↓

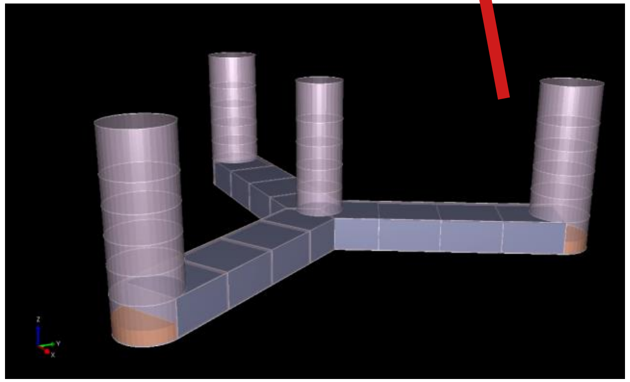
Multidisciplinary Design, Analysis, Optimisation (MDAO)

Novel configuration	Novel critical design aspects

Platform design and dynamics
Progress

N.B.
Only an illustrative example, will change shape/dimension





Definition of NOVEL, SPECIFIC critical objectives/constraints

Based on literature and feedback from industry

"Illustrative example" platform numerical model, in realistic metocean

Allow quantification of critical obj/const | Parametric design, allow optimisation

Summary of Platform's weights

	mass [t]	[%]	LCG [m]	TCG [m]	VCG [m]
Total	20679.08	100%	-0.001	0.000	-2.040
Hull struct	3914.00	19%	0.000	0.000	-4.467
Solid ballast	2540.00	12%	0.000	0.000	-18.614
Liquid ballast	11300.00	55%	-0.002	0.000	-16.956
Tower	1263.00	6%	0.000	0.000	56.528
RNA	1016.64	5%	0.000	0.000	149.327
Others (mooring, etc.)	645.44	3%	0.000	0.000	-14.000

Summary of internal volume capacities

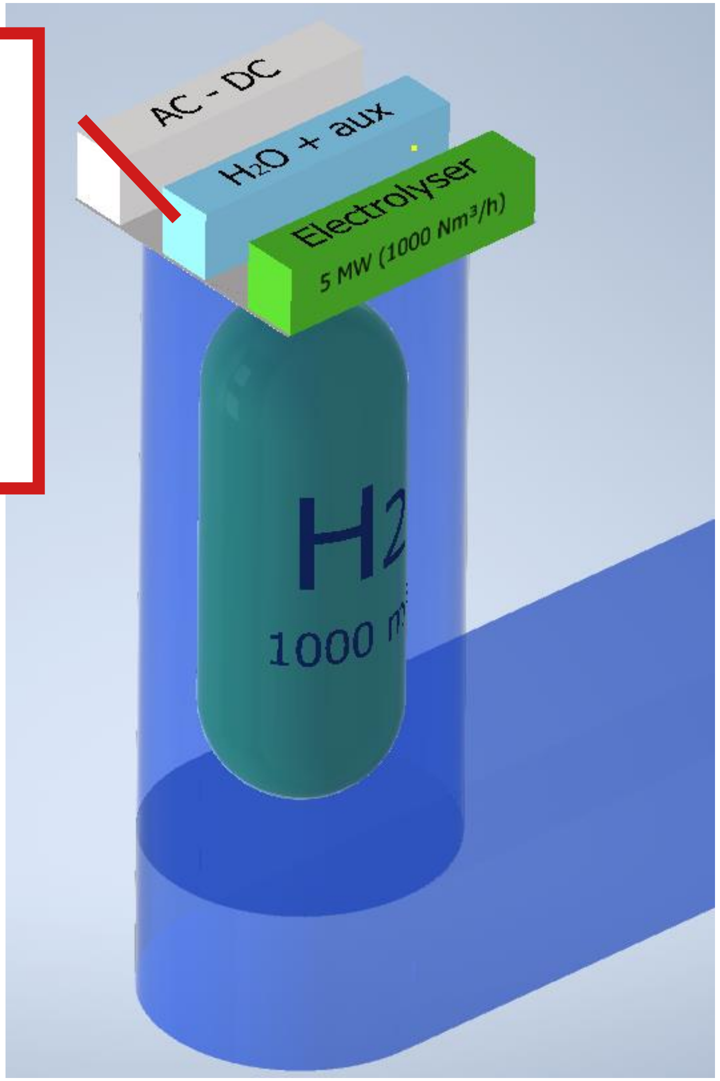
	Volume [m³]	%
Total	26308.12	100%
Pontoons LB	12848.55	49%
Pontoon SB	1257.59	5%
External columns	10060.69	38%
Central column	2141.29	8%

Platform design and dynamics

Progress

N.B.
Only an illustrative example, not the final nor optimised.

Will change shape/dimension



Structures and materials

Knowledge gaps

Area ->	Structures and materials	Example
Gaps	1. New circumstances compromising structural integrity Failure mode, effect and criticality analysis (FMECA) based on multi-stakeholder approach	1.1 FMECA should involve experts from throughout the whole life cycle to avoid costly design modifications. 1.2 Fuzzy-Multi-criteria decision-making seems a promising solution to account for uncertainties regarding the expert opinion.
	2. Structural design of semi-submersible structure is unknown. Especially the column where the buffer hydrogen storage will be placed.	2.1 Design load cases should be investigated for fatigue and ultimate load limit states for the new Floating SS. 2.2 How can the hydrogen storage and the protection affect the columns design? - Stored hydrogen is a direct variable for column scantling.
	3. Damage tolerant design is very new to offshore wind; however, there is massive opportunity due to having a FOWT (we can tow it back when needed) and digitalisation	3.1 Risk-based life cycle management (design, inspection, maintenance, and end-of-life strategies)? 3.2 Adaptive control to mitigate damage and maximise lifetime energy yield? 3.3 Certify structural design through digital twinning – smart certification?

Structures and materials
Plan

Risk identification & prioritisation

Failure, mode, effect & criticality analysis (FMECA)

↓

Structural design using damage-tolerant approach

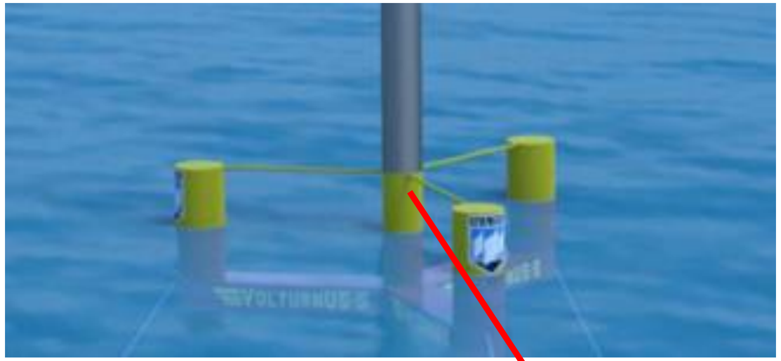
Design of non-standard structural details (doubled-hull column, tubular joints)	Coupling with MDAO via Structural reliability

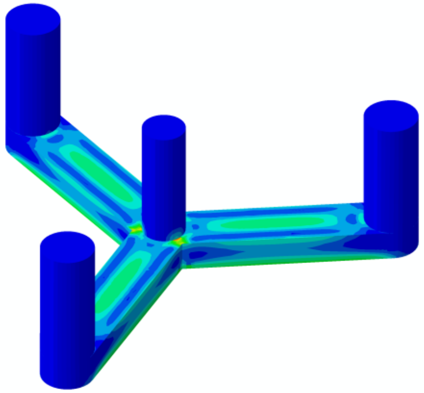
↓

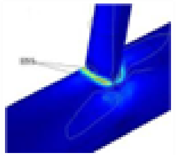
Risk-based structural integrity management

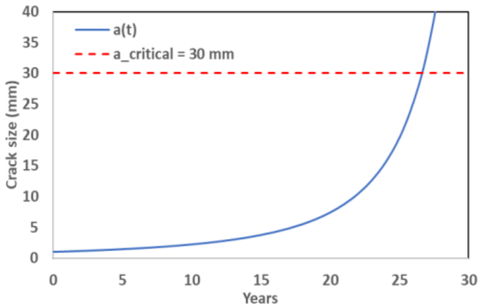
Adaptive control system for optimal inspection & maintenance planning	Smart certification by digital twinning

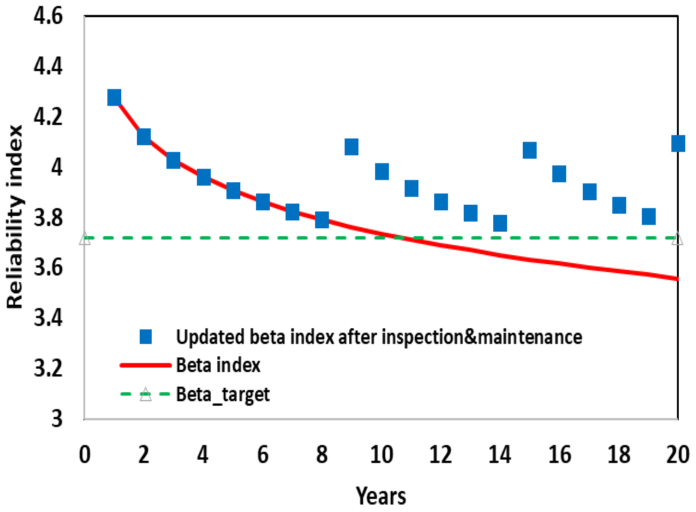
Structures and materials
Progress











Risk identification & prioritisation

Primary failure causes identified, secondary failure causes to be investigated (HSE consideration)

Structural design

Coupling with MDAO	Fatigue design of welded connections	Non-standard details?

Structures and materials

Progress

Digital twinning (Model updating)

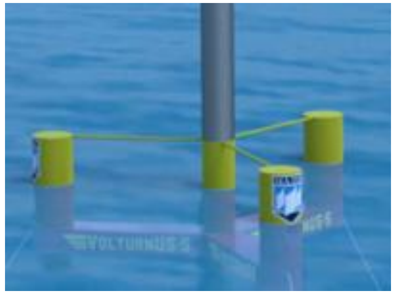
Updating digital model using monitored data to minimise modelling discrepancy

Digital twinning (Real-time simulation)

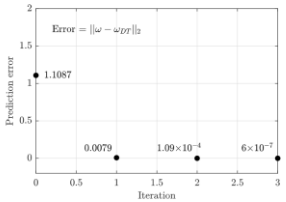
Extrapolate monitored response to enable virtual monitoring of critical yet inaccessible structural details in (near) real time

Strain gauge

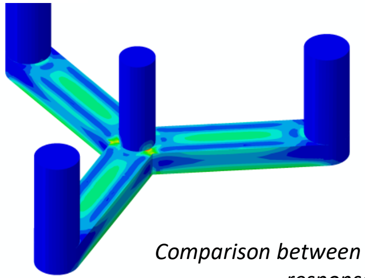
Motion sensor



Sensitivity-based natural frequency model updating

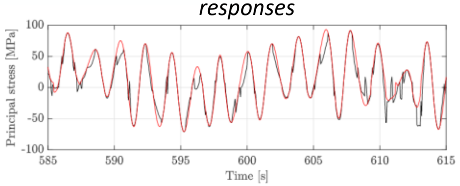


Real-time strain/stress, motion etc.



Design certified? Inspection & maintenance required?

Comparison between real and virtual responses



Conclusions

- WS1.1 completed, working on WS1.2, WS1.3
- Main knowledge gaps in *platform design and dynamics* and in *structures and materials* identified
- Plan for gaps: novel platform for novel purpose, therefore:
- Redefinition of objectives and constraints for the overall design (from wind turbine side)
- Modelling to quantify impact of A) motion B) power fluctuation on H2 production and storage equipment (payload side)
- Reassessment of the risks (risk identification and prioritization)
- Novel approaches in structural design – damage-tolerant structure and risk-based SI mgmt.
- Digital twinning

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University of Strathclyde Engineering

Ocean-REFuel (Ocean Renewable Energy Fuel)

Workstream2: Power to carbon free fuel

Mohamed Mamlouk

School of Engineering, Newcastle University

29th March 2023, Nottingham University

Overview

1. Overarching questions of Workstream 2
2. Literature Review
3. Modelling membrane-less electrolyser results
4. Catalyst for AEM based Electrolysers results
5. Questions and open discussion

1. Overarching questions of Workstream 2
2. Literature Review
3. Modelling membrane-less electrolyser results
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5. Questions and open discussion

Introduction to WS2

1. Can seawater be used directly for efficient production of hydrogen or can seawater purifications be performed effectively offshore producing electrochemically chemicals for water treatment?

2. Which electrolyser technology and conditions are most suited to meet performance, cost and hydrogen purity requirements for offshore storage and hydrogen pumping?

3. Can electrolysers operate effectively and safely on offshore moored and floating platforms?

4. Can offshore electrolyser technology deliver stack performance target <48 kWh/kg (82% electrical efficiency) and costs of system < £800/kW?

1. Overarching questions of Workstream 2
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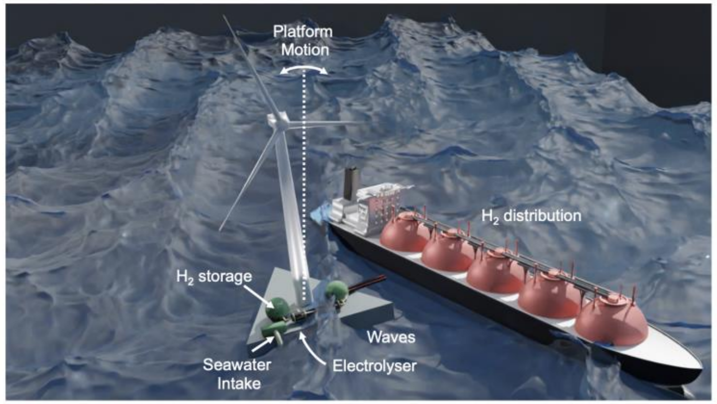
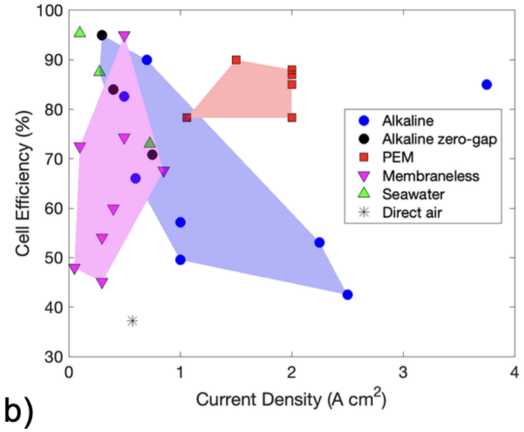
Review articles submission

- 1- Review of next generation hydrogen production from offshore wind using water electrolysis





2-Offshore green hydrogen production and storage



b)

AWE Advantage and limitations

- Advantage:
- Cheaper CAPEX than PEM, doesn't use precious metal.

- Limitations:
- Bulkier, Poor chemical separation/low H2 pressure, slow system response time, high minimum load

ASR	250 - 350 mΩ cm^2
Foot print	20MW 70-150 m2 MW^{-1} 1GW 0.1 - 0.17 km^2 GW^{-1}

Nominal current density	0.15-0.7 A/cm2
Operating temperature	70-90C
Lifetime system with stack replacement	20-30 years
Lifetime stack	60,000-90,000h
Electrode area	1-3 m2
Stack capacity	1-2 MW
Capital cost system for 10MW system	$500-1000/kW
Produced H2 pressure	<30 barg
System energy requirement	54 (50-78) kWh/Kg H2
Water feed	Ultra pure DI-water 18 MΩ/cm
Cold start to minimum load	20 mins
Ramp up 20-100%	8s (10% /s)
Load range of full capacity	15-100%

PEMWE Advantage and limitations

Newcastle University

- Advantage:
- More compact, higher H2 pressure, faster system response.

- Limitations:
- Require precious metal (e.g. Ir and Pt), more expensive, operate at lower efficiency than alkaline system. Current IrO_2 mining capacity support only

Nominal current density	1-3 A/cm2
Operating temperature	50-80C
Lifetime system with stack replacement	10-30 years
Lifetime stack	20,000-70,000h
Electrode area	1.5 m2
Stack capacity	2 to 5 MW
Capital cost system for 10MW system	$700-1400/kW
Produced H2 pressure	20-70 barg
System energy requirement	57 (50-83) kWh/Kg H2
Water feed	Ultra pure DI-water 18 MΩ/cm
Cold start to minimum load	5 mins
Ramp up 20-100%	2s (40% /s)
Load range of full capacity	5-120%

ASR	50 - 120 mΩ cm^2
Foot print	20MW 35-50 m^2 MW^{-1} 1GW 0.08 - 0.13 km^2 GW^{-1}

AEMWE Advantage and limitations

Newcastle University

- Advantage:
- More compact, higher H2 pressure, faster system response than alkaline.
- Limitations:
- Poor stability of membrane separator, poor stability of non precious metal catalyst

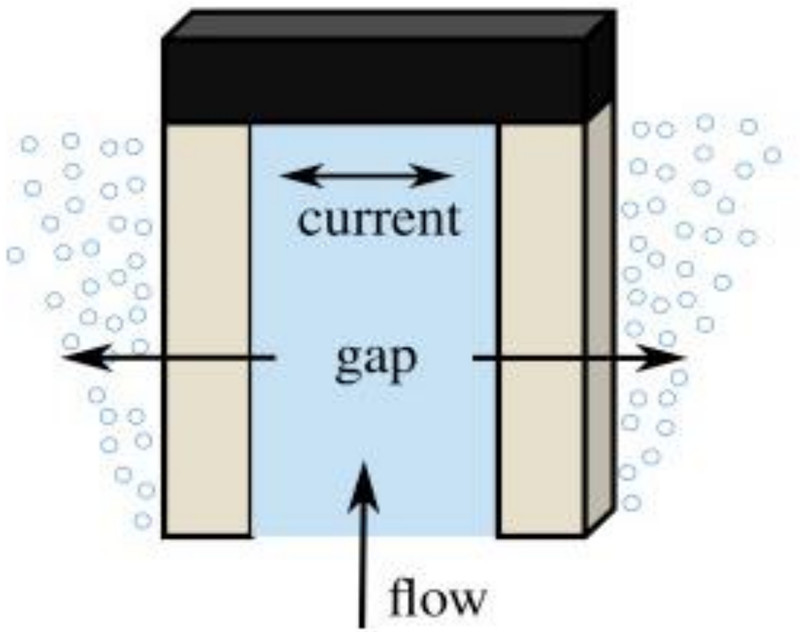
ASR	100 - 200 mΩ cm²

Nominal current density	0.2-1 A/cm2
Operating temperature	40-60C
Lifetime system with stack replacement	4 years
Lifetime stack	5,000-10,000h
Electrode area	0.3 m2
Stack capacity	2.5 kW
Capital cost system for 10MW system	n/a
Produced H2 pressure	20-30 barg
System energy requirement	59 (54-69) kWh/Kg H2
Water feed	Ultra pure DI-water 18 MΩ/cm
Cold start to minimum load	5-10 mins
Ramp up 20-100%	2-4s
Load range of full capacity	5-100%

Membrane-less design

- Advantage:
- Cheaper system due to elimination of membrane cost.
- Can operate with KOH or NaCl electrolyte.

- Limitations:
- Not mature technology. Requires laminar flow, bulkier, lower hydrogen purity, lower current density, balancing flow distribution in electrodes.



To purify or to directly electrolyse sea water?

Challenges

- Chlorine evolution reaction
- pH gradient (energy loss and precipitation)
- Electrode low stability and activity in corrosive Cl- containing electrolyte
- ASR > 0.25 ohm cm^2 (sea water 30-60 mS cm^{-1})
- AEM with Cl- ions 2.61 slower than OH^-
- Concentrated NaCl?

