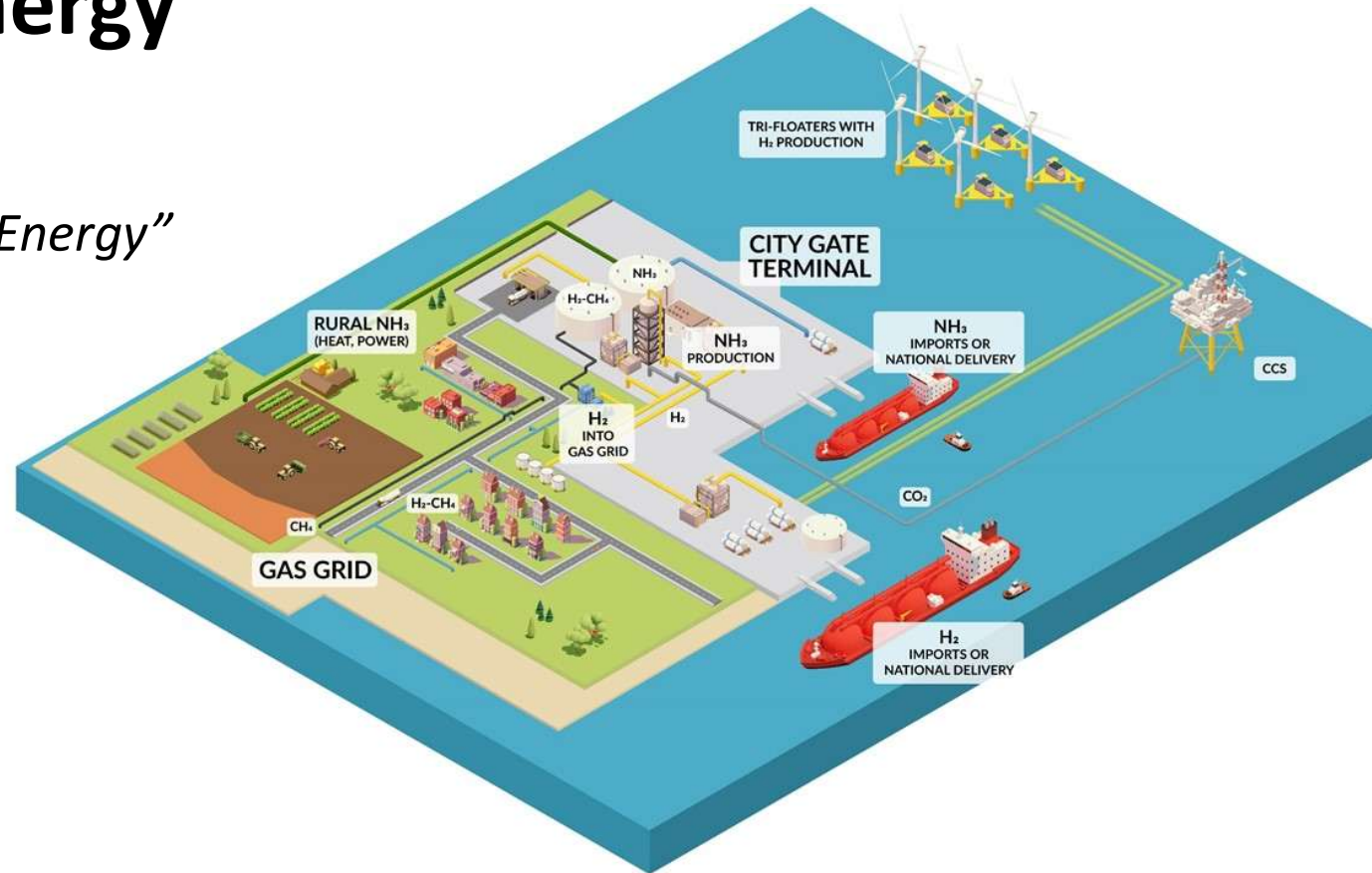


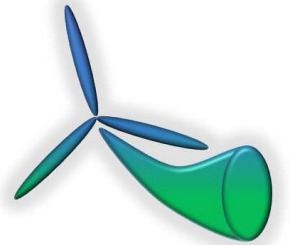
Ocean-REFuel (Ocean Renewable Energy Fuel)

“Next generation Renewable Ocean Energy”

31st March 2026
Stakeholder Update



Ocean REFuel Stakeholder Meeting - Agenda



- **09:30 – 10:00** Registration, refreshments
- **10:00 – 10:10** Ocean REFuel intro/welcome
- **10:10 – 10:30** Work Stream 1 Update (Offshore structures, logistics and power generation)
- **10:30 – 10:50** Work Stream 2 Update (Power to Carbon Free Fuel)
- **10:50 – 11:05** *Q&A/Discussion/Feedback*
- **11:05 – 11:25** Work Stream 3 Update (Carbon Free Fuel Transportation & Storage)
- **11:25 – 11:45** *Comfort/Coffee break*
- **11:45 – 12:15** Work Stream 4 Update (Ammonia, Carboniferous H₂, System Optimisation)
- **12:15 – 12:45** Cross cutting themes (Economics, public perception & LCA)
- **12:45 – 13:00** *Q&A/Discussion/Feedback*
- **13:00** Close
- **13:00 – 14:00** Lunch