Energetics

- H2 HHV 39.4 kWh kg_{H2}^{-1}
- Electrolysis 48-54 kWh kg_{H2}^{-1}
- Multistage flash evaporators (MSFE) 24-240 Wh L^{-1} (H_2O) or 0.215-2.15 kWh kg_{H2}^{-1}
- RO 4.2 Wh L^{-1} (H_2O) from sea water or 0.038 kWh kg_{H2}^{-1}
- IEC 0.28 Wh L^{-1} (H_2O)

15 MW electrolyser needs 5.4 m^3 h^{-1}
Lenntech 10 m^3 h^{-1} 11kW (low saline)
RO plant footprint 3.5 m^2
Wartsila 10 m^3 h^{-1} 1.85MW MSFE footprint 20 m^2, 32 ton

1. Overarching questions of Workstream 2
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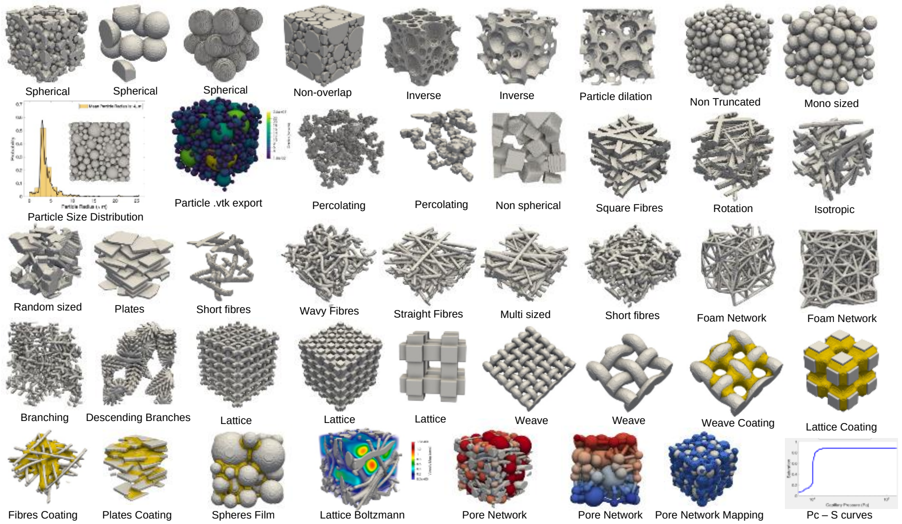
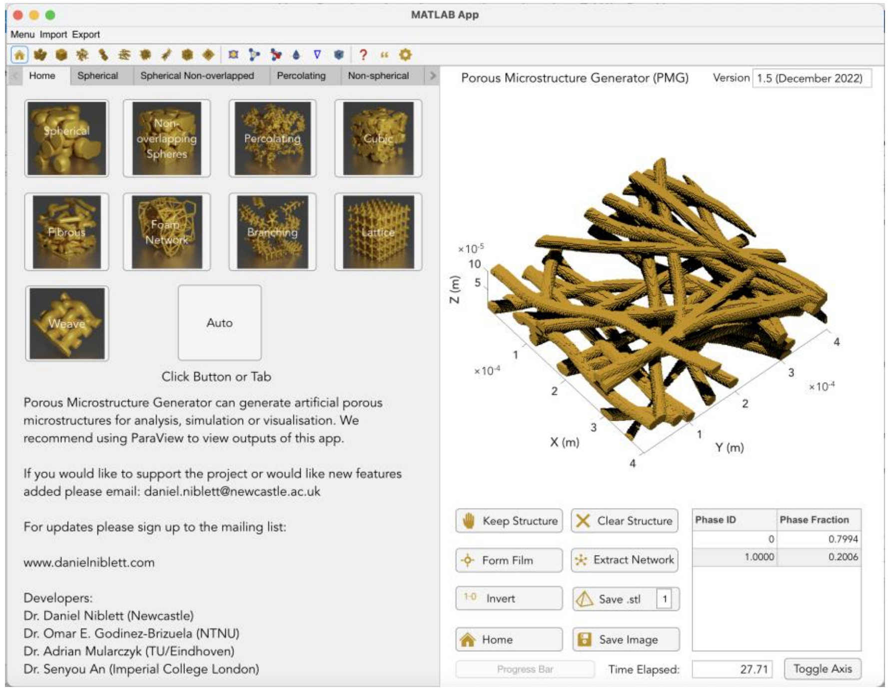
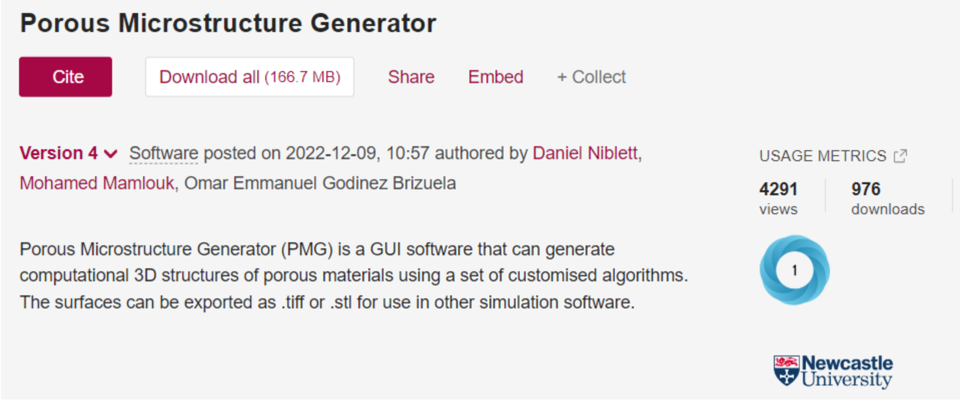
Porous Microstructure generators



Porous Microstructure Generator (PMG)

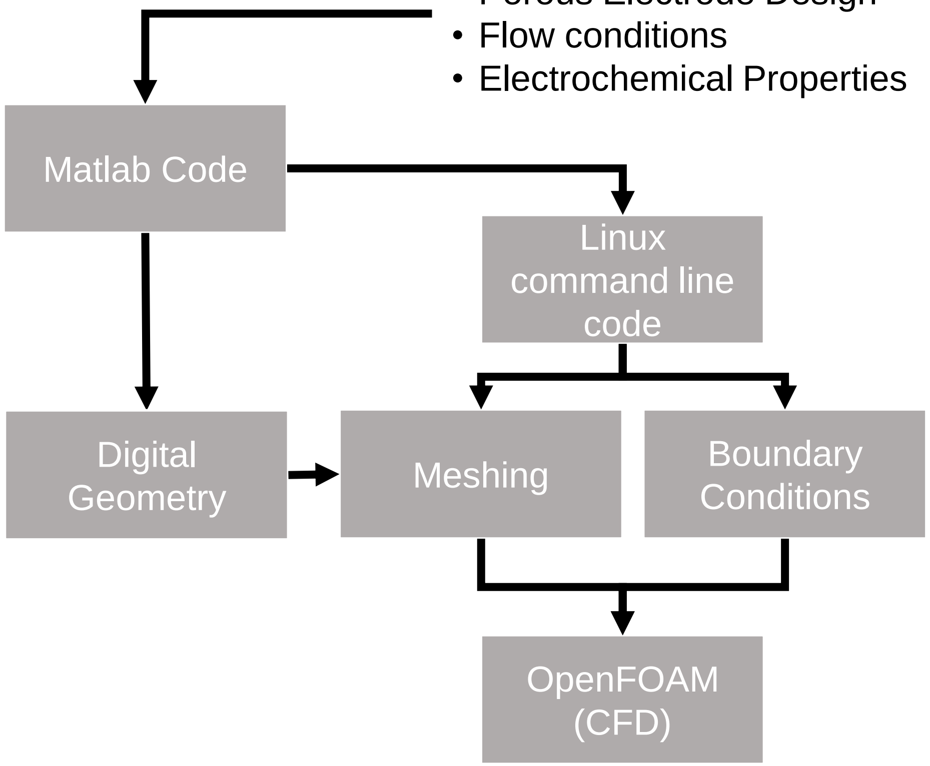
Daniel Niblett

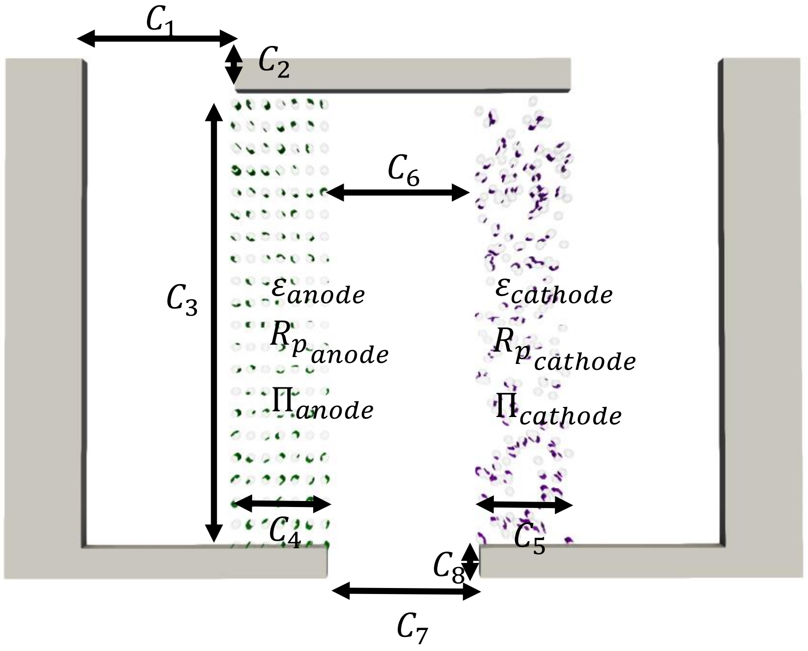




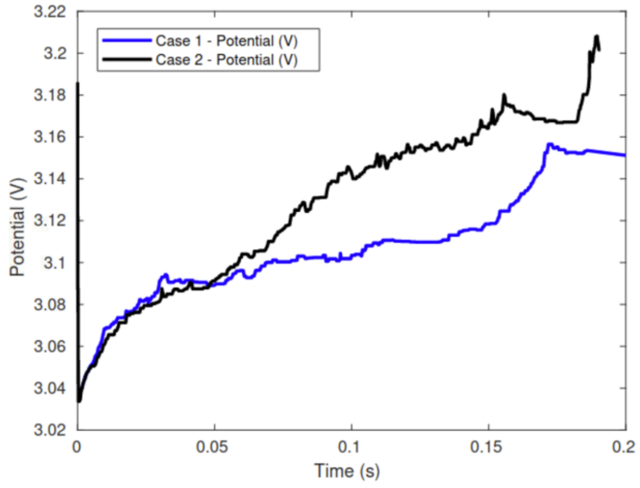
Programme development for cell model creation

- Cell Geometry
- Porous Electrode Design
- Flow conditions
- Electrochemical Properties



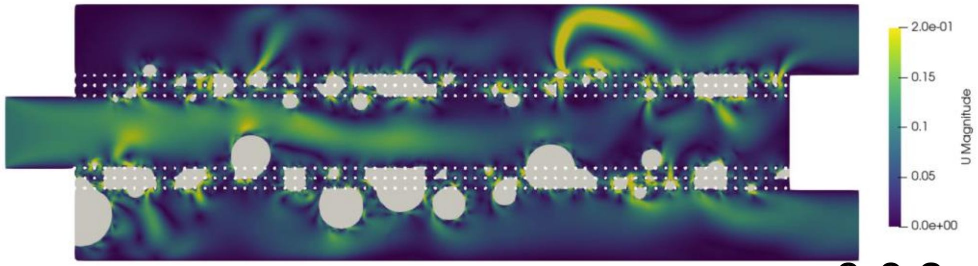


Dynamic 2D 2phase simulations



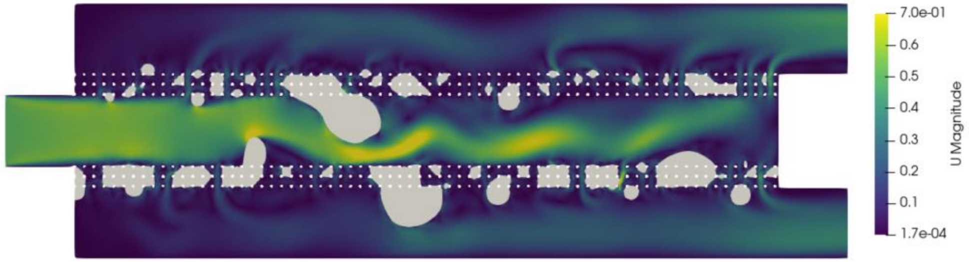
Operating potential profile at a current density of 1 A/cm2 for case 1 and case 2.

Case 1 - 0.1 m/s flow rate at 0.18 s 1 A/cm^2

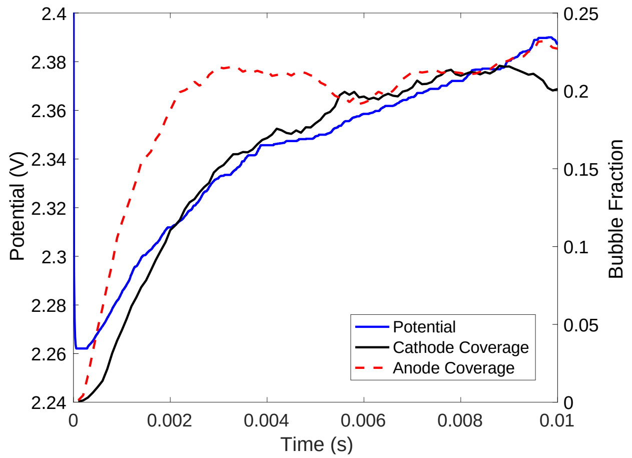


0-0.2m/s

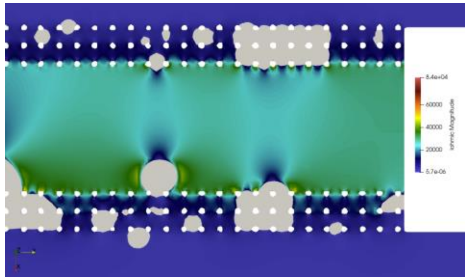
Case 2 - 0.5 m/s flow rate at 0.18 s 1 A/cm^2



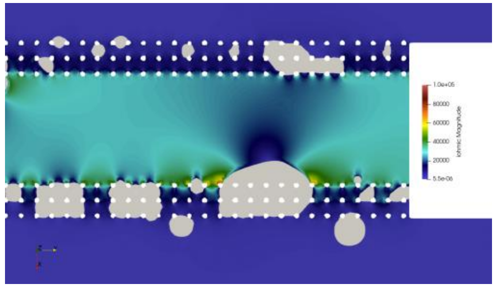
0-0.7m/s



Dynamic potential profile and bubble coverage of electrodes

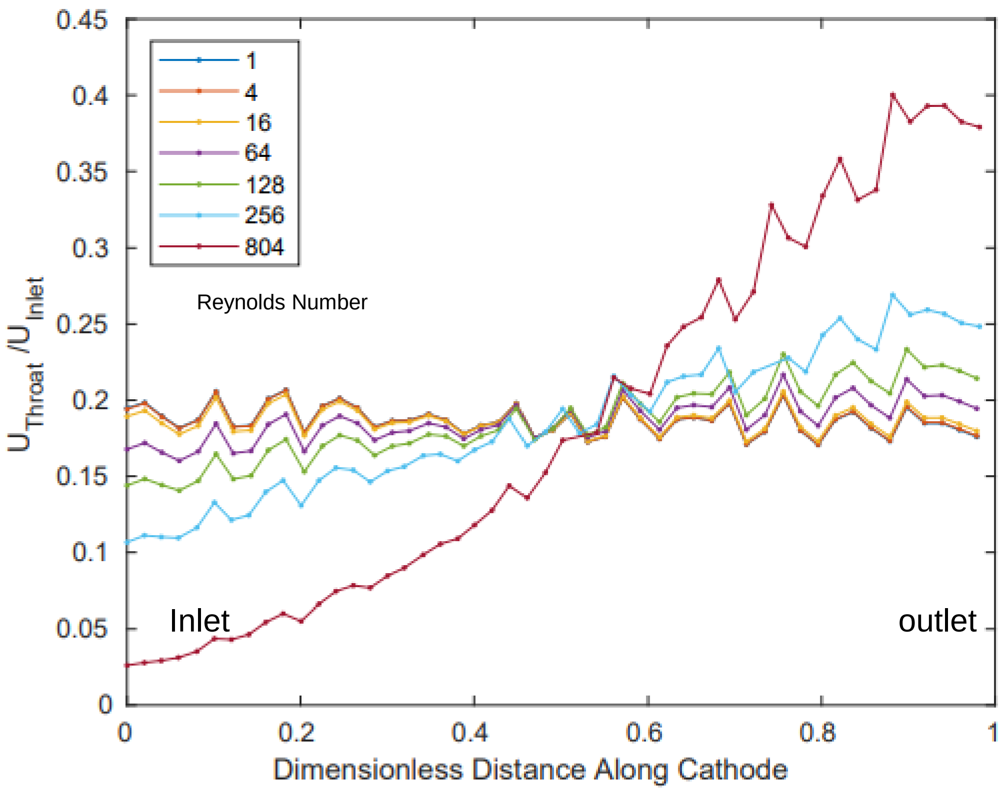


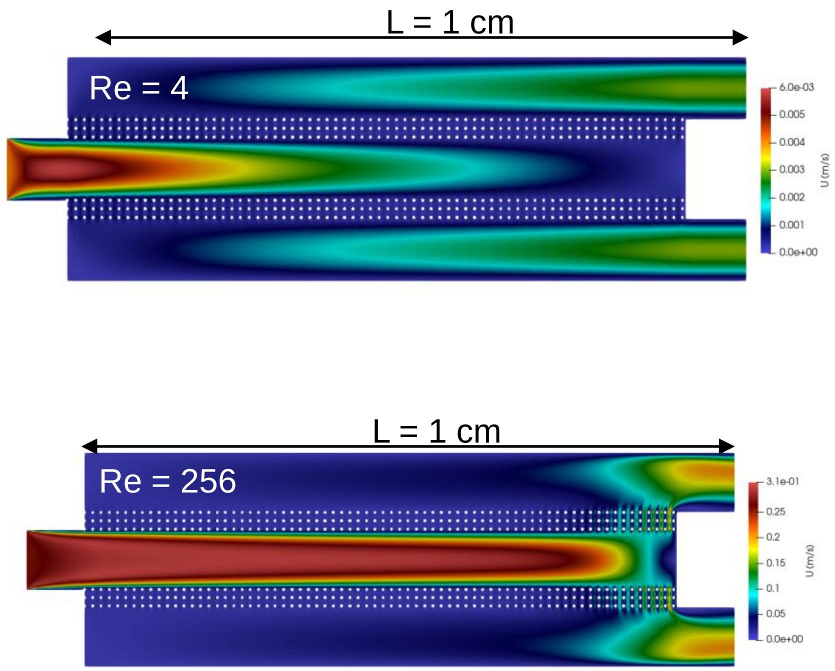
0-84kA/m^2

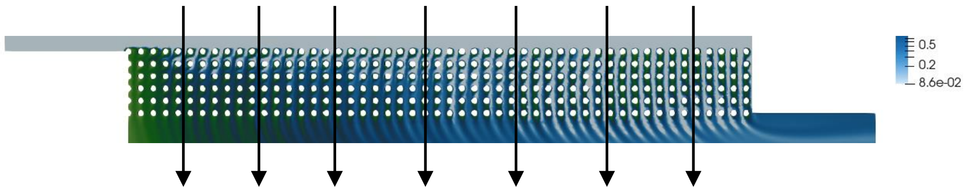


0-100kA/m^2

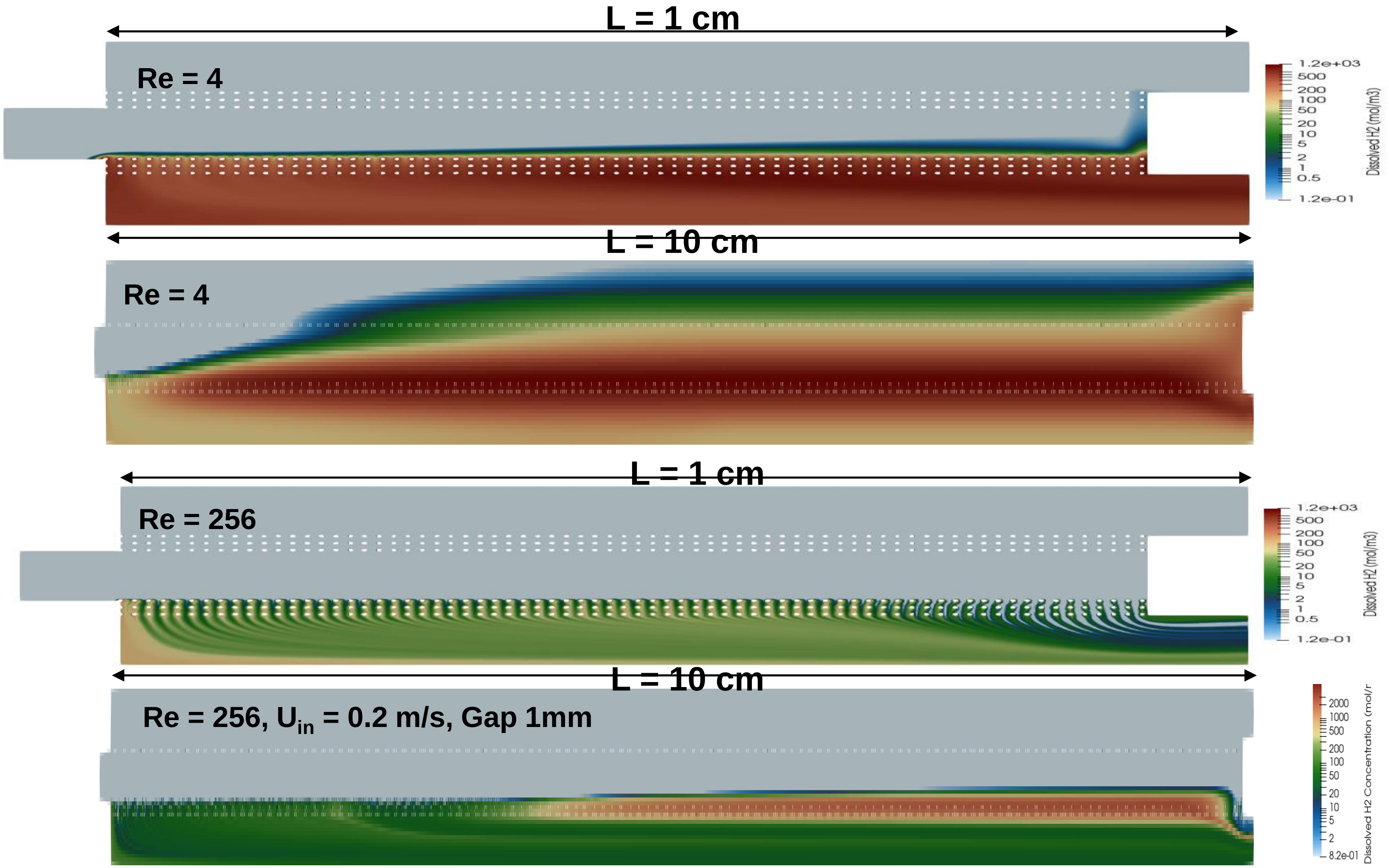
Velocity distribution (1phase)



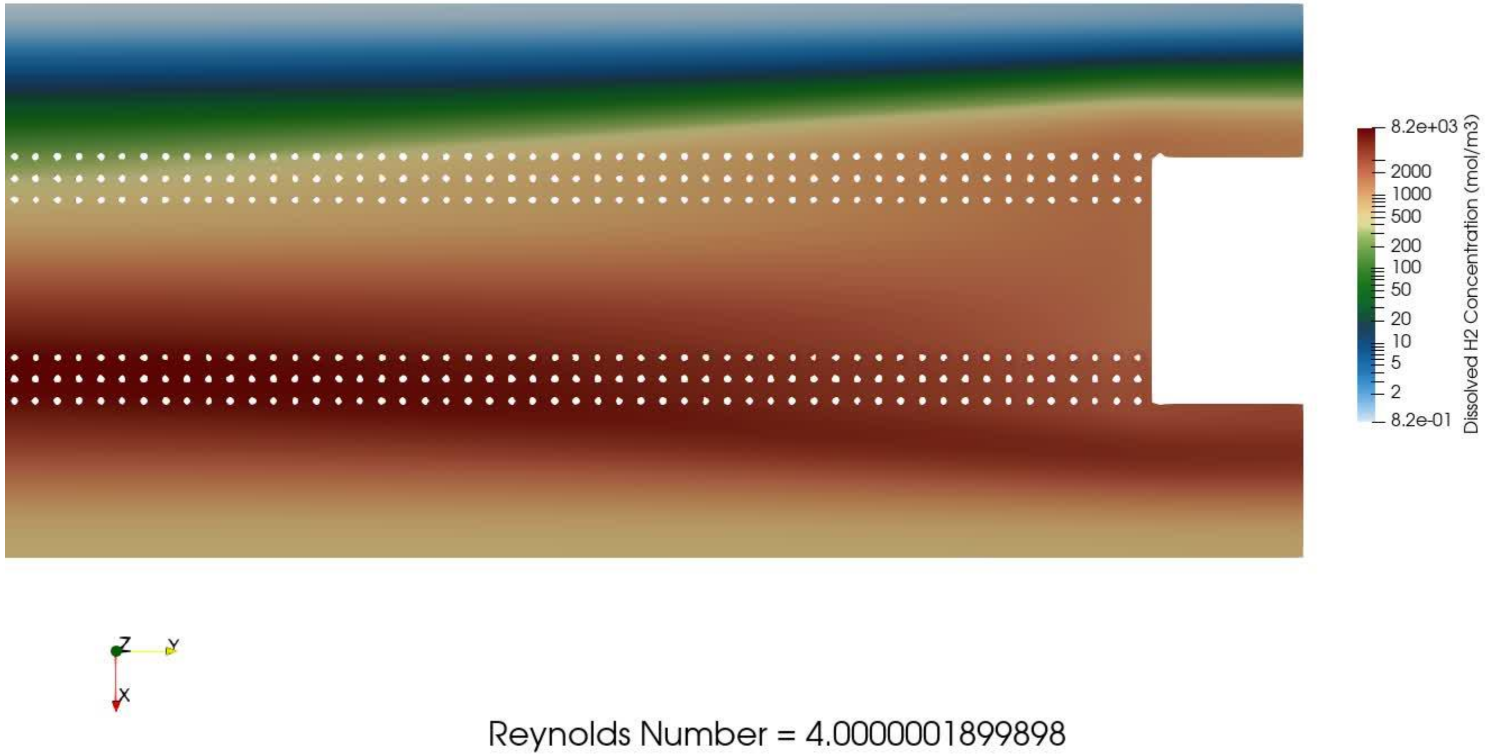




Dissolved gas crossover

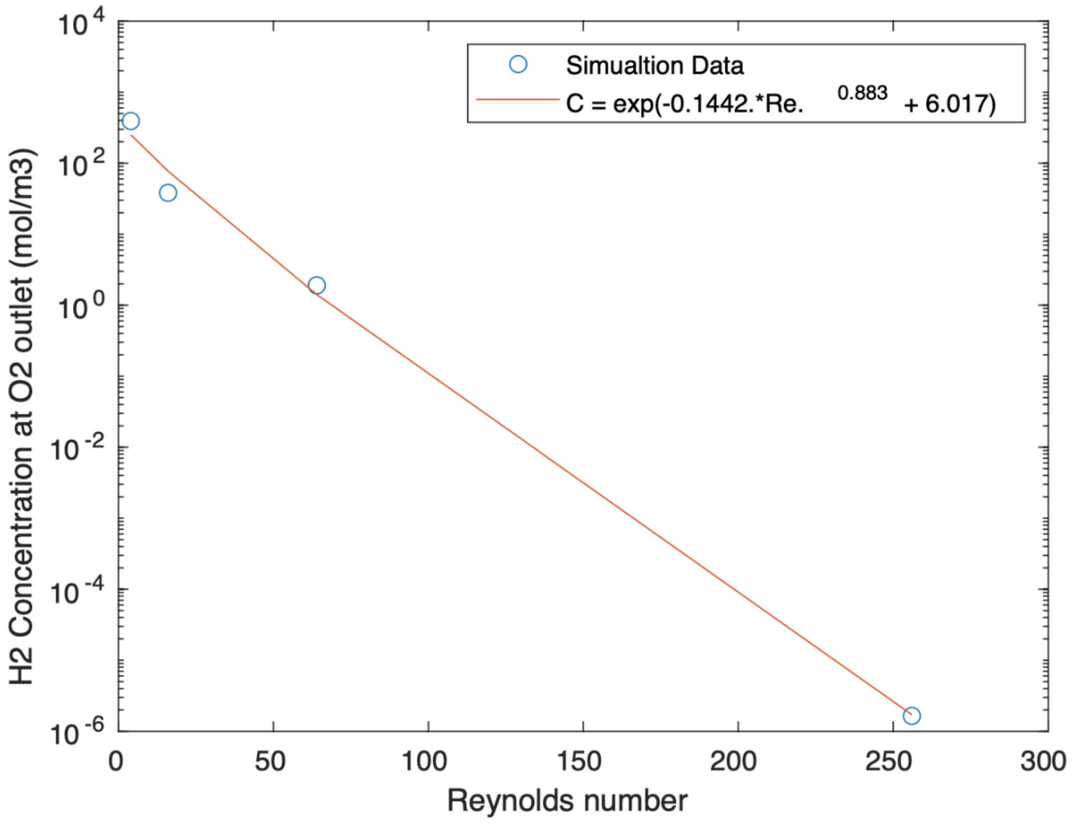


Dissolved H2 concentration with Reynolds number



Video @ 1 A/cm2. 10 cm geometry.

H2 concentration in O2 stream

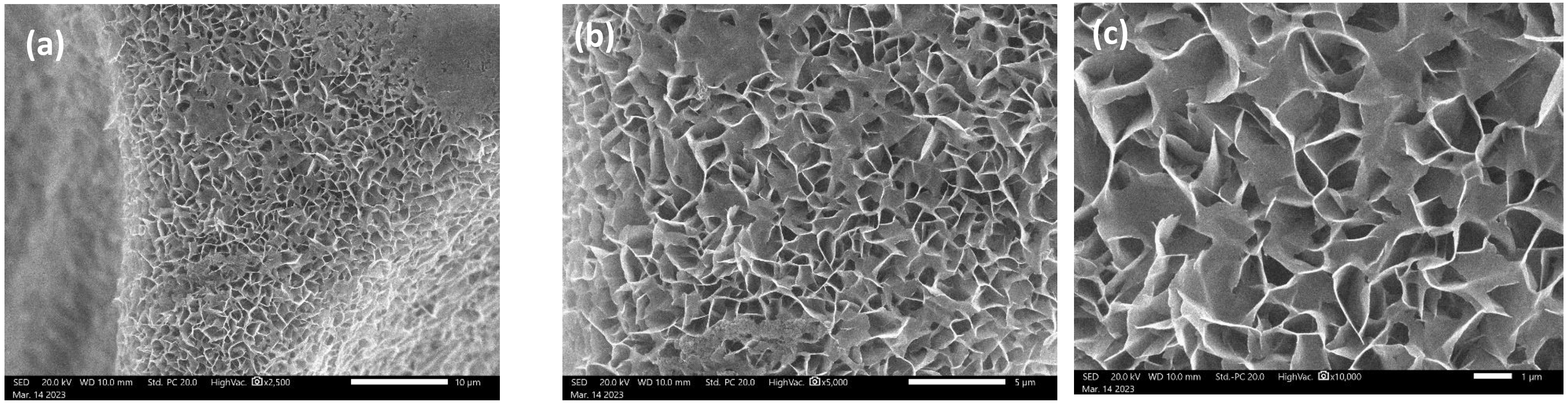


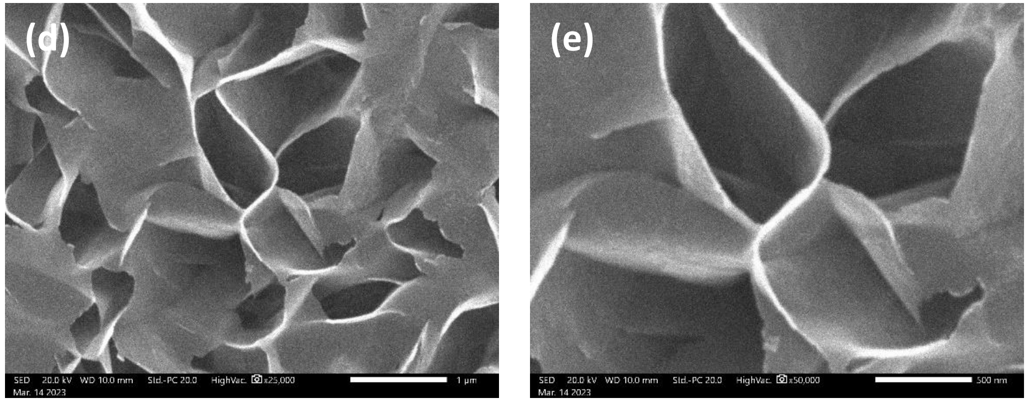
- Safety
- Gases purity
- Minimum load and dynamics

1. Overarching questions of Workstream 2
2. Literature Review
3. Modelling membrane-less electrolyser results
4. Catalyst for AEM based Electrolysers results
5. Questions and open discussion

Ni based LDH electrode for OER

Ramakrishnan Shanmugam

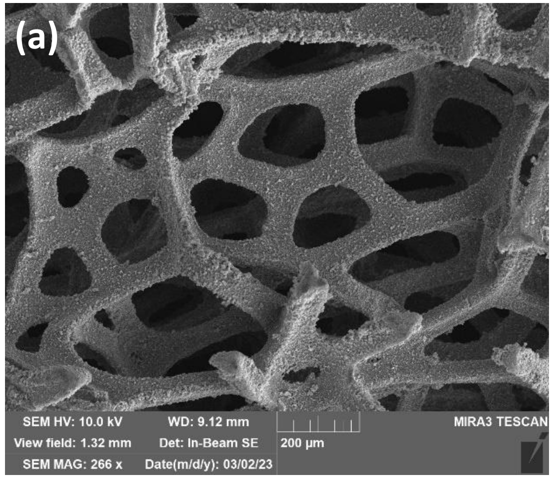


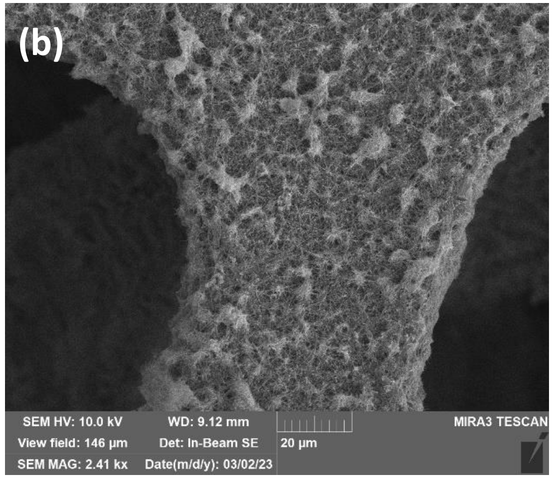


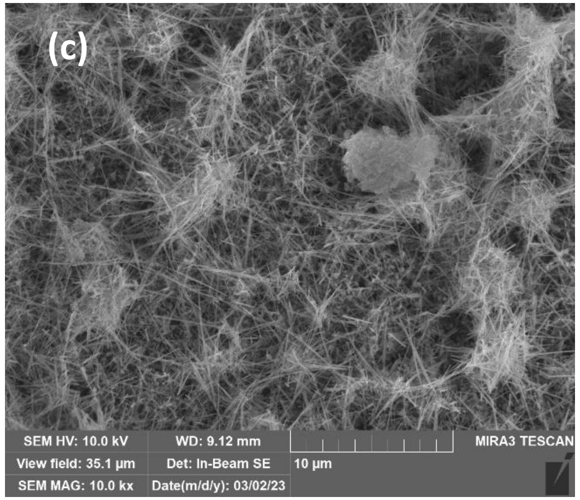
Direct growth of Layered double hydroxide on Ni Foam by using hydrothermal method

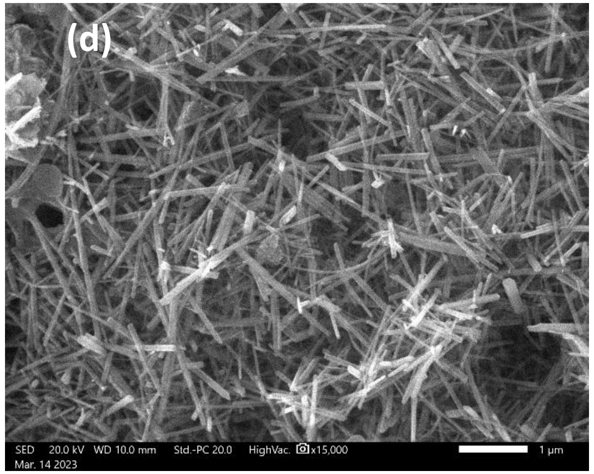
Morphology analysis : (a-e) SEM images of LDH @ Ni foam with different magnifications

MOx on LDH electrode for OER





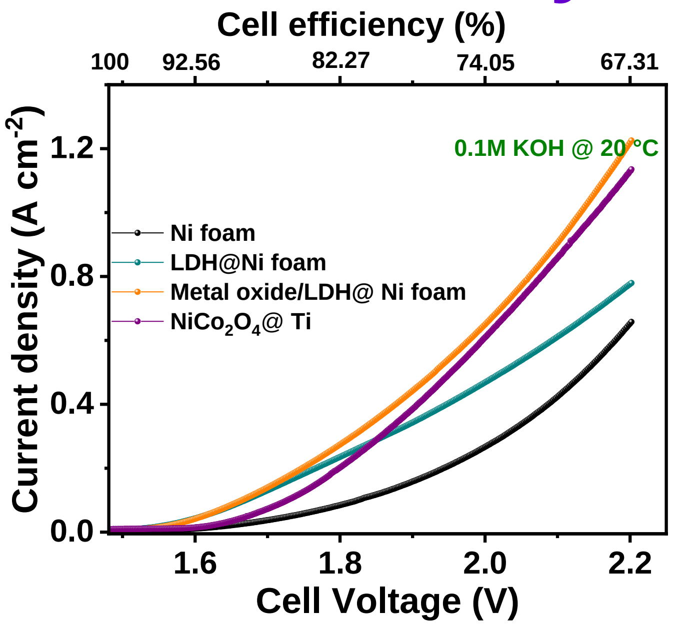


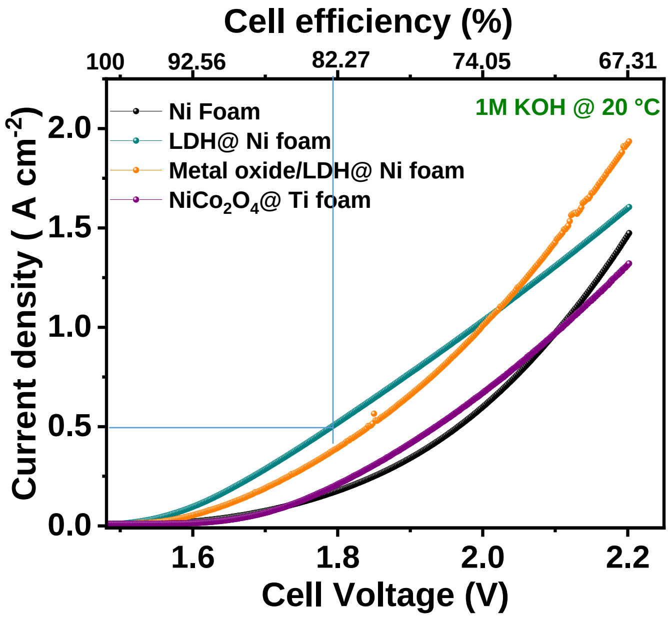


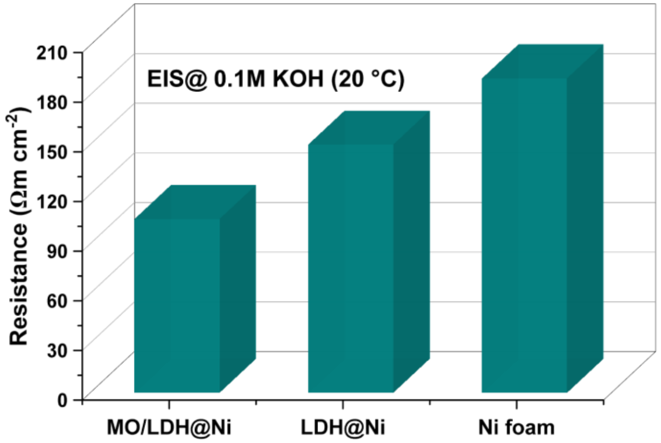
Growth of metal oxide on LDH / Ni foam by using hydrothermal method

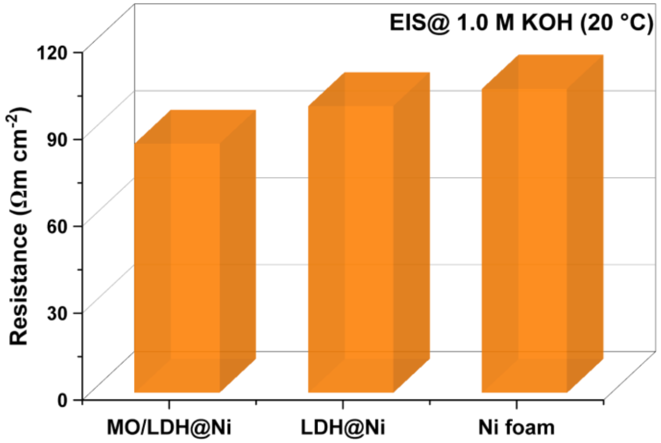
Morphology analysis : (a-d) SEM images of metal oxide /LDH @ Ni foam with different magnifications

Electrochemical performance AEM electrolyzer (1)

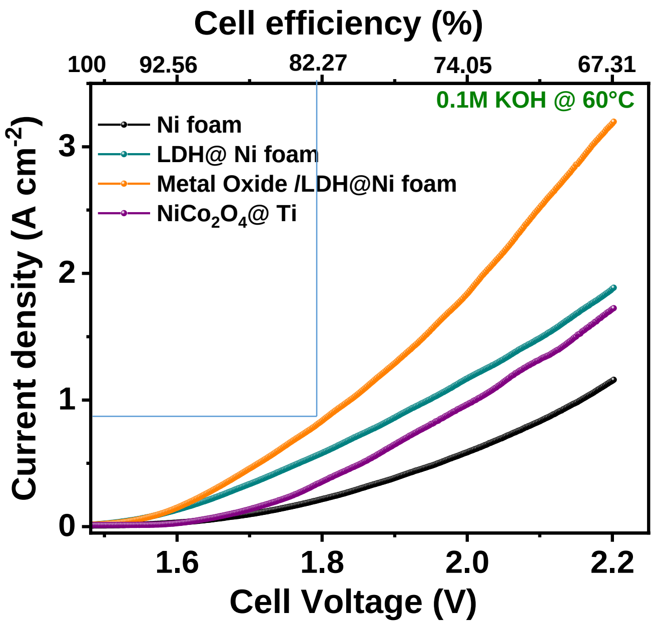


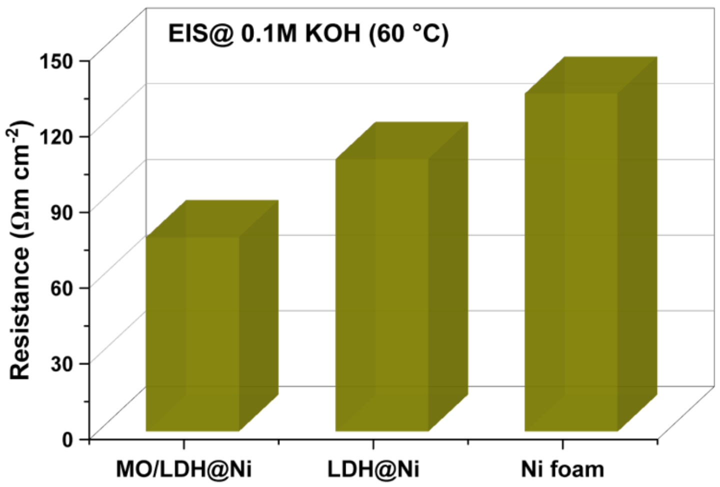






Electrochemical performance AEM electrolyzer (2)





Newcastle University Newcastle University

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Questions and discussion

Ocean Refuel funded by
EP/W005204/1

UK Research and Innovation

Ocean-Refuel

Work Stream 3: Transportation and Storage

WP3.1 Solid State Hydrogen
WP3.2 Ammonia as a Hydrogen-Rich Carrier

Cardiff University Prifysgol Caerdydd
Imperial College London
Newcastle University
University of Nottingham UK | CHINA | MALAYSIA
University of Strathclyde Glasgow

University of Nottingham
Energy Institute

UoN Hydrogen Research

Ocean-Refuel

Work Package 3.1
Solid State Hydrogen storage and compression

Marcus Adams, Amelia-Rose Edgley
Alastair Stuart, David Grant, Gavin Walker

Work Packages

- WP3.1.1: Impact of impurities from a range of cost-effective electrolysers
- WP3.1.2: Metal Hydride Hydrogen Buffer Store
- WP3.1.3: Metal hydride compressors as an efficient, non-mechanical compression system
- WP3.1.4: Fuel transportation to other regions (HT or LT MHx)