University of
Strathclyde
Engineering

Ocean REFuel

Workstream 1

Offshore structures, logistics, and power generation

London, 31 March 2026 – Stakeholder event

www.strath.ac.uk/engineering

Workstream 1: the team

Prof Feargal Brennan, PI



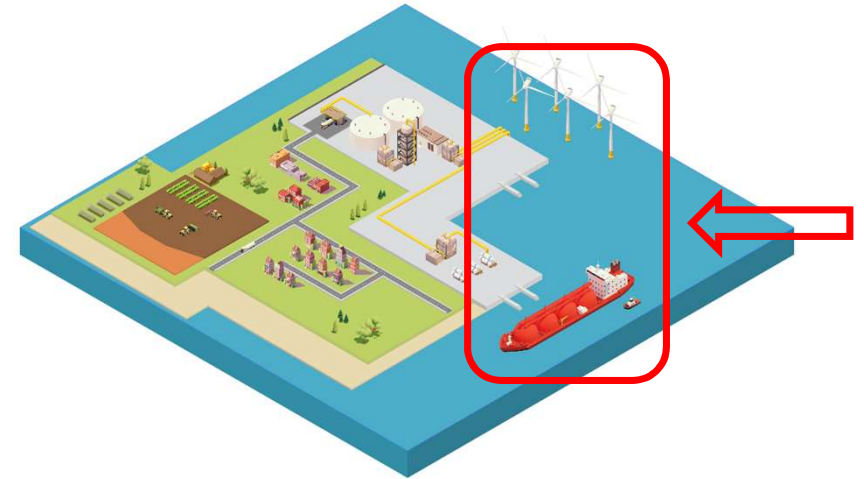
Prof Maurizio Collu, WS1 Lead



Dr Shen Li, Lecturer



Dr Claudio Rodriguez-Castillo, PDRA



Dr Abel Arredondo-Galeana, PDRA



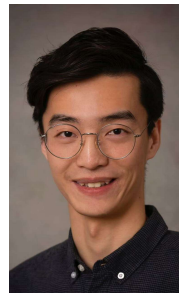
John Harris, PhD res.



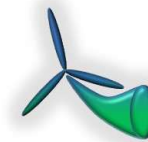
Miracle Mbaekwe, PhD res.



Xiaoming Ran, PDRA



Dr Xintong Wang, PDRA



Ocean-REFuel

Research Workstreams

| 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 | | ● | | | |

Workstream 1 – WPs and tasks

| | |
|--|---|
| 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 |

1 journal paper

- Rodríguez et al, 2023. A critical review of challenges and opportunities for the design and operation of offshore structures supporting renewable hydrogen production, storage, and transport. Wind Energy Science, 9-3, pp.1-34.

3 conference papers/seminars

- OMAE 2024, Singapore
- WESC 2023, Glasgow- UK;
- Seminar SINDIC2023, Lima-Peru;

9 journal papers:

- **Ran X.** et al., (2026). A Review of Fluid-Structure Interaction Modelling for Integrated Analysis of Floating Offshore Wind Turbine Substructures (journal, in revision)
- **Arredondo-Galeana, A.**, Scarlett, G. T., Collu, M., & Brennan, F. (2026). A hybrid floating wind-wave energy platform for minimum power baseload. Ocean Engineering, 343(Pt. 1), 123090.
- **Rodríguez et al**, 2026. Adapting floating offshore wind-hydrogen systems for emerging markets: the case of the Ica region, Peru. Marine Systems & Ocean Technology. Springer.
- **Rodríguez et al**, 2025. "Feasibility of a Centralised 200 MW Floating Hydrogen Production System on a Tri-Column Semisubmersible: Design and Dynamics" (under review).
- Rodríguez et al, 2025. "Comparative Design Space Exploration of Centred and Off-centred Semisubmersible Configurations for Floating Offshore Wind Turbines". Ocean Engineering, 324,p.120740.
-

6 conference papers/seminars:

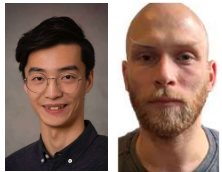
- DeepWind 2026, Jan. 2026, Trondheim, NO
- COPINAVAL 2025, Oct. 2025, Lima, Peru
- OMAE 2025, Jun. 2025, Vancouver, Canada
- Supergen ECR Forum, Apr. 2025, Manchester, UK
- Supergen ECR Forum, Oct. 2024, Manchester, UK
- Supergen ORE Hub 2024 Annual Assembly, Apr. 2024, Plymouth, UK

Workstream 1 – Tasks & Interactions



Platform design and dynamics
 Floating substructure design and overall dynamics

Overall offshore system



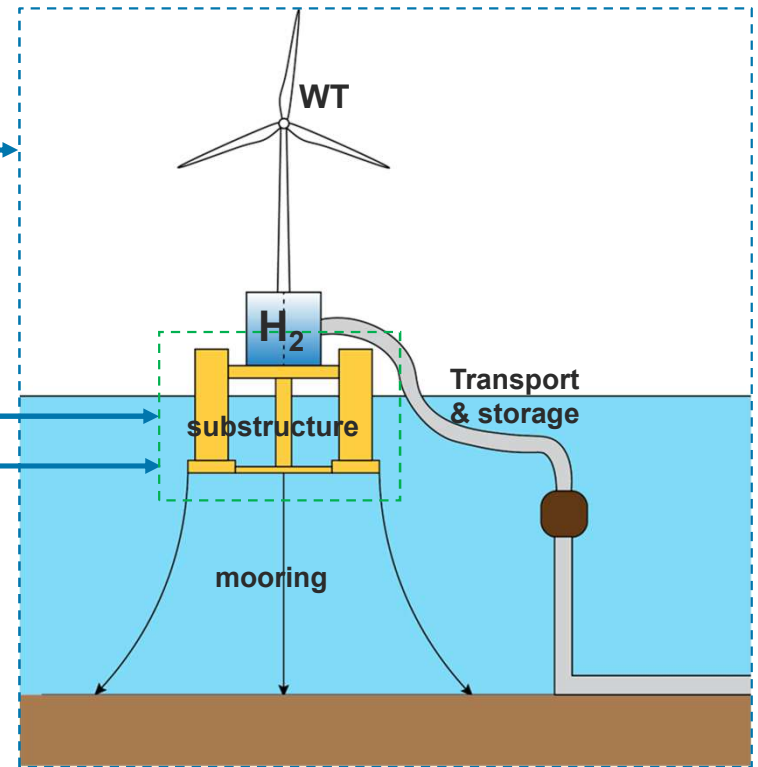
Risk-based structural design
 Ensuring safety with high degree of freedom for innovative design