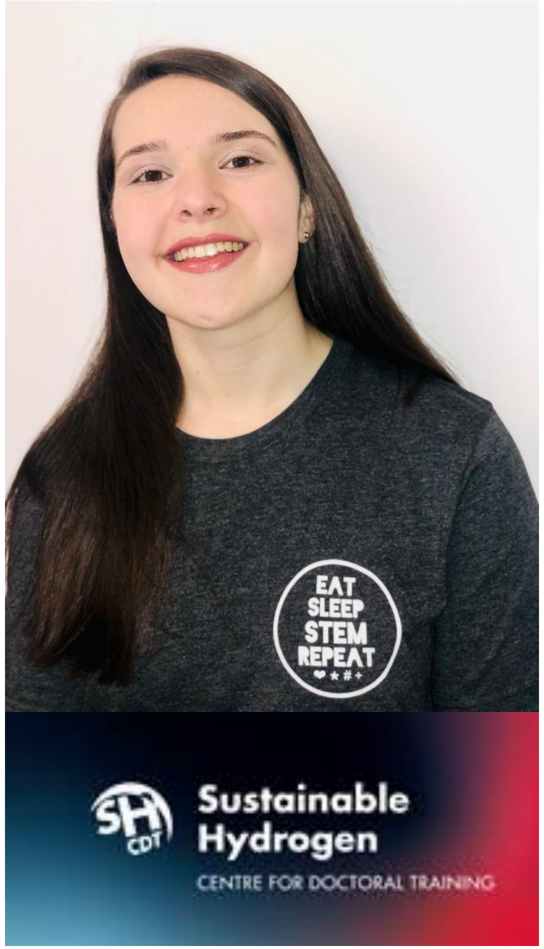
University of Nottingham Energy Institute

UoN Hydrogen Research

WP3.1.1: Impact of impurities from a range of cost-effective electrolysers

Nanostructured hydrogen materials for offshore green hydrogen

Amelia-Rose Edgley



Aims

- Create higher capacity metal hydride stores
- Improved tolerance to impurities

Materials challenge

- Low temperature for hydriding/dehydriding
- Maintain good volumetric capacities
- Retain good kinetics

Wind Turbine | Electrolyser | Metal Hydride Buffer Store | Compressor | Salt Cavern Store

WP3.1.2: Metal Hydride Hydrogen Buffer Store

Metal Hydride (MH) Buffer Store

Hydrogen Production System → 30 bar → Buffer Tank → Compressor station → 100 - 200 bar → Long term hydrogen Storage

Hydrogen density at 30 bar and 25 °C

2.4 kg /m³

Hydrogen density in MH AB_2 bed (fill density)

≈ 45 kg /m³

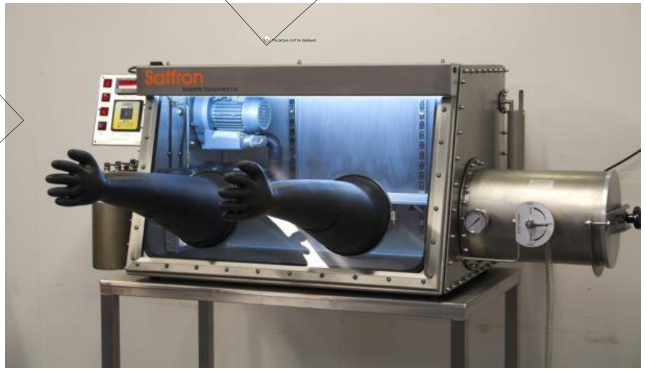
MH Scaling-up

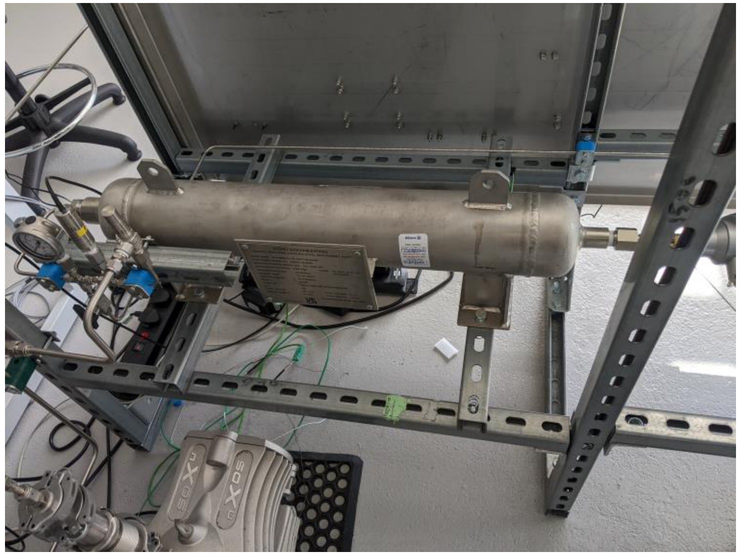
Placing a jaw crusher inside a glove box

Crushing kg of UoN hydrogen storage alloy

Formulation preparation

Charging and testing





MH Buffer Store Test Facility

- Hardware in the Loop test facility
- 100 bar max pressure
- Test stores up to 1 kg hydrogen

Simulate Electrolyser

Ocean Refuel Metal Hydride Store

Simulate controlled hydrogen delivery

MH Store small scale store

- Manually crushed 1.6 kg of solid-state H_2 alloy

- To test activation method at larger scale

University of Nottingham
Energy Institute

UoN Hydrogen Research

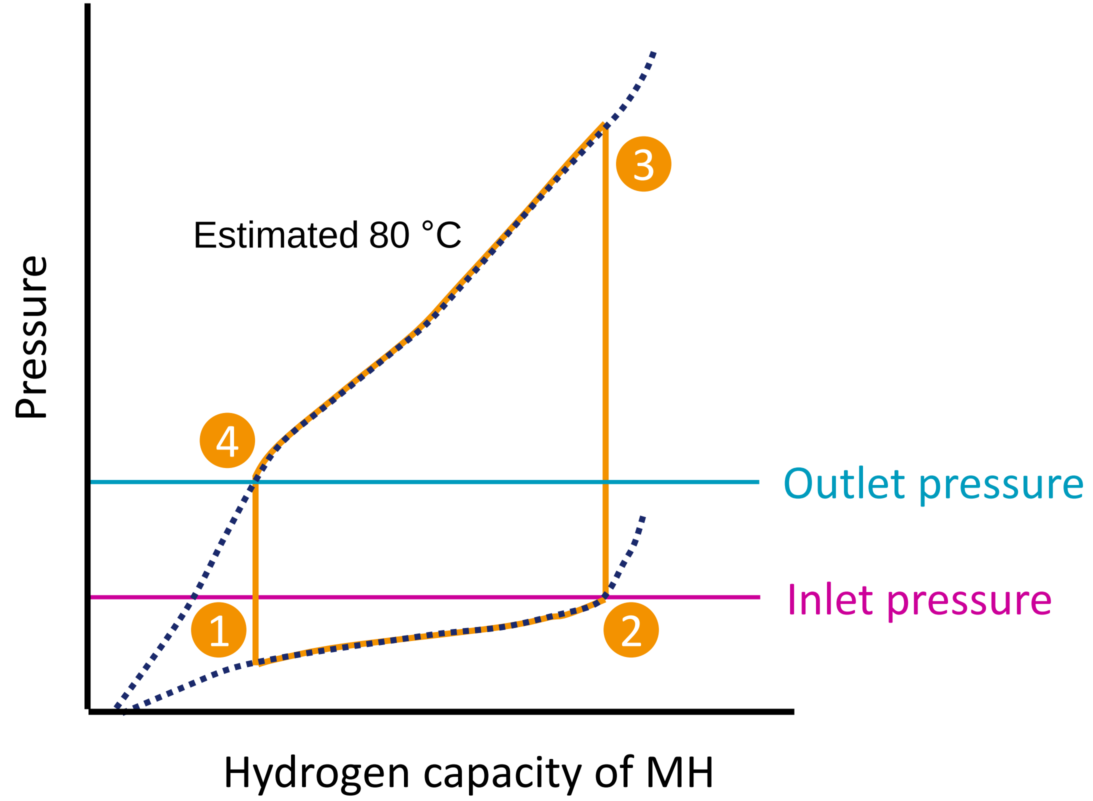
WP3.1.3: Metal hydride compressors

MH Compressors - explained

- MH Compressors are driven by heat, not electricity.
- Electrolyser waste heat can be used to compress hydrogen.
- The minimum energy requirement for a single stage is ≈ 4 kWh/kg H_2

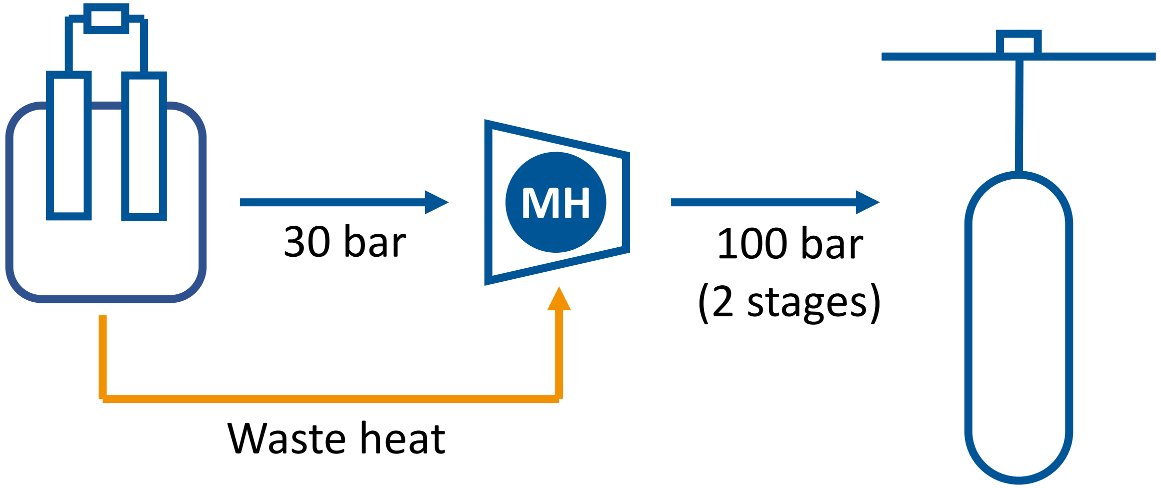
- (1 - 2) Hydrogenation
- (2 – 3) Bed heating
- (3 – 4) Dehydrogenation
- (4 – 1) Bed cooling

- A 2nd stage can be added if a higher pressure is needed.



Why MH Compressors?

- Electrolyser waste heat can be used to compress hydrogen.
- The minimum energy requirement for a single stage is ≈ 4 kWh/kg H_2
- Example electrolyser (Enapter):
  - Electrical consumption 53.3 kWh/kg(H_2)
  - Waste heat = 13.9 kWh/kg(H_2)
    - based on HHV

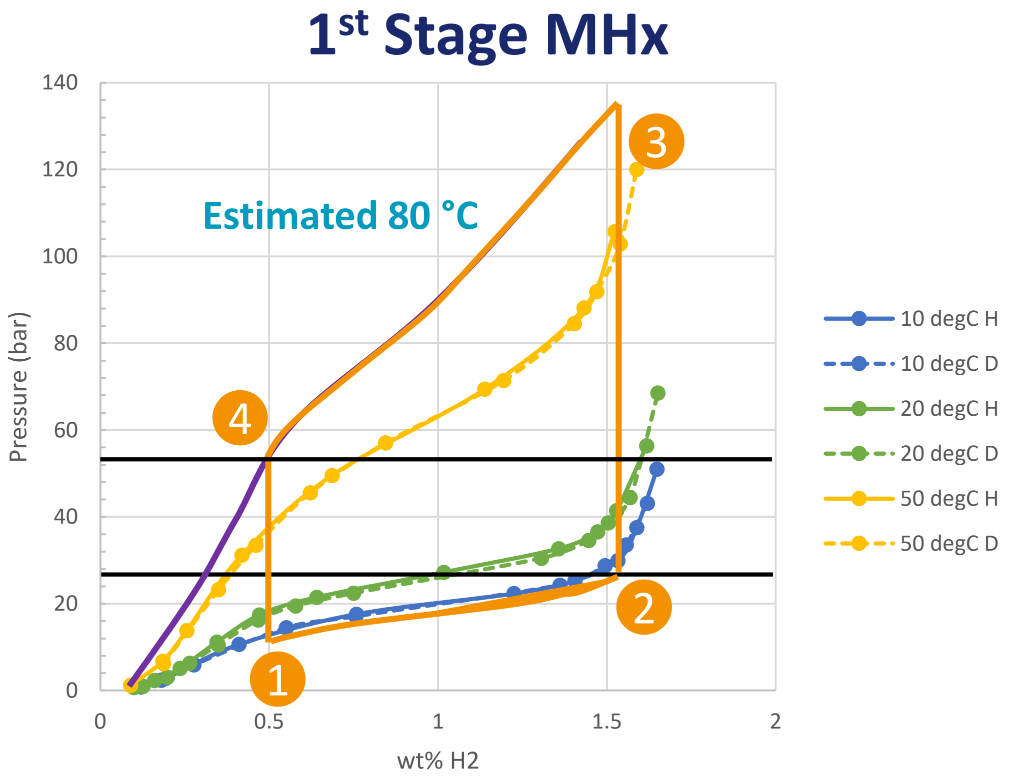


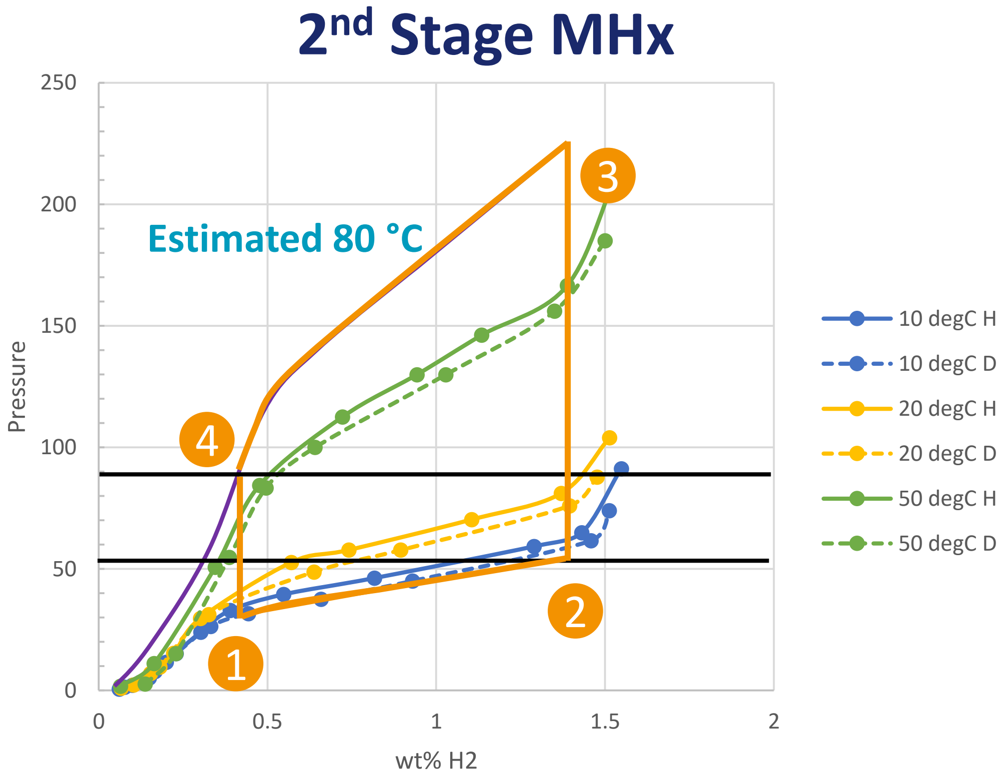
www.enapter.com/newsroom/kb_post/what-is-the-overall-efficiency-of-enapters-electrolyser

MH Compressor - example

Aim: Compress from 30 bar to 100 bar using only waste heat from an electrolyser.

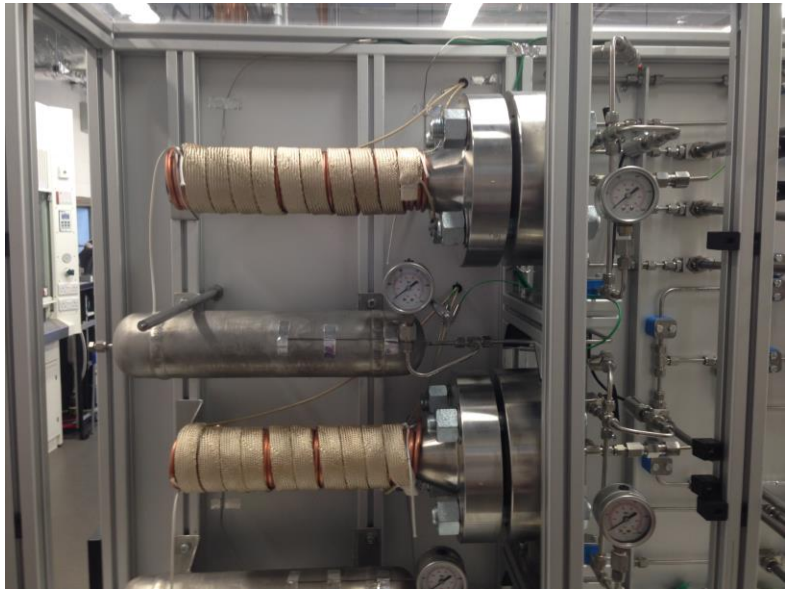
Hydrogenate @ 5 – 15 °C. Dehydrogenate @ 80 °C

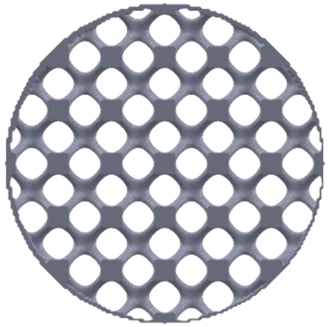




Material challenge: Reduce the slope for the plateau to make each stage more efficient.

Commissioning MH Compressor





- Commissioning a 2-stage MH compressor test facility.
- Intend to use a lattice structure for improved heat transfer.
- Initial plan to optimise materials and test effectiveness of these materials to compress from 30 bar to 100 bar.
- Based on AB2 compositions

Ocean-Refuel

UKRI
Engineering and Physical Sciences Research Council

Any questions?

WP4 - Networks, Compatibility and Demand

H2 may be transported in its pure form, transformed into a different energy carrier and/or blended to form part of a gas stream to be transported. Ammonia can support the concept, whilst methane produced from capture CO2 and H2 could mitigate the impact of excessive carbon dioxide emissions.

The WP addresses

WP4.1. Use of NH3 as an alternative long-term/long-distance energy vector

WP4.2. ‘Carboniferous’ Hydrogen Supply

WP4.3. Public Perception of technologies

WP4.4. LCA and System Metrics

WP4.5. Overall System Optimisation

4.1. Use of NH3 as an alternative long-term/long-distance energy vector

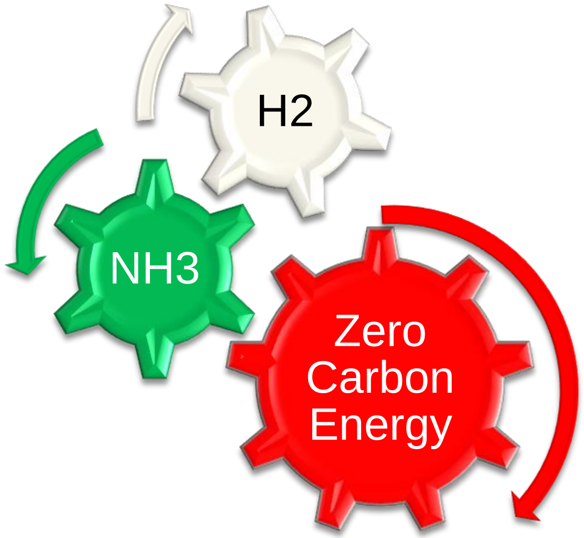
Task 4.1.1. Numerical and experimental data on efficiency, energy, costs for LCA and system studies.

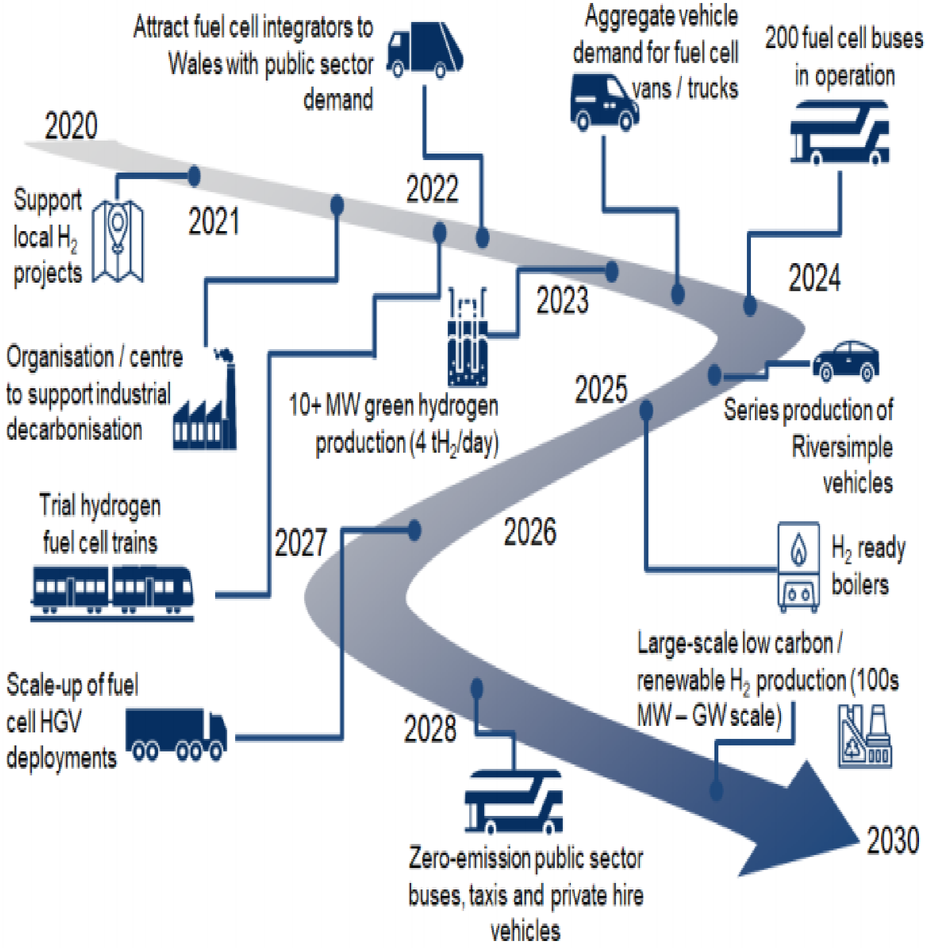
Task 4.1.2. Integration of systems for higher efficiencies to various sectors.