Floating substructures

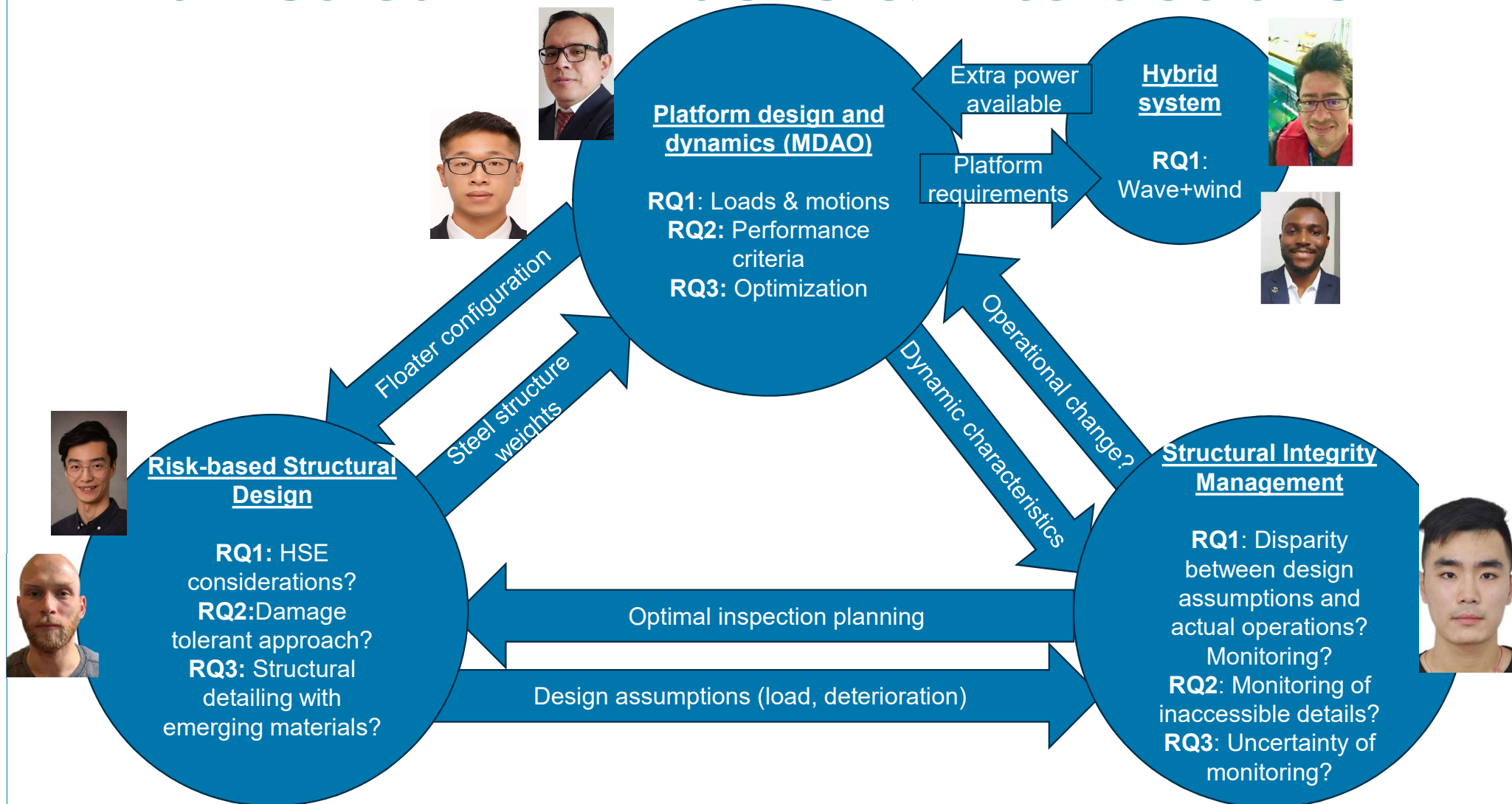


Structural integrity management
 A rational in-service scheme to support through-life fitness-for-service

Floating substructures



Workstream 1 – Tasks & Interactions



Workstream 1 – Focused Areas



- **Centralised Offshore production system** floater design methodologies;
- **Hydro-structural model integration** potentially considering a novel energy flux approach allowing an unconstrained shape and optimising this through a seamless hydromechanics structural analysis;
- **Hybrid materials & structures** e.g. concrete, composites.
- Re-examine/revise the **design/control strategy** for optimised H2 production (turbines are currently designed for production of cheapest electricity not to optimise feed to H2 production).

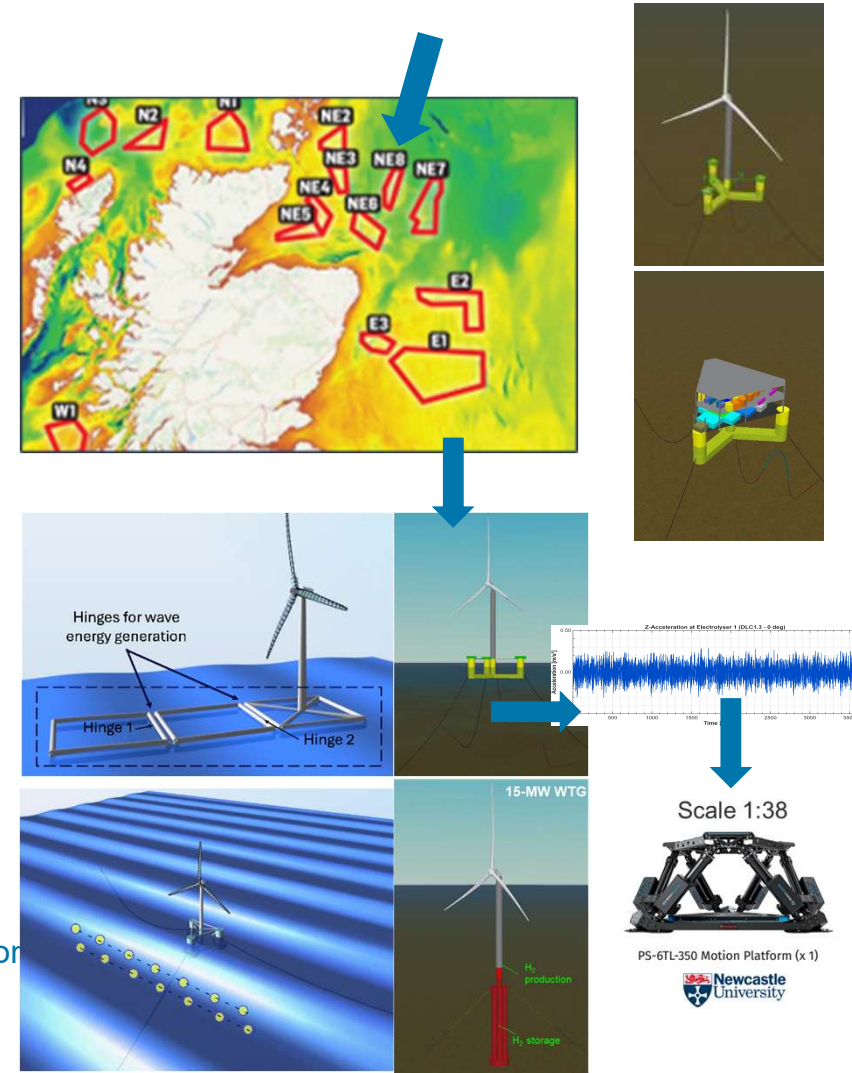
Recap of previous results

➤ WS 1.1:

- T1.1.1: NE8 Scotwind site:
 - 960 MW (FOW), 330 km², depth: 75 – 110 m, ~75 km from coast
 - 20 years of hourly data (wind, wave, surface temp)
- T1.1.2: FOWT most promising for local H2 production (wind-wave system also investigated)