Task 4.1.3: Study for the reconversion of ammonia to hydrogen at a larger "city-gate" scale.

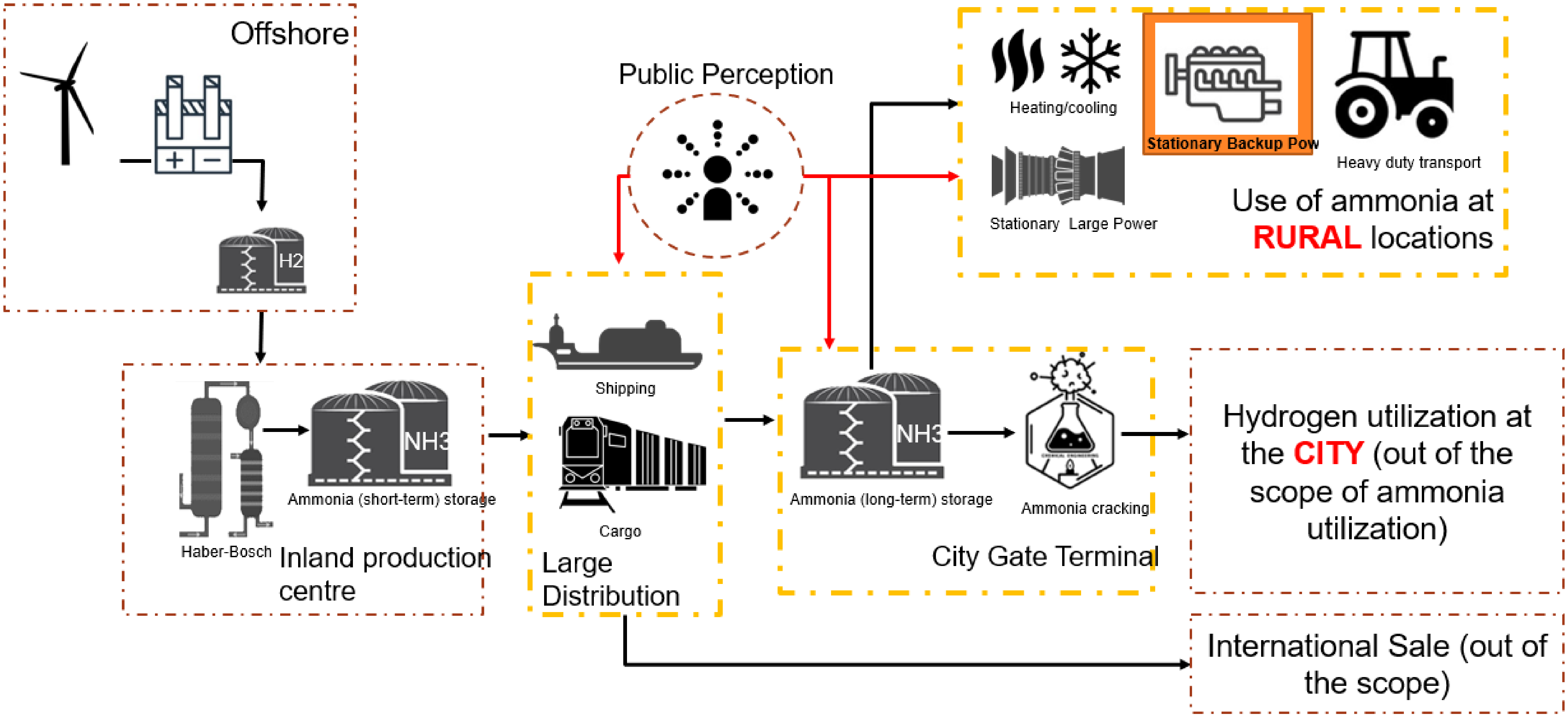
WP4.1. Ammonia application prospect

- Ammonia is a widely used chemical in the production of fertilizers, plastics, and other industrial products.
- Ammonia has a high energy density and can be used as a fuel in combustion engines, gas turbines, and fuel cells.
- Ammonia is a promising energy carrier for renewable energy sources.
- Ammonia is a cost-effective alternative to conventional fuels, such as gasoline and diesel, particularly in regions with high renewable energy potential.

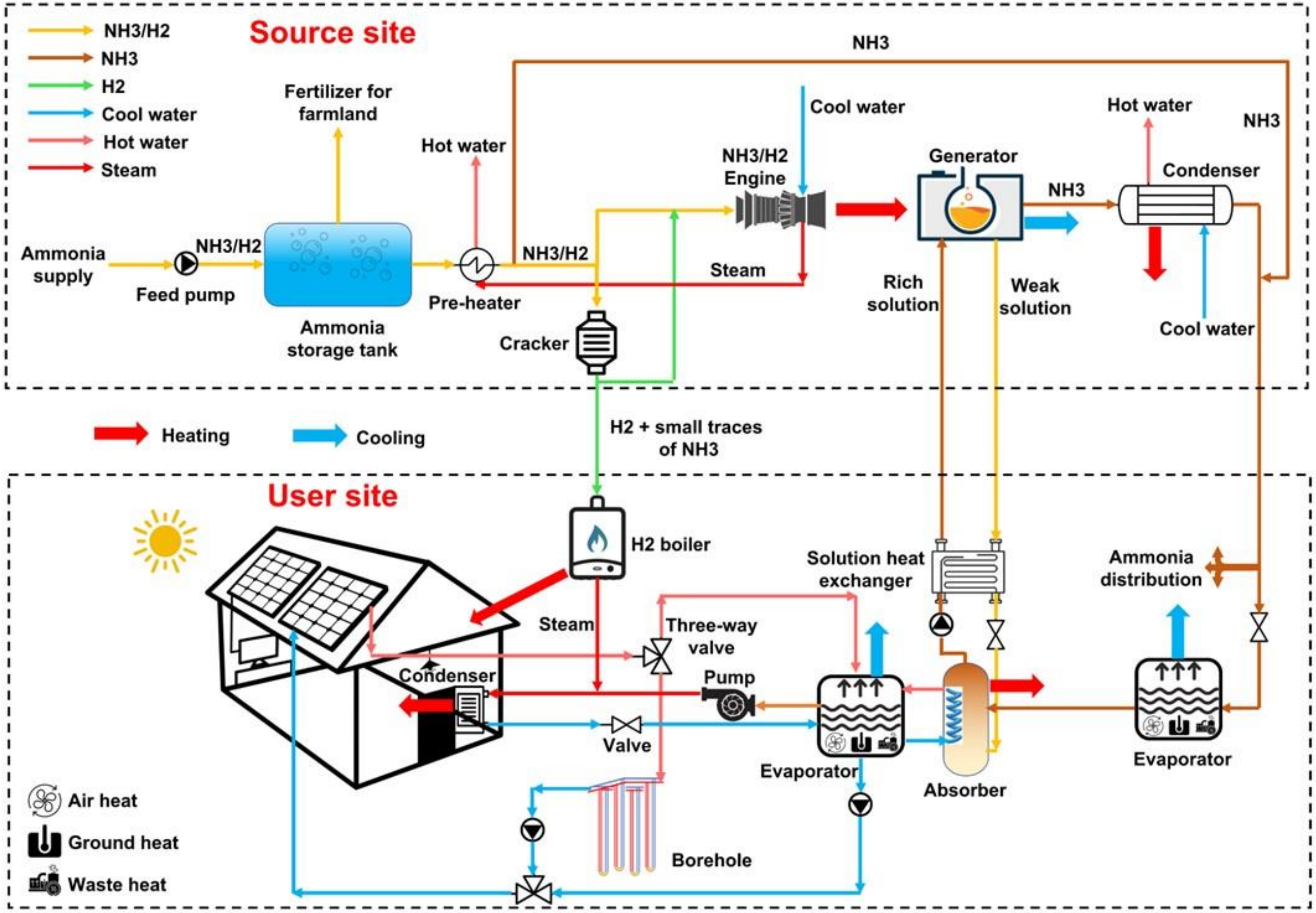




Overview

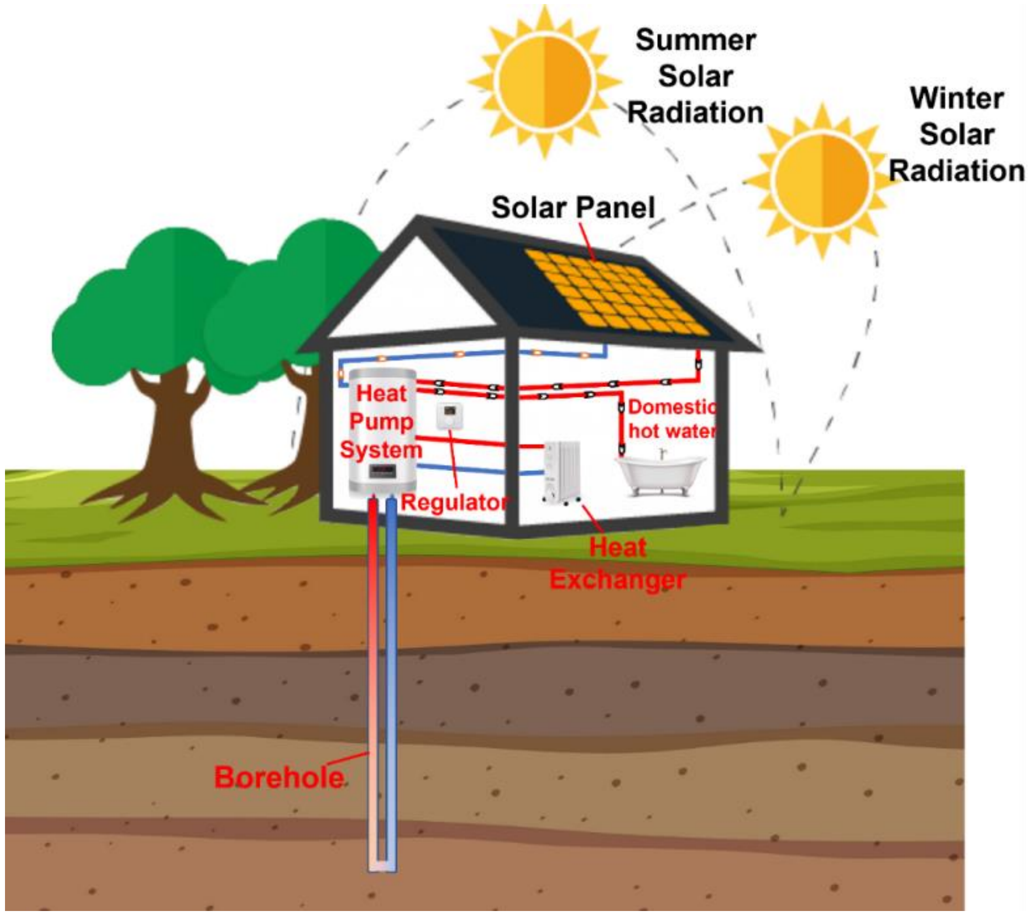


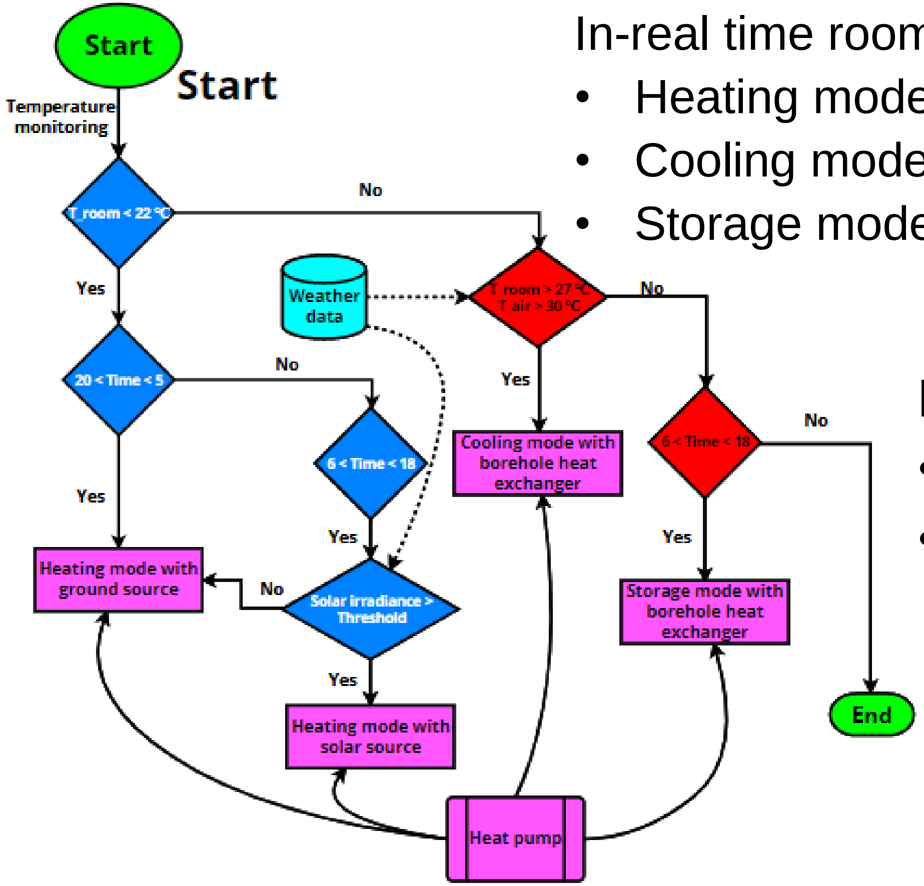
Offshore
H2
Public Perception
Heating/cooling
Stationary Backup Pow
Heavy duty transport
Stationary Large Power
Use of ammonia at RURAL locations
NH3
Ammonia (short-term) storage
Haber-Bosch
Inland production centre
Shipping
Cargo
Large Distribution
NH3
Ammonia (long-term) storage
Ammonia cracking
City Gate Terminal
Hydrogen utilization at the CITY (out of the scope of ammonia utilization)
International Sale (out of the scope)



- Ammonia storage;
- Ammonia distribution;
- Ammonia combustion;
- Ammonia cracking;
- H2 boiler;
- Storage of heat from renewable and sustainable energy source;
- Long-distance of ammonia transportation;
- In-real time household heating.

Dual heat source ammonia-based heat pump system





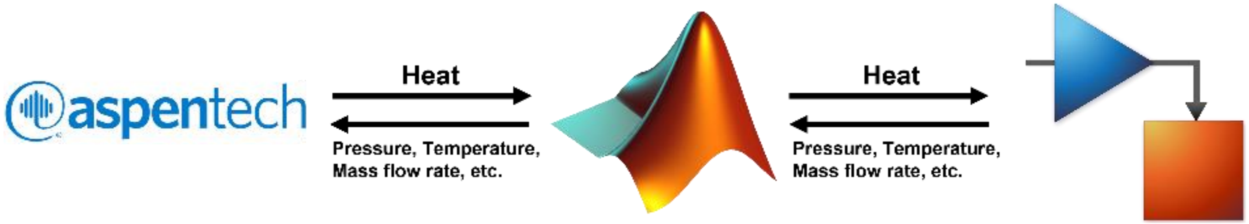
In-real time room temperature control:

- Heating mode;
- Cooling mode;
- Storage mode

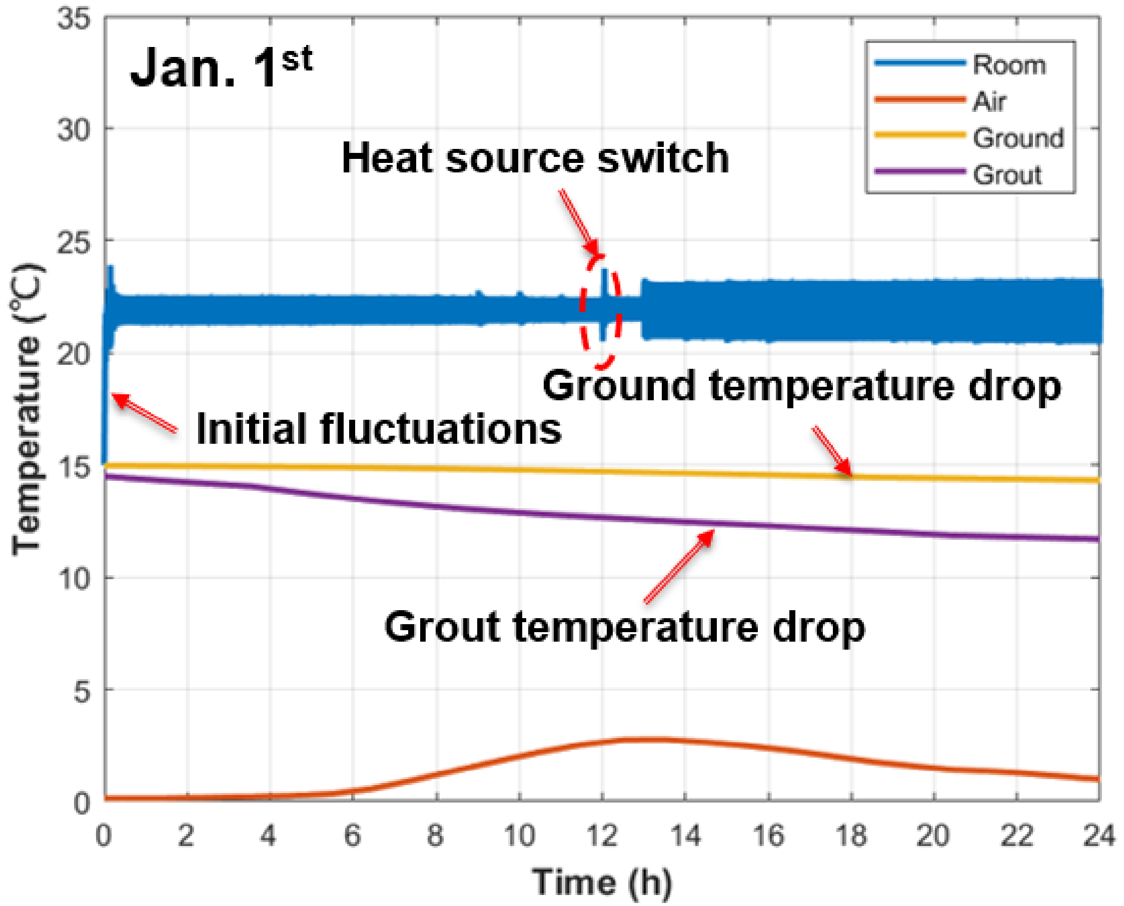
Dual heat source:

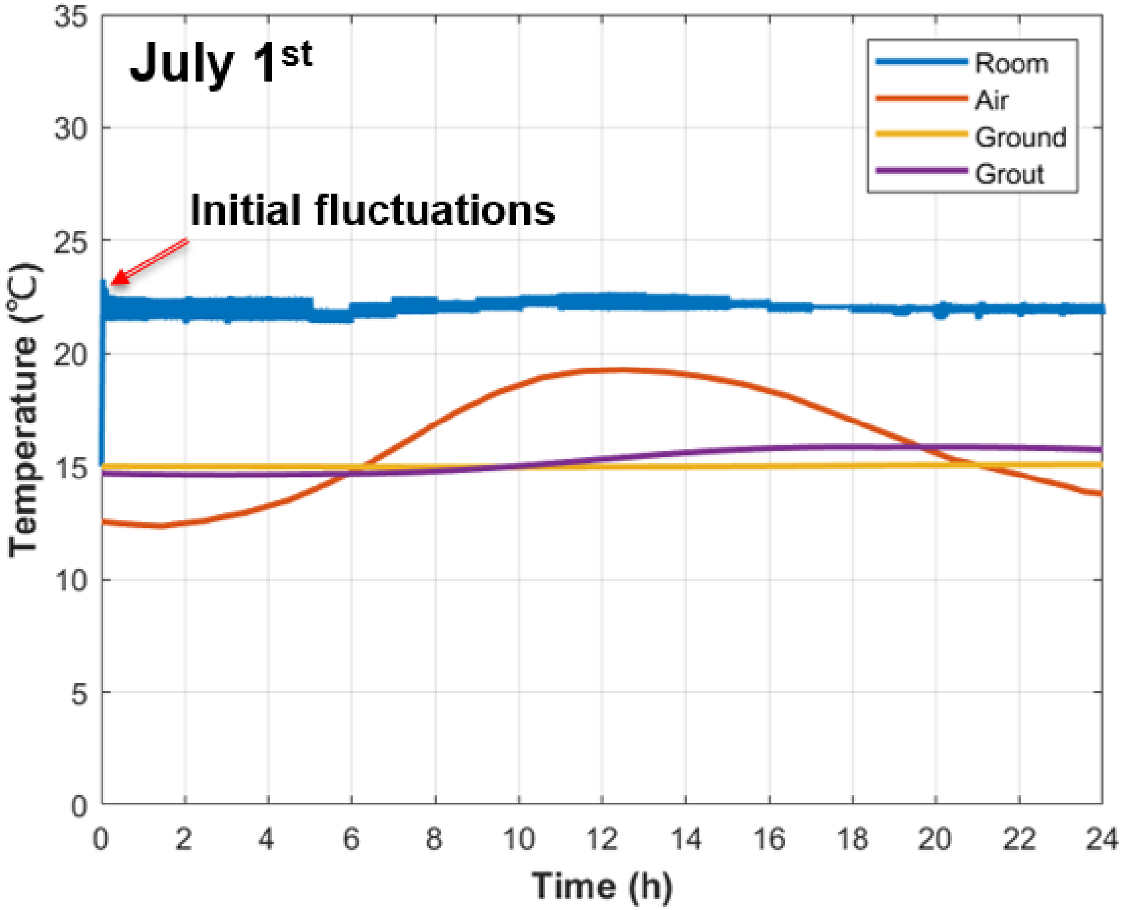
- Solar radiation;
- Geothermal heat;

System modelling



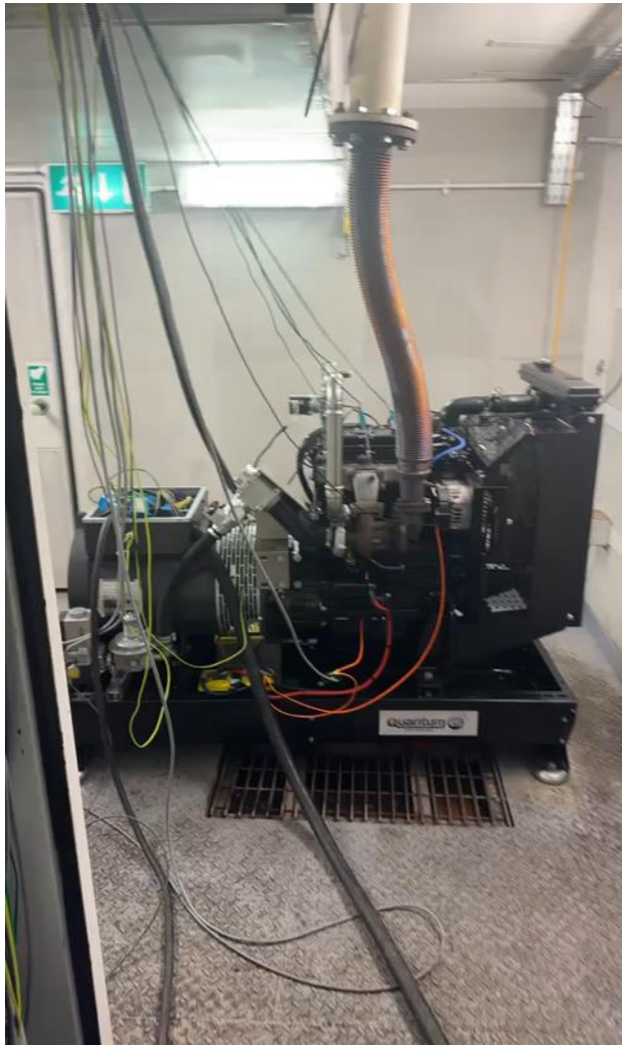
Temperature variations





- Room temperature can be maintained at a desired set point under various weather conditions.
- Initial flow rate control and heat source switch may cause minor temperature fluctuations.
- Soil and grout temperature may gradually decrease during winter.