➤ WS 1.2 & 1.3:

- “Strawman” case scenario (explore design reqs. & premises):
 - Decentralised: 64 x 15-MW WTG (12-MW Electrolysis)
 - Centralised: 4 x 200-MW Electrolysis
- Substructure:
 - Open access WT data
 - EoS → Tri-column semisubmersible (UMaine VoltturnUS);
- Production and storage :
 - Hybrid platform and co-located farm; Hyfloat concept
 - Short- and long-term dynamics → Platform motions → H2 production

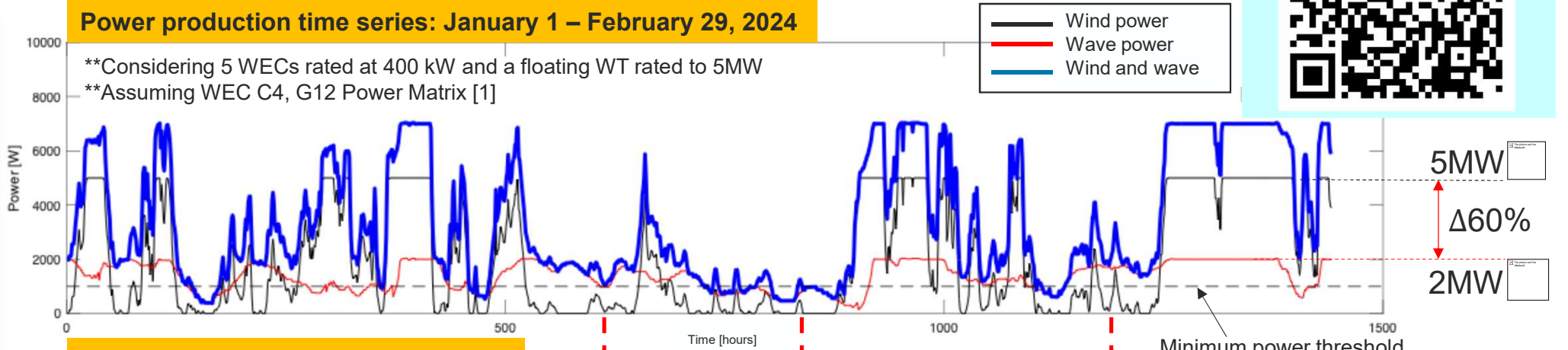


Co-location webinar:

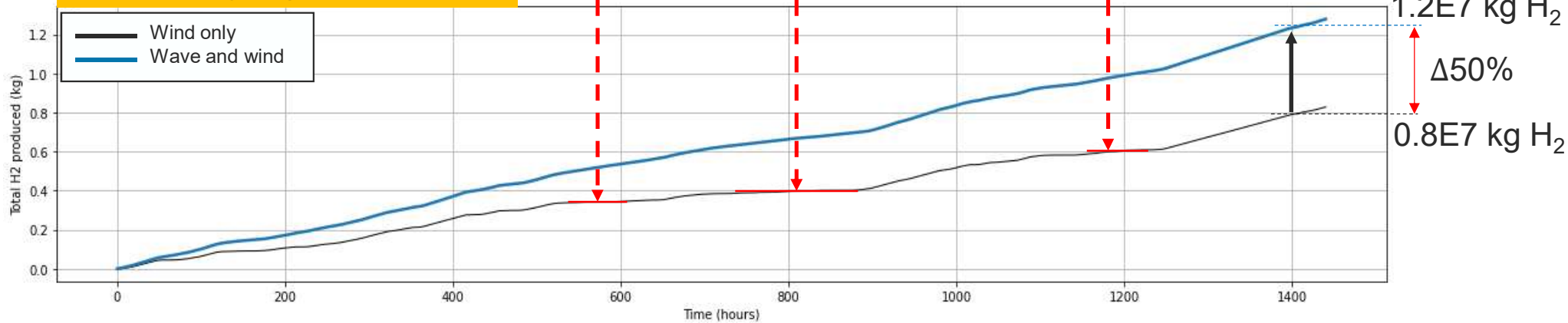


From swell waves and wind to produce H₂

Power production time series: January 1 – February 29, 2024



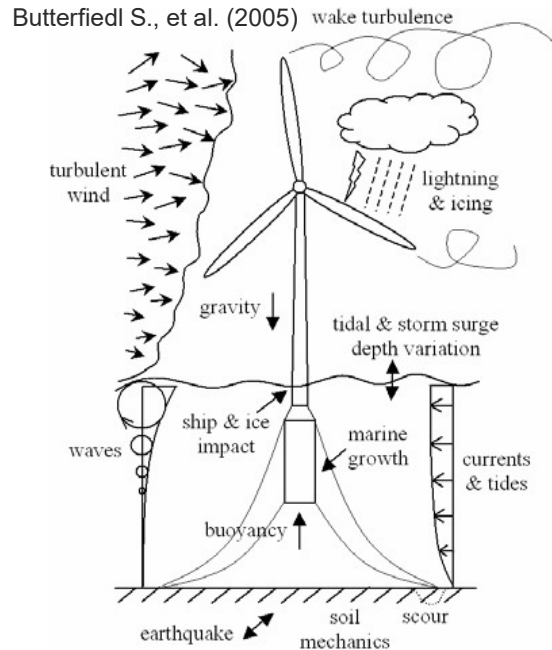
Cumulative hydrogen production [2]