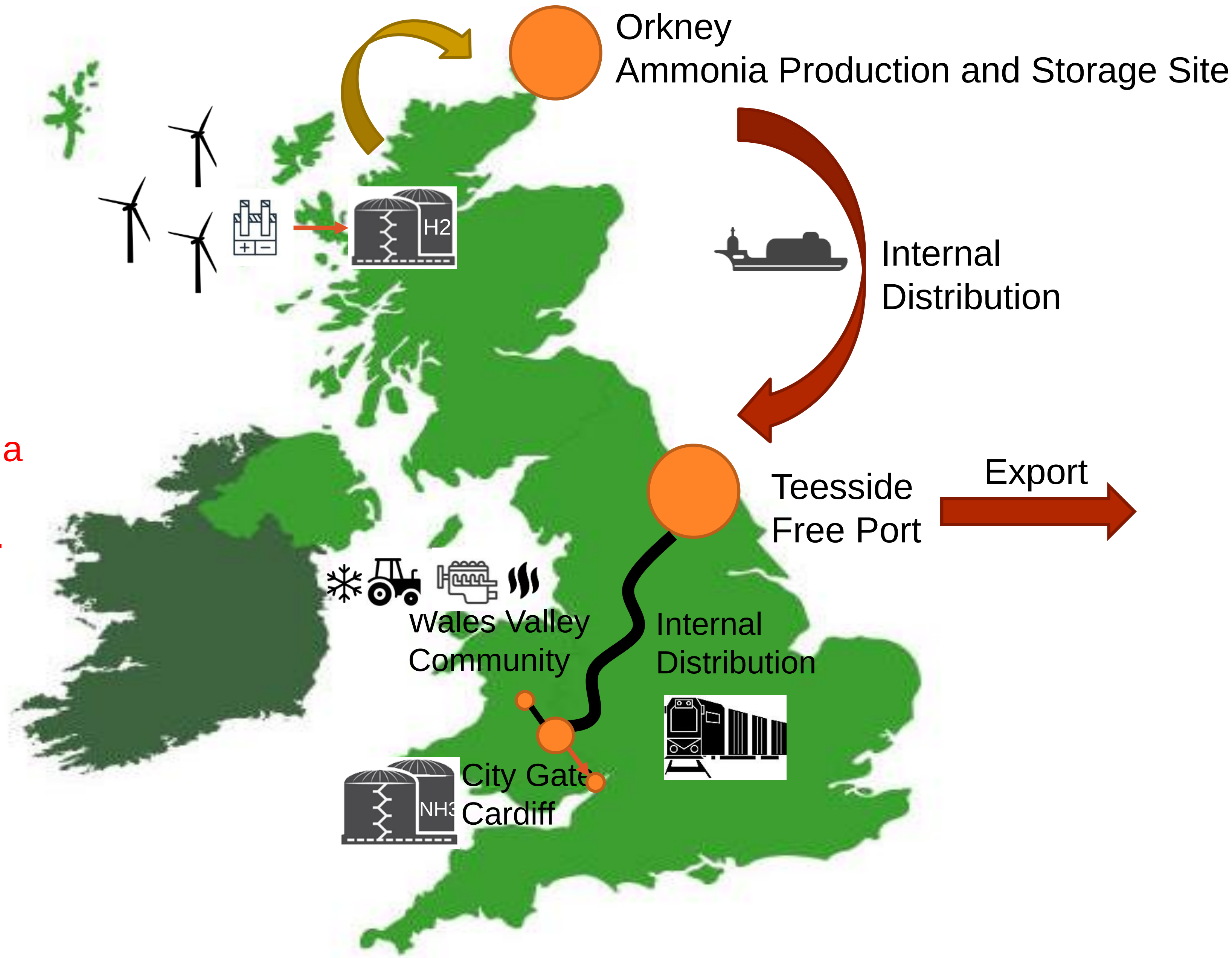
IC Engine (Experimental Component)



- ICE Purchased and promised by October 2022. However, supplier issues (caused by the war), staff problems and other inconvenients have delayed the delivery of the unit.
- Latest run (15 March 2023) showed that the engine is still suffering from poor ignition (?).
- The company is bringing specialists from Denmark and Germany to support them and deliver ASAP.

UK SCENARIO FOR AMMONIA UTILIZATION

- Unfortunately, Orkney project has been cancelled. ENEUS is providing us information for the analysis of the ammonia plant based on a project they are commissioning in the US.



4.2‘Carboniferous’ Hydrogen Supply

4.2.1 Safety Assessment

4.2.2 End-use performance

(4.2.3 Accurate Flow metering)

What on earth is ‘Carboniferous’ H_2 ?

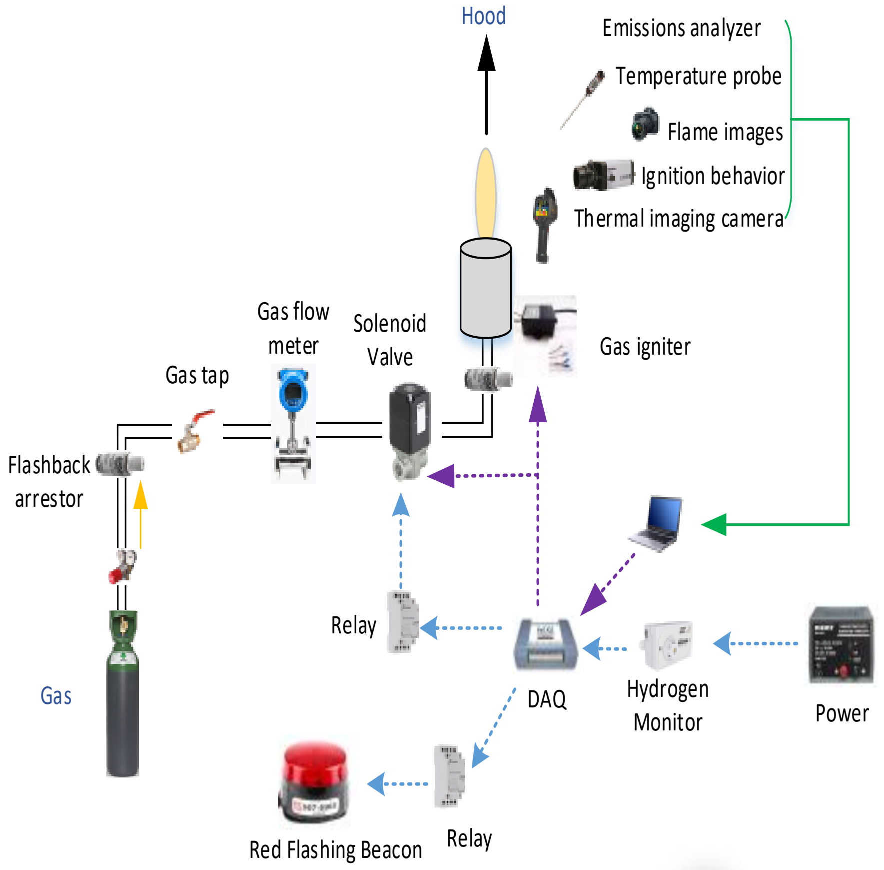
- Two operational scenarios

1. Early operation - limited hydrogen availability – H_2 blended into NG systems
2. Late operation systems incapable of retrofit with pure H_2 – supplied by a blend of H_2 and CH_4 synthesised from H_2 and captured CO_2.

Need to understand the capabilities – and operational range – of components that may need to operate on a range of gas compositions during their useful lives.

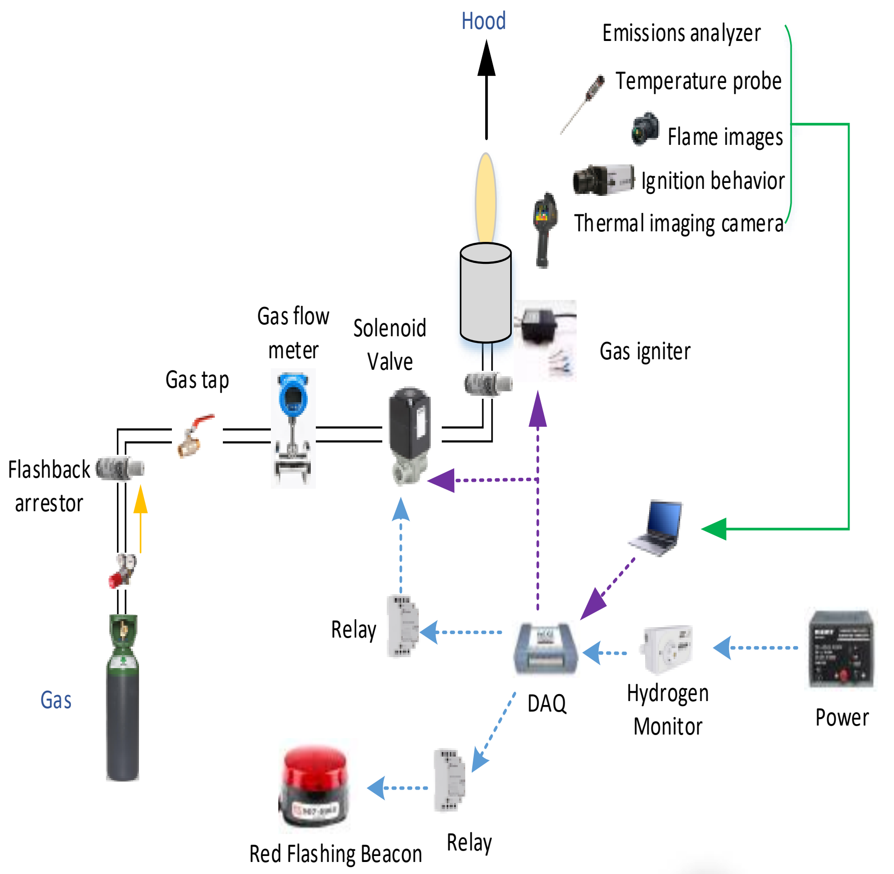
4.2.1 Safety Assessment

- Design and procurement of new test equipment to domestic-scale appliances at blends from 0-100% H_2 in CH_4
- Conversion of lab-space to put in place safety improvements to enable H_2 use – extraction, flashback protection, gas detection and safety interlock systems
- Imminent system installation and commissioning
- 'Learning by doing' our own safety considerations inform the wider safety debate



4.2.2 End-use performance

- Acquisition of ‘commercial’ burners designed for 50% H_2 optimal operation and 100% H_2 optimal operation
- Both burners to be tested at, and away from, nominal design conditions (blends)
- Emissions, stability, appearance and other operational parameters to be assessed.
- Review of literature complete – data for up to 30 (mol) % H_2 and ‘pure’ H_2 but little in between.
- Active interaction with regulators to understand what likely future performance targets may be.



UNIVERSITY OF BATH

WP4.3. Public Perception of technologies

Task 4.3.1 Assessment of publics' perceptions

- Dr Christina Demski moved from Cardiff University to Bath University, taking this task with her.
- Bath and Cardiff are finishing the signature of an agreement to work on the project. As soon as the final signature is agreed (exp. April 2023), Bath will start the recruitment process of an RA to start with the Public Perception analysis.

4.4 LCA and system metrics

- Recruitment for PDRA post in contract stage
- Initial literature survey and analysis completed by PGR researchers with focus on:

1) Resource requirements of PEM electrolysers and potential for circular management
2) Wind turbine technology types and associated material requirements

Comfort Break

Ocean-REFuel (Ocean Renewable Energy Fuel)

Cross-cutting: systems engineering

WPS4

Cardiff University Prifysgol Caerdydd | Imperial College London | Newcastle University | University of Nottingham UK | CHINA | MALAYSIA | University of Strathclyde Glasgow

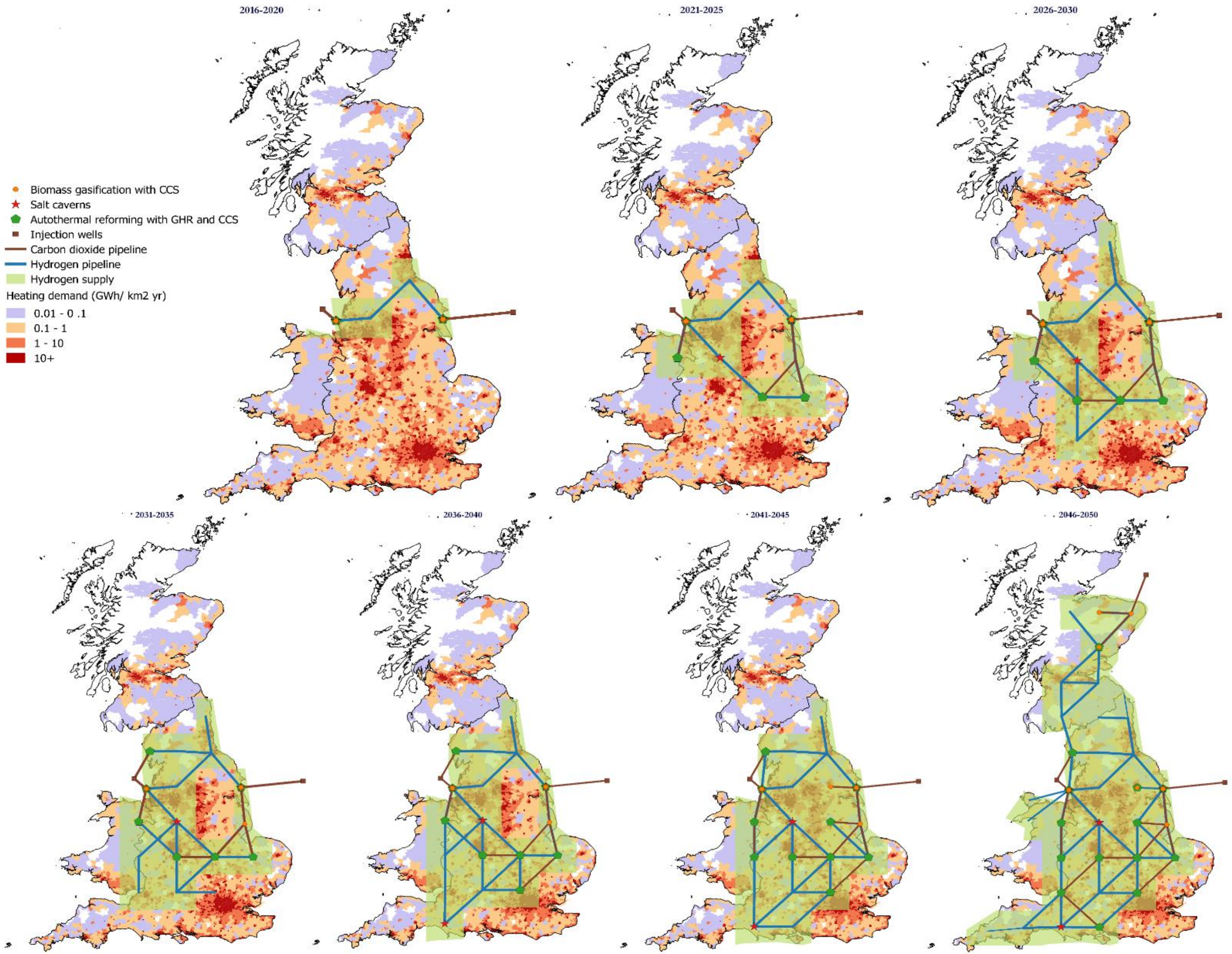
Systems engineering questions

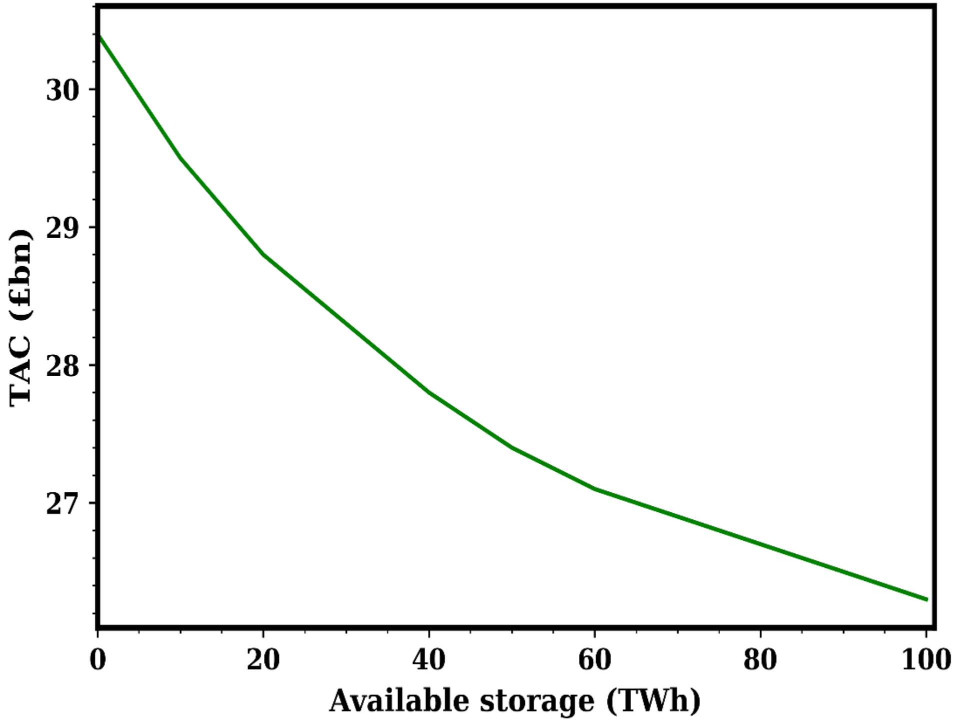
- Where to establish the system boundary (especially on the demand side)
  - How far onshore to explore infrastructure (in conjunction with WP4)
- Where will our fuels be most valuable?
- How does that compare with the most favourable supply location?
- Are there opportunity costs in the conversion process (displacement of useful renewable electricity)?
- What vectors are best to move between locations (electricity, H2, chemical fuels, …)?
- How to operate the system dynamically?
- How does the system dovetail with the UK's energy (and hydrogen strategy) to 2030 and beyond?
- Where are the innovation and policy pinch-points in the system?