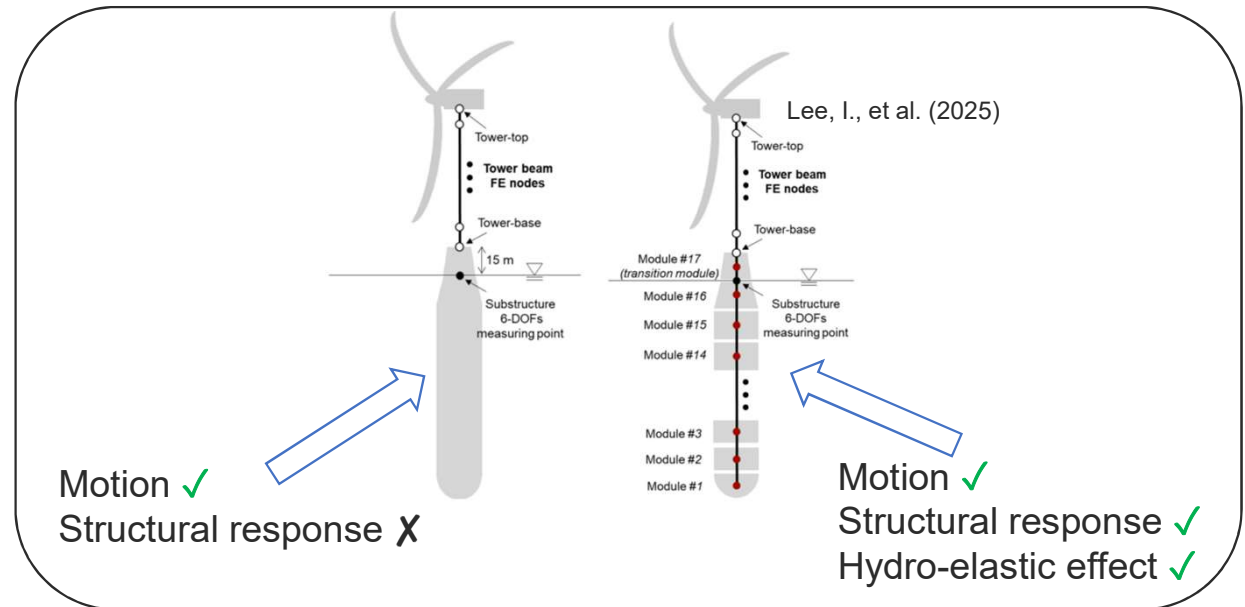
[1] Blech, E. M. (2023). *Developing a cost model For combined offshore farms: The advantages of co-located wind and wave energy* (Master's thesis, Universitat Politècnica de Catalunya, KTH Department of Technology).

[2] Niblett, D., 2023. *powertoelectrolysis*. <https://github.com/DNiblett/powerToElectrolysis>. GitHub repository. Ocean Refuel. University of Newcastle, UK.

Integrated dynamic analysis for FOWT with H2



Review focus: State of the Art on Fluid–Structure Interaction Modelling for Integrated Analysis of Substructure



Complex dynamics:

- Loads: wind, waves, currents, etc.
- Dynamics: structural dynamics, hydrodynamics, etc.
- Components: **platform**, tower, turbine, etc.

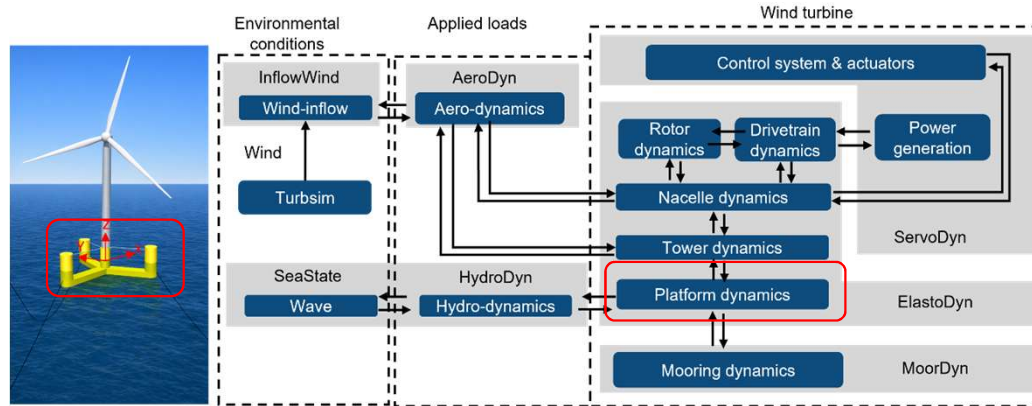
- Tool development for large-scale FOWT/FWHS is essential
- Integrated analysis with **multibody/flexible-body** for platform is achievable
- Continued effort for **aero-hydro-servo-elastic tools** is needed

Ran X. et al. (2026). A Review of Fluid–Structure Interaction Modelling for Integrated Analysis of Floating Offshore Wind Turbine Substructures (journal, under revision)

Integrated analysis with rigid coupled model

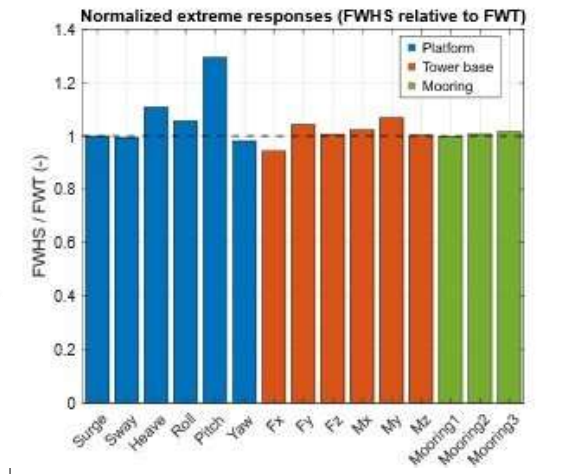
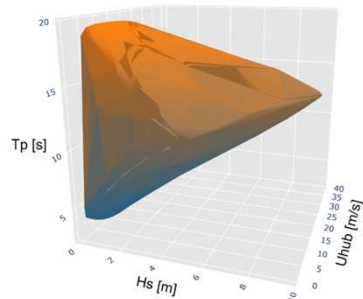
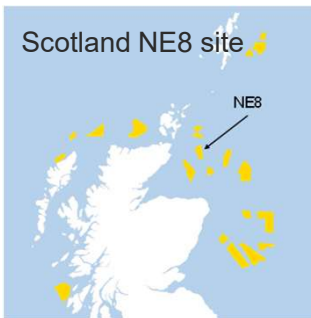
Framework: integrated analysis of floating wind turbines (FOWT) and floating wind hydrogen system (FWHS)

- **rigid** platform



Application: estimate of extreme dynamic responses

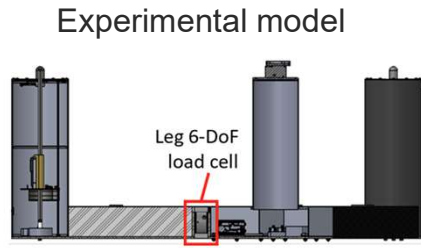
Environmental contour



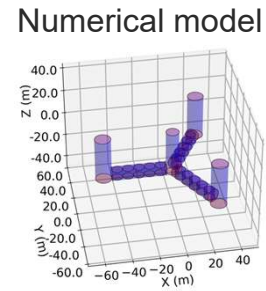
- The floating wind turbine with hydrogen equipment has a **similar extreme dynamic response** except the platform **pitch** due to the increased center of gravity.
- These extreme-response results further indicate that integrating hydrogen production into a floating wind platform is feasible.

Integrated analysis with multibody coupled model

State of the art: sectional structural responses from time-domain coupled simulations



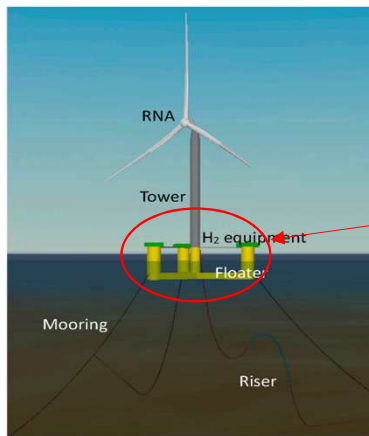
Carmo, L., et al. (2024)