Context: Hydrogen – roles in the future energy system

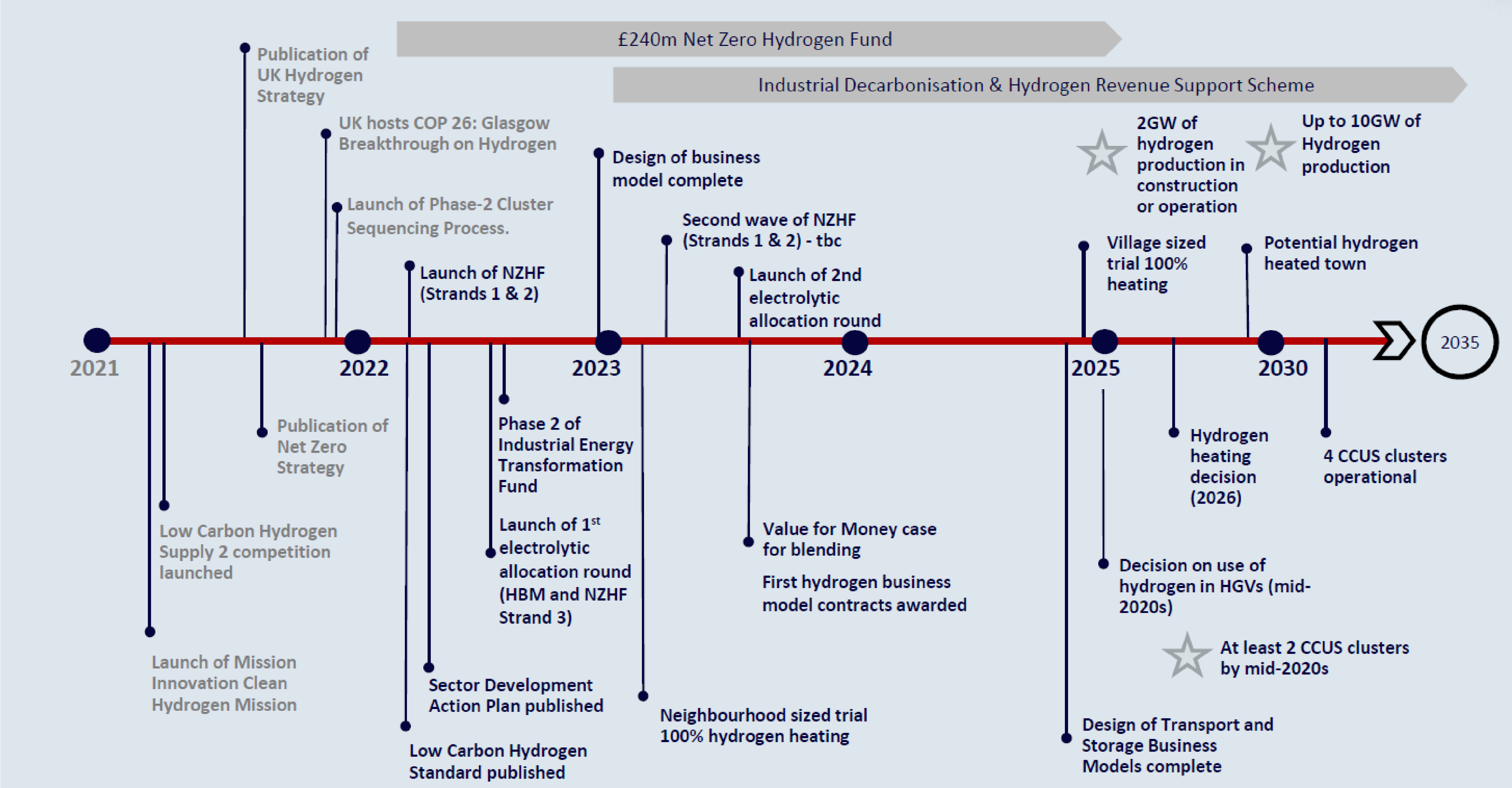
- Industrial feedstock and reductant
  - Existing and new processes (iron, synthetic fuels, …)
- Industrial, commercial and residential heating
- Low carbon power generation/CHP
- Transport
  - Heavier duty/longer range vehicles, trains, marine, aviation?
- Energy storage and renewables integration/cost reduction
- Long distance low-carbon energy transport
- …

Systems engineering: aim to establish how "best" the system evolves over time





Context: UK H2 roadmap



System design: problem statement

Identify the best strategy of expansion planning for offshore wind power generation in terms of:

1. location of offshore wind farms,
2. Technology selection
   - 2.1. Electrolyser type : turbine-integrated, wind farm hub, alkaline, PEM, or SOEC (centralised or decentralised)
   - 2.2. Energy transmission method: direct through cable , indirect through hydrogen carrier (hydrogen, ammonia, etc)
   - 2.3 Desalination technology
3. Dynamic operation and control
4. Integration with onshore infrastructure – what is required at port-side and what is assumed beyond?

What are the metrics to assess the system (e.g. system value, levelised cost of energy, ….)?
How to ensure effective integration (not competition) with onshore fuel production?

Ongoing research: System optimisation problem formulation

Objective function: levelized costs of fuel

Constraints: Satisfying demand for electricity and hydrogen over the time horizon

Constraints: modelling economics, including capital costs and operational expenses,

Constraints: energy balance of electricity flows,

Constraints: mass balance of hydrogen flows,

Constraints: lean model (perform. curves) of electrolysers,

Constraints: lean model (perform. curves) of fuel cells,

Constraints: Electricity network model

Constraints: technical limitation of process equipment, and infrastructure

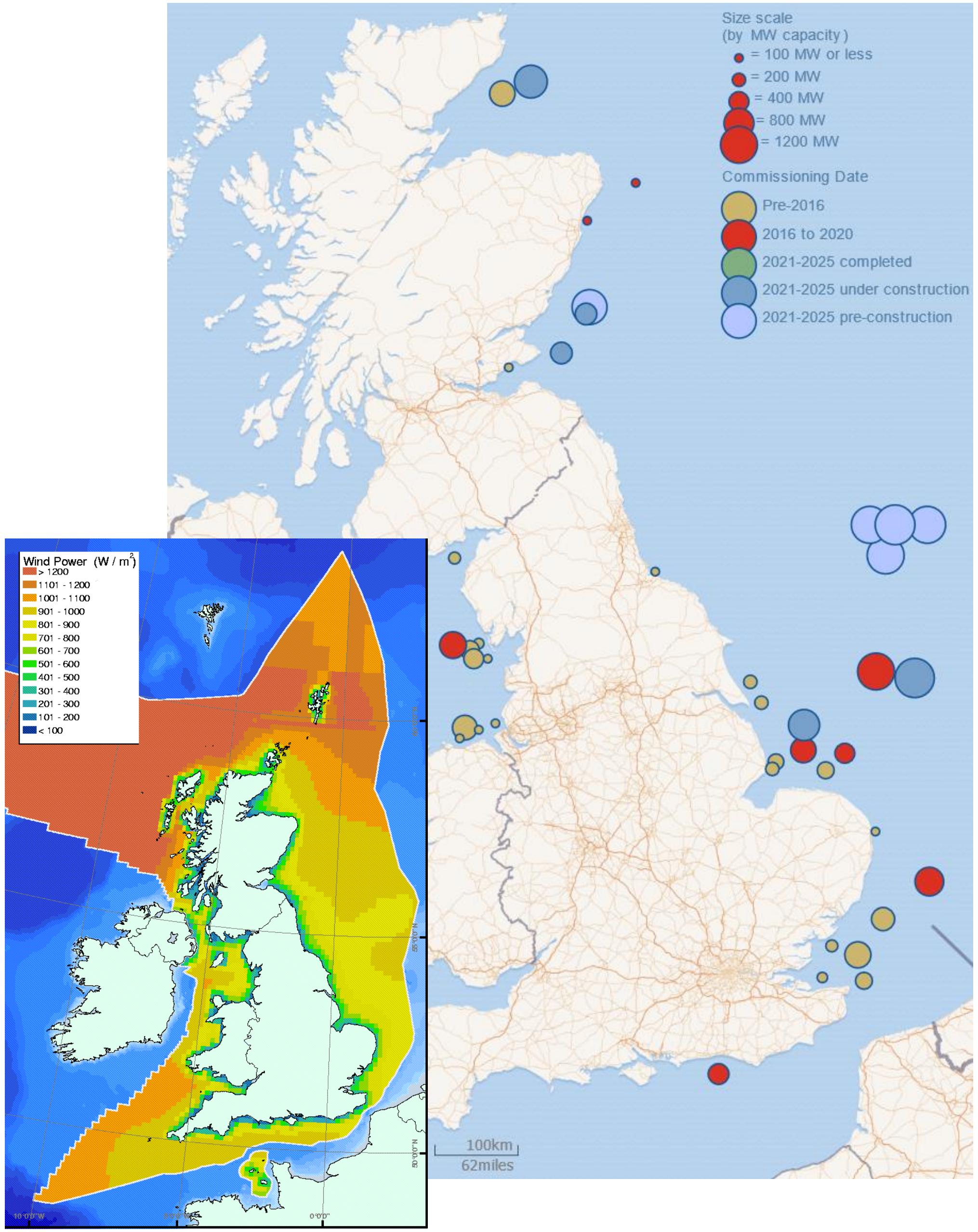
Integration with LCA and wider environmental analysis (UNott)

Exploration of different on- and off-shore storage options (UNott)

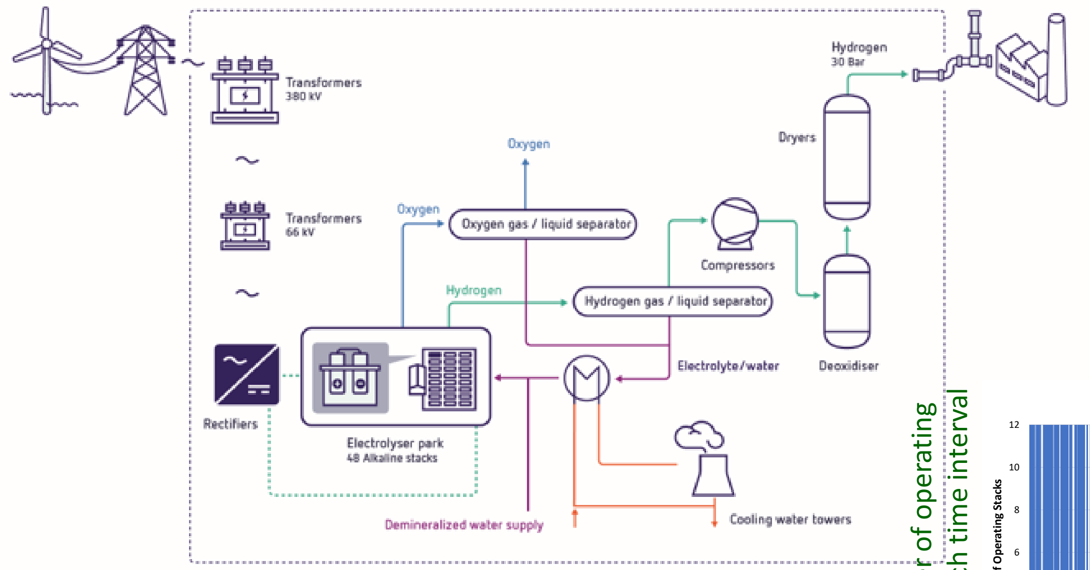
Source: ArcGIS – UK Offshore Wind Energy (Link)

Data requirements

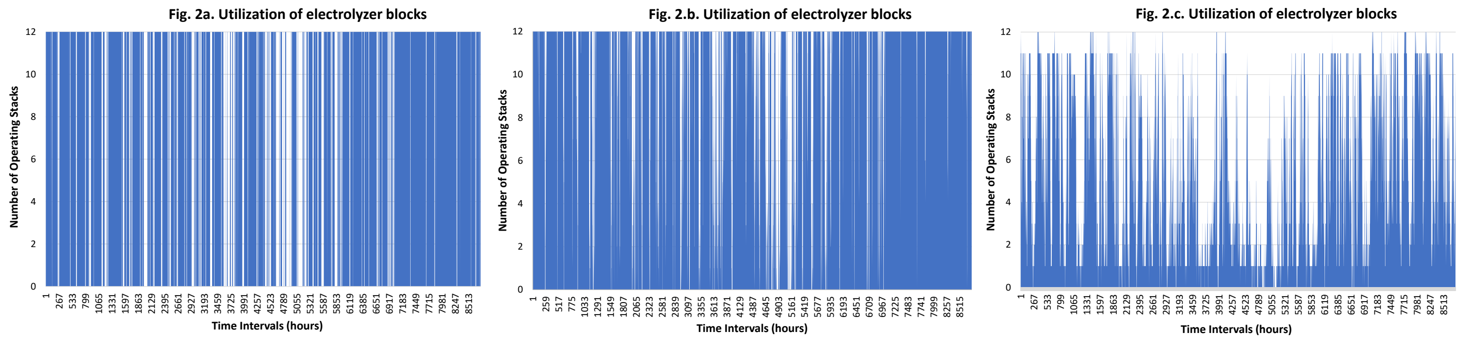
- The location of existing offshore wind farms,
- The potential location of future offshore wind farms,
- The wind profile associated with the location of existing and potential wind farms
- The potential of integrating electrolyser with future WTs, and possible architectures
- The temporal distribution of demand for hydrogen and electricity over 2023-2030 time horizon
- The (offshore) performance of the electrolyser technologies [PEM, AWE, SOEC, ….]



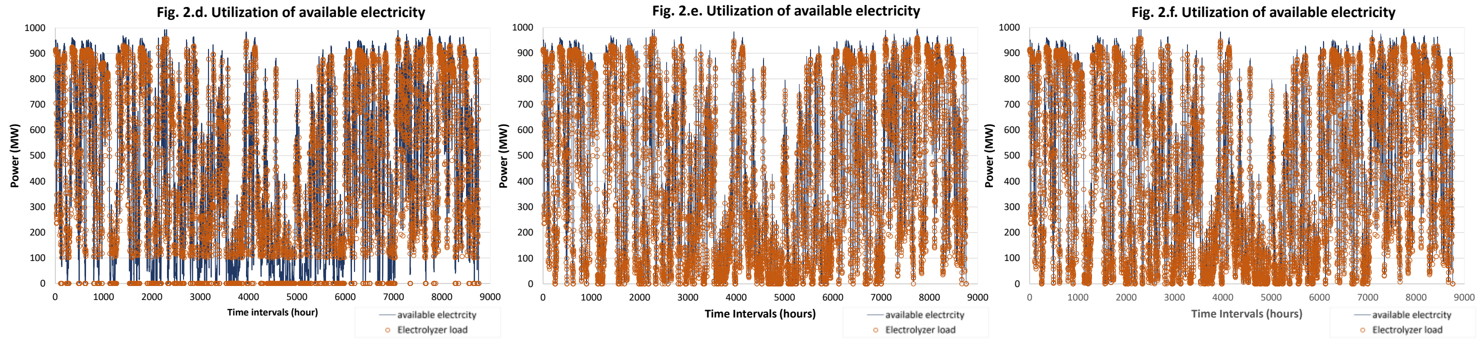
Previous related research: Integrated design and operation of 1GW facility



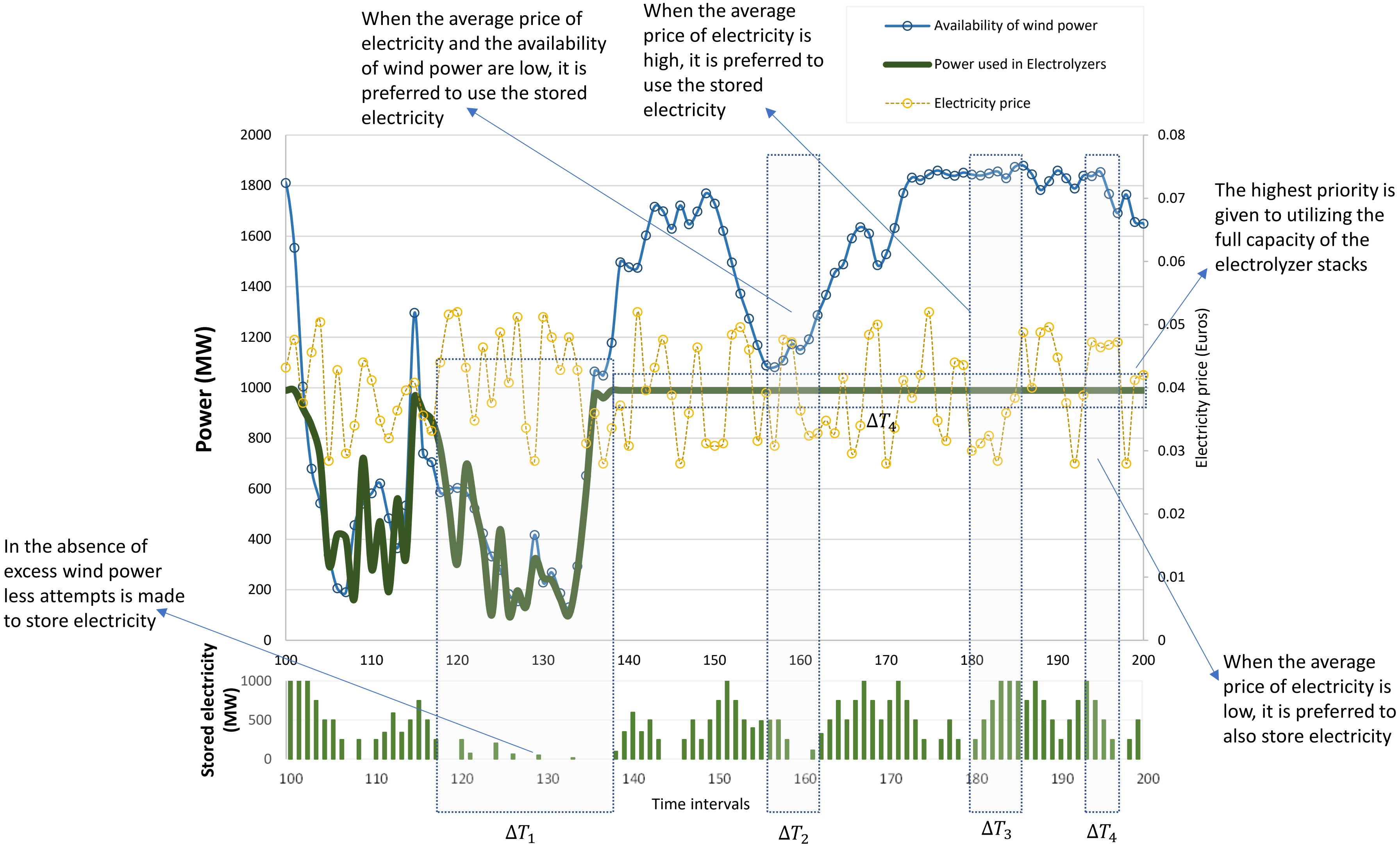
The number of operating stacks at each time interval



Electrolyzer utilization vs wind power

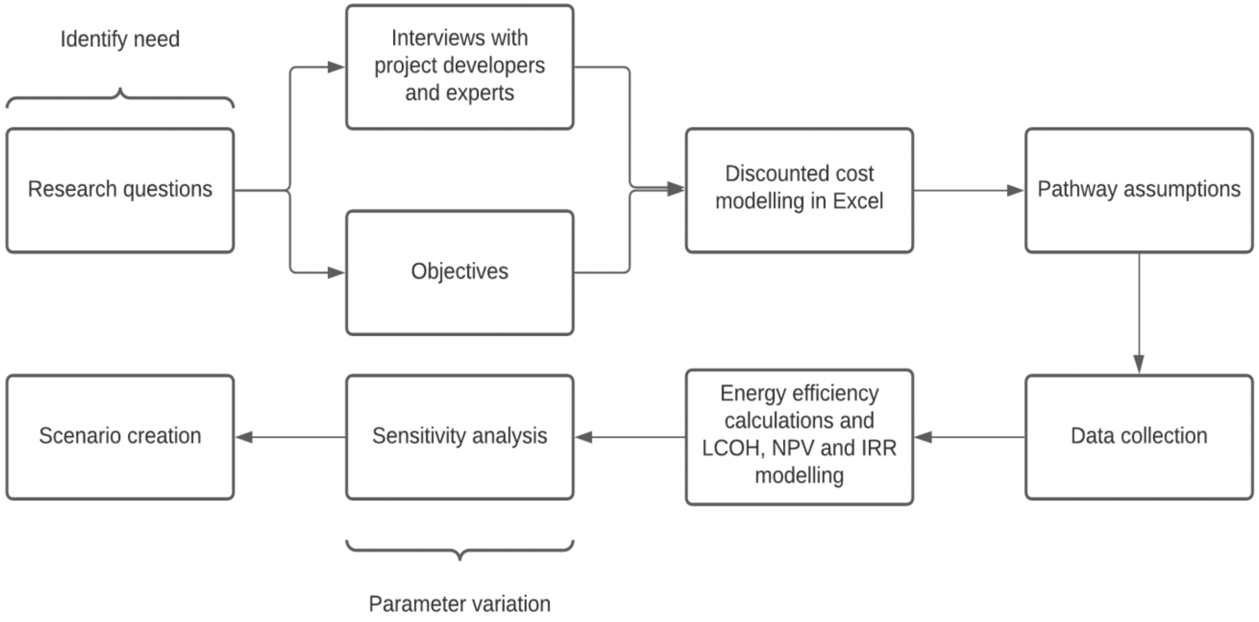


System dynamics

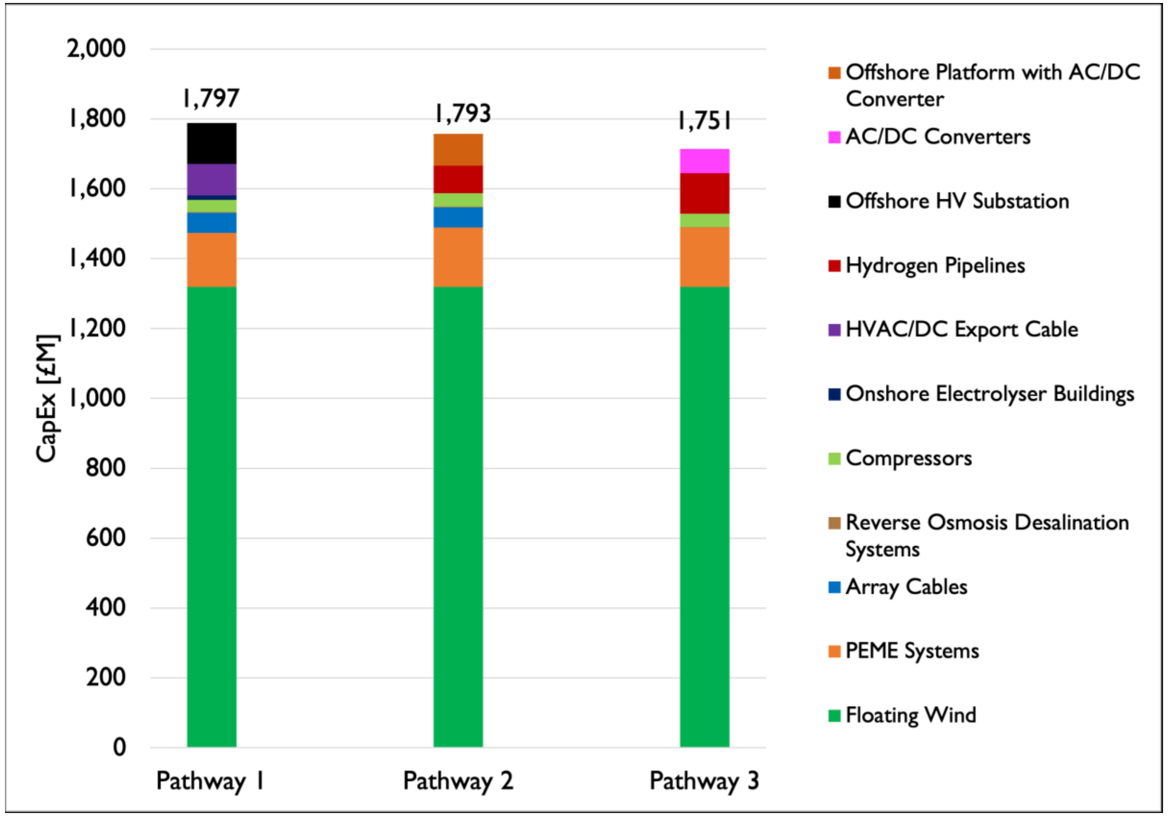


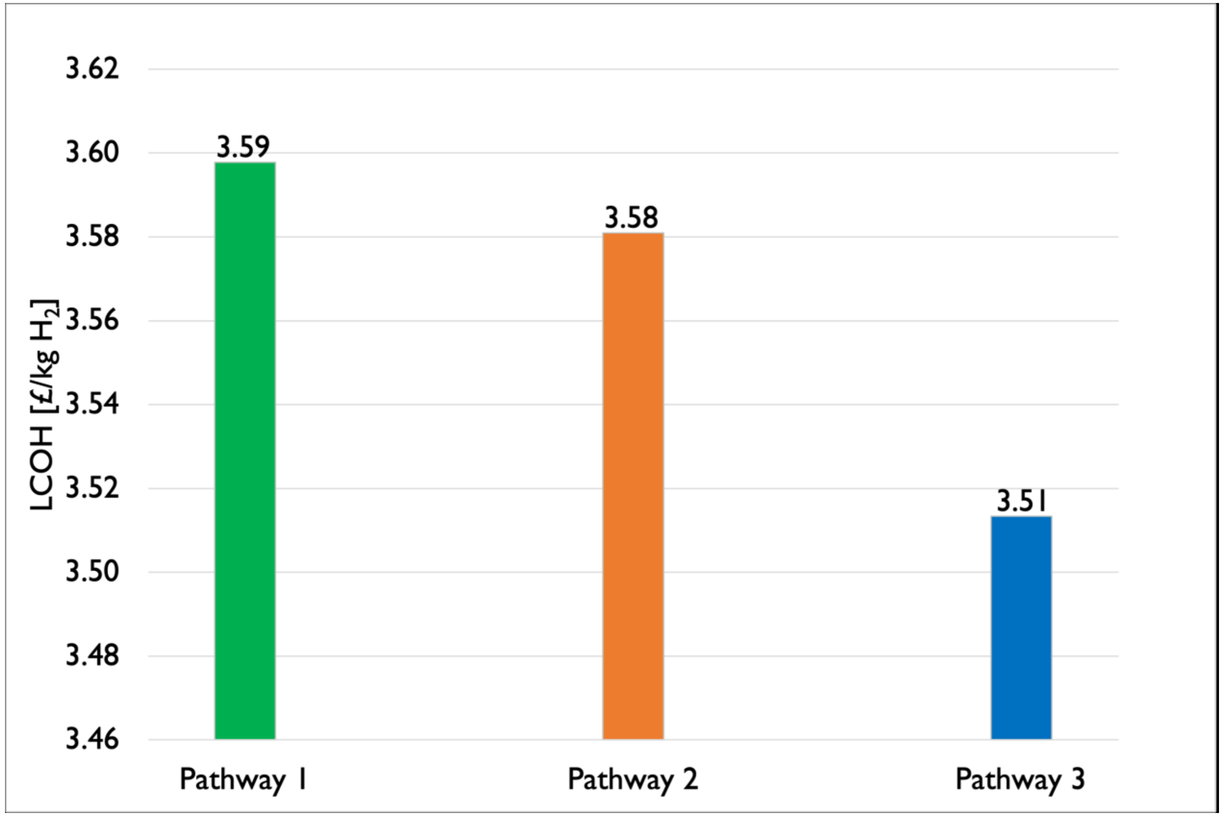
Current analysis: trade-offs

- Pathway 1: floating wind array, offshore electrical substation, HV export to onshore substation, PEME onshore
- Pathway 2: floating wind array; inter-array cables to a centralised PEME electrolysis off-shore platform. Hydrogen gas pipeline to shore.
- Pathway 3 integrated electrolysis at each floating turbine with inter-array hydrogen collectors and hydrogen pipeline to shore.



Preliminary results: CAPEX and LCOH





Next steps

- Finalise version 1.0 of systems optimisation model
- Locate this in a specific geography based on the “strawman”
- Data integration with other workstreams
- Develop a “base case” design
- Explore sensitivities and identify performance-limiting aspects of the system
- Explore trade-offs….

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Workstream 5
Policy framework/economic modelling

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Workstream 5: the team

Professor Karen Turner, WS5 lead

Dr Abdoul Karim, postdoc researcher

Dr Antonios Katris, CEP Research Associate

Hannah Corbett, knowledge exchange fellow

Overview

- The wider policy challenge
- Ocean REFuel capability and capacity for policy and economic analyses
- Learning from previous research and energy supply activity
- Policy and research challenges

The wider policy challenge

From our bid, linking to Networks, Capability and Demand

‘How will industry, public and regulators/politicians perceive the technology solutions themselves, and the wider economy impacts of developing, deploying, and using the technology? This is crucial in informing policy narratives around which consensus can build.’

Capability and capacity for policy and economic analyses

Expertise in modelling of wider economy implications, consequences, identifying policy trade-offs and considering routes to mitigating less desirable outcomes

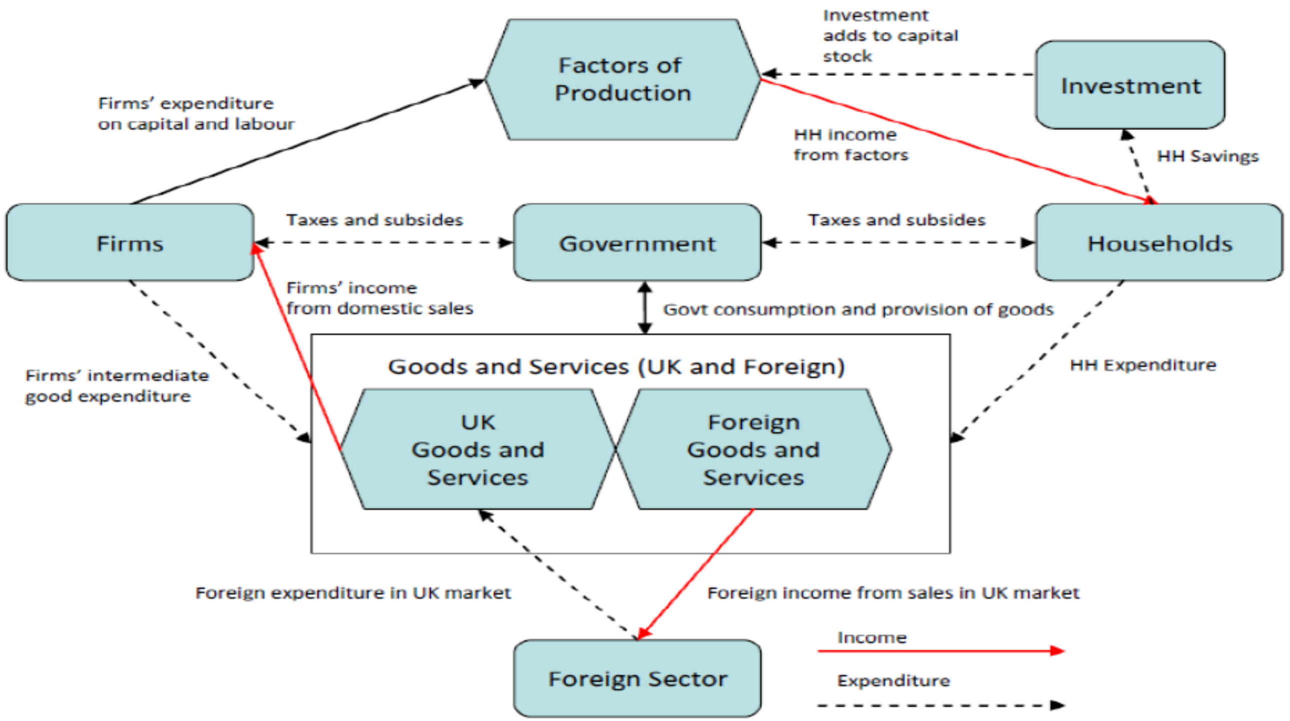
- ‘WS5’ defined across other workstreams, to complement and build on technoeconomic analyses through use of multi-sector economy-wide computable general equilibrium scenario simulation models
- Aim of building understanding of how in terms of how energy supply, storage and transportation solutions emerging may integrate with current energy supply and use sectors and impact across the wider UK economy.
- Use of results to inform policy analyses and narrative development.

Computable general equilibrium (CGE)

- Multiple sectors (industries and consumer) and markets
- ‘General equilibrium’
- Options regarding specification at industry/sector and final consumer level, in different markets, and what we assume about government budgetary approach, how labour markets function etc.
- Aim to avoid ‘black box’
- Widely used and trusted in research and policy communities

- Simple basis – circular flow of income https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/263652/CGE_model_doc_131204_new.pdf

Figure 2.1: Circular flow of income



Learning from previous research: e.g., CCS and integrating a new CO_2 transport and storage industry into the economy

- Once operational, CO_2 T&S likely to share supply chain characteristics with existing UK Oil and Gas industry
- Extensive upfront infrastructure investment required
- Competition with other sectors and projects for resources; likely need for government intervention to involve guaranteeing demand for capacity
- Depending on who pays, how and when, has potential to deliver sustained net wider economy expansion with new jobs and GDP creation

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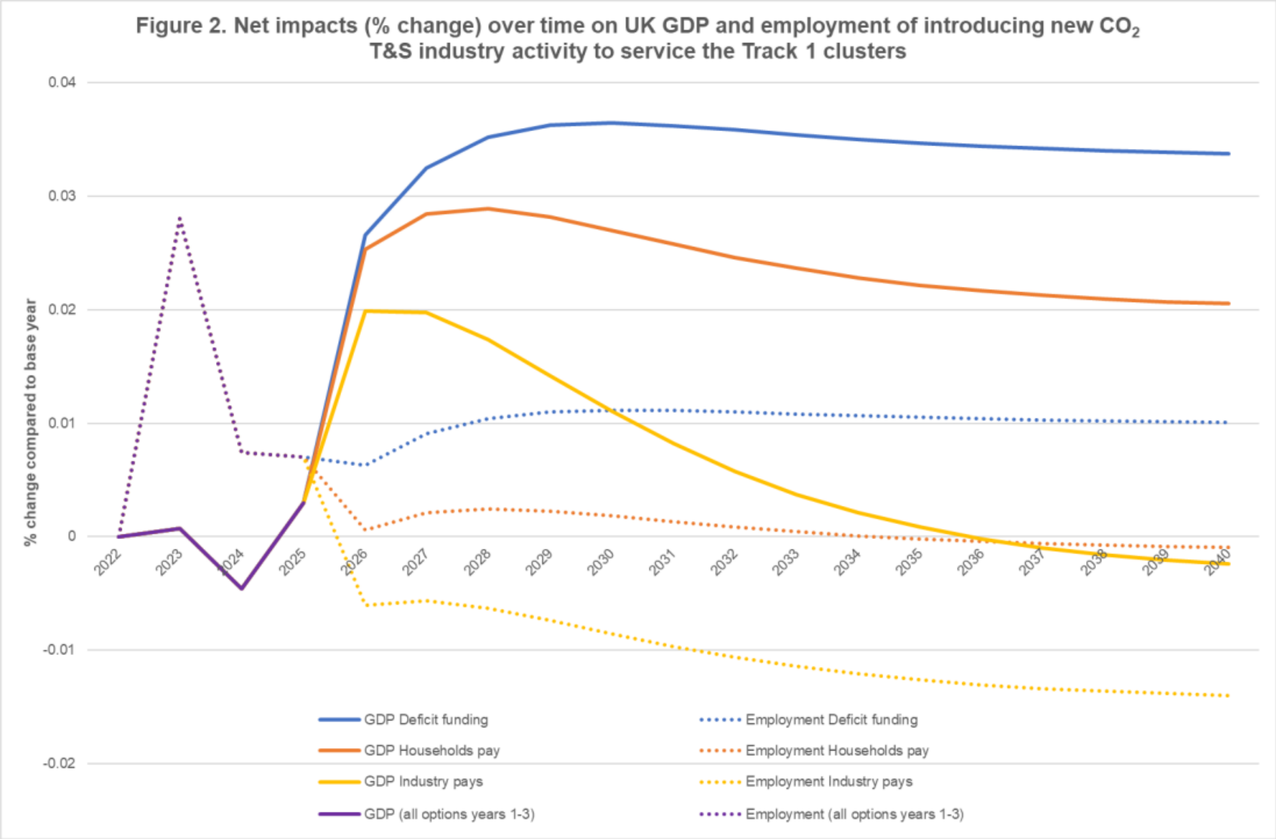

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Competition for constrained resources, particularly labour

- Where demand for workers/skills increased and labour supply is constrained, introduces wage cost pressure that benefits workers/households, but pushes up costs in all sectors
- Consequent domestic and international competitiveness challenges and consumer price impacts
- Displacement of employment across multiple sectors (particularly labour-intensive – e.g. services)

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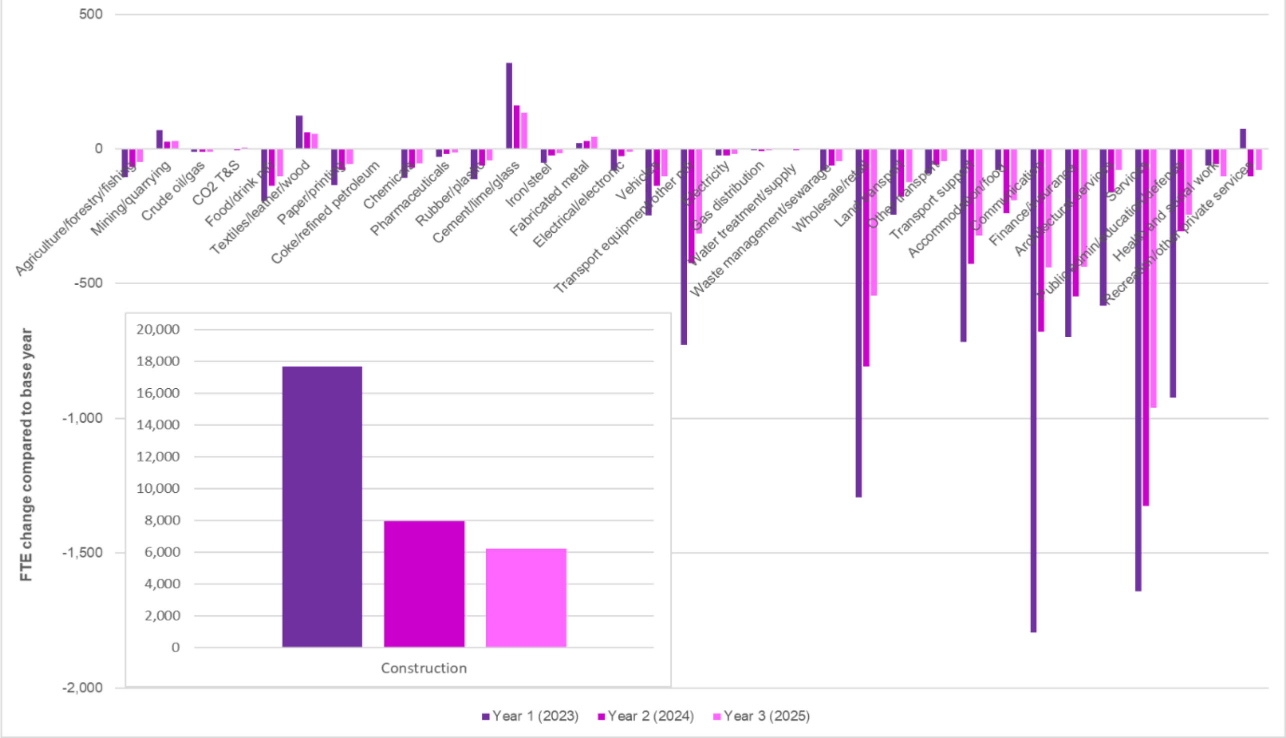
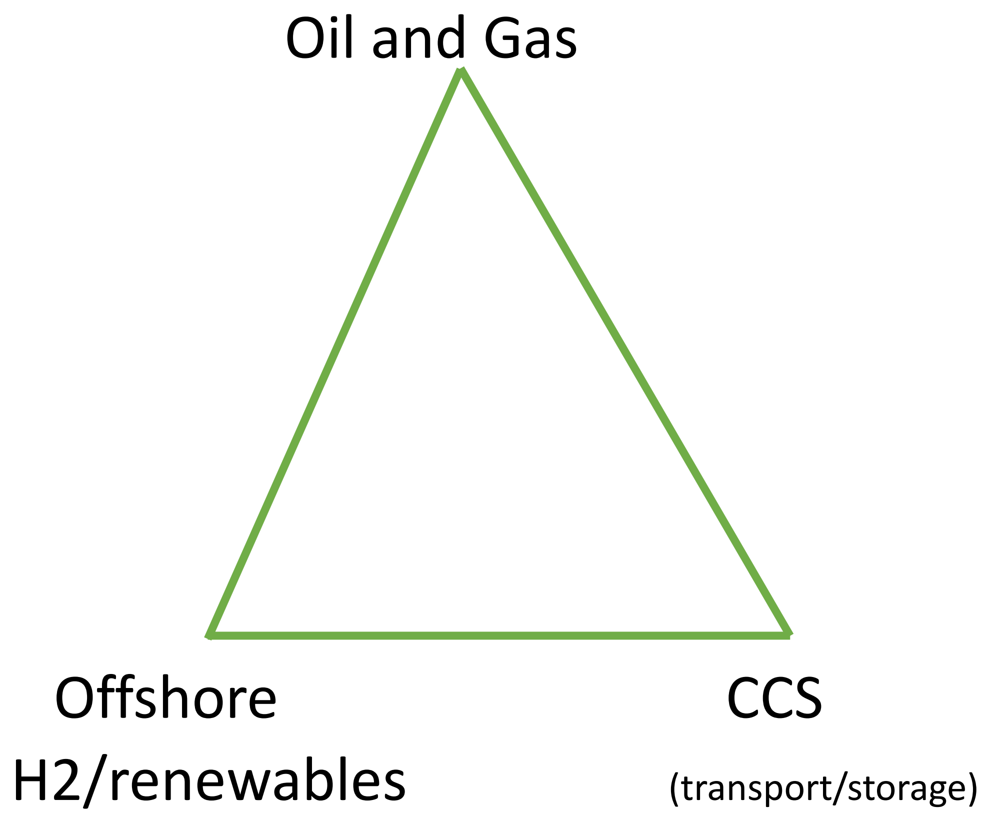
Figure 3. Impacts on sectoral (full-time equivalent, FTE) employment between 2023 and 2025 of introducing the CO_2 T&S industry to service the Track 1 clusters



Conceptualising the nature and role of the offshore energy sector

- Effectively a new sector(s) in the economy?
- That is, doesn't yet exist/report in economy-wide national accounts (input-output, IO, tables reported by ONS)
- Can we identify benchmarks/proxies from current IO?
  - Electricity, transmission and distribution?
  - Gas; distribution of gaseous fuels through mains; steam and air conditioning supply?
- Currently working on breaking out single national accounting 'electricity' sector to identify network, trade, different types of generation and storage potential.
- Enables initial 'what if' reporting and scenario simulation
- Including focus on benefits of retaining already established supply chain capacity *and* addressing challenges where domestic capacity has not developed (e.g., onshore renewables in Scotland)
- But also need to investigate differences in what is produced, how valued and by whom
- Benchmark basis for consultation to ultimately refine to how new industry activity actually integrates into economy



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A wide range of policy and research challenges

- The integration of new energy supply options into the economy is complex
- Once we've established what new energy supply, storage and transportation sectors look like, and what are they producing, just how are they deployed?
    - E.g., is there a need to initially over-size capacity – what are the capital expenditure implications, who pays, how and when, how can the process be de-risked?
    - How can competitive domestic supply chain capability and capacity emerge where it has been lacking before (e.g., onshore renewables)?
- What demand do new sectors serve, what and how do they replace and/or integrate with via existing/new networks and markets?
    - E.g., industrial use of hydrogen may begin with continued purchase and 'in-house' reforming of natural gas, which will have (sunk?) investment and network implications for firms – how does hydrogen ultimately become a substitute for industrial users?
- Which actors (industry, regulator, government) are responsible, able and willing to act at what stages in the supply/demand process?
- How can/will the picture evolve over time and under different circumstances?

Questions and discussion

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UK Research and Innovation