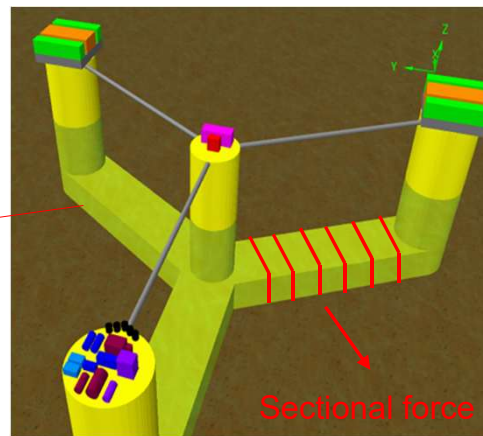
Integrated model in OpenFAST

- New tool functionality
- Multibody
- Structural responses of platform

Multi-body coupled model: development, simulation, and analysis



Integrated model in OpenFAST



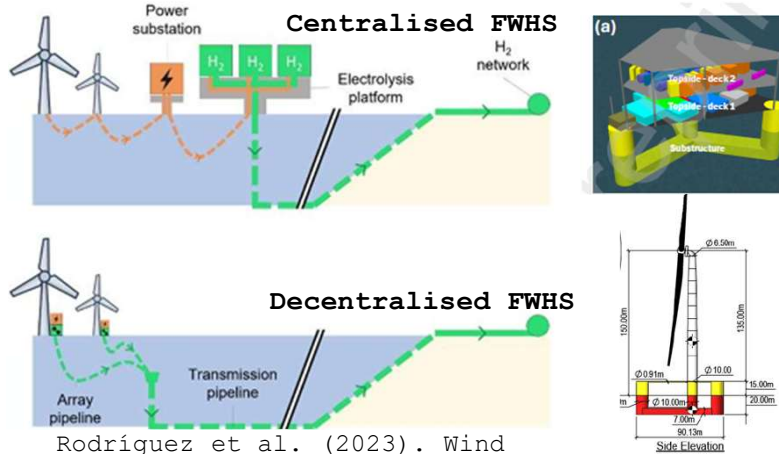
Multibody platform

Highlights:

- Tool/model development
 - Multibody platform
 - Fully coupled dynamics
- Evaluation of platform structural responses
 - Time-domain structural responses
 - Various load cases
 - Within integrated framework
 - Computationally efficient

Local Structural Design and Integrity Analysis

- Focus: Local structural design of floaters for both centralised and decentralised platform



Rodríguez et al. (2023). Wind Energy Science.

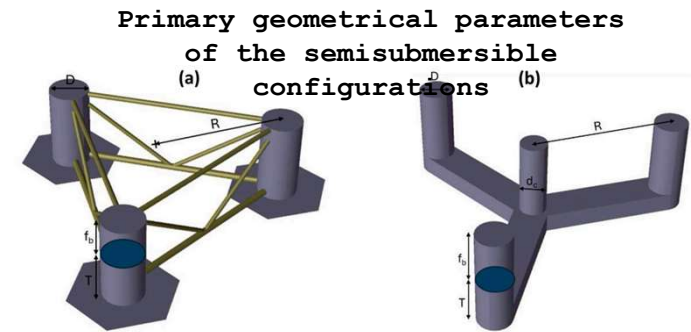
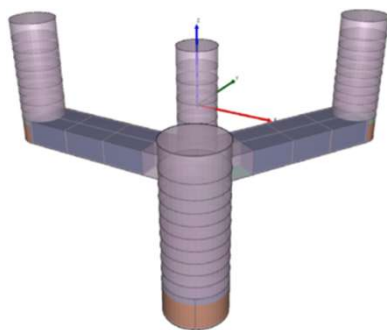


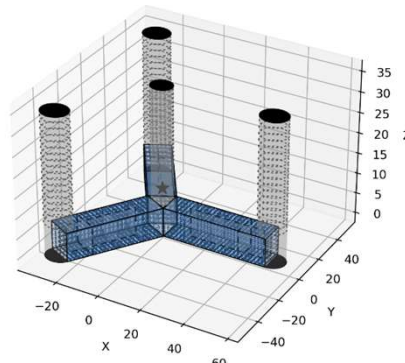
Fig. 2. Primary geometrical parameters of the semisubmersible configurations: (a) off-centred, (b) centred.

Rodríguez et al. (2024) International Journal of Hydrogen Energy

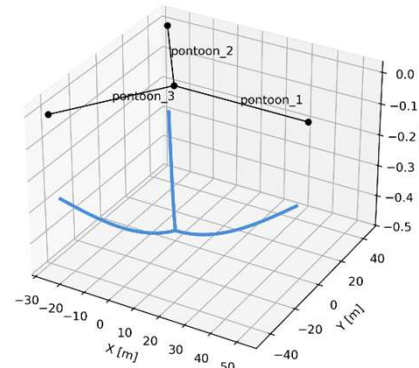
- Methodologies: Global design framework by Claudio + Analytical structural model + Design guidelines



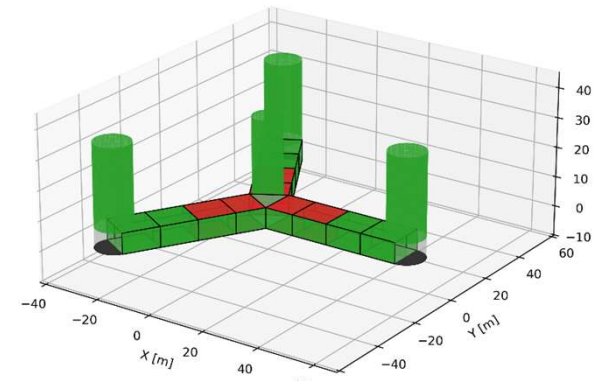
Proposed compartmentation and contents (Rodríguez et



Floater with local structures (bulkhead, stiffeners, frames)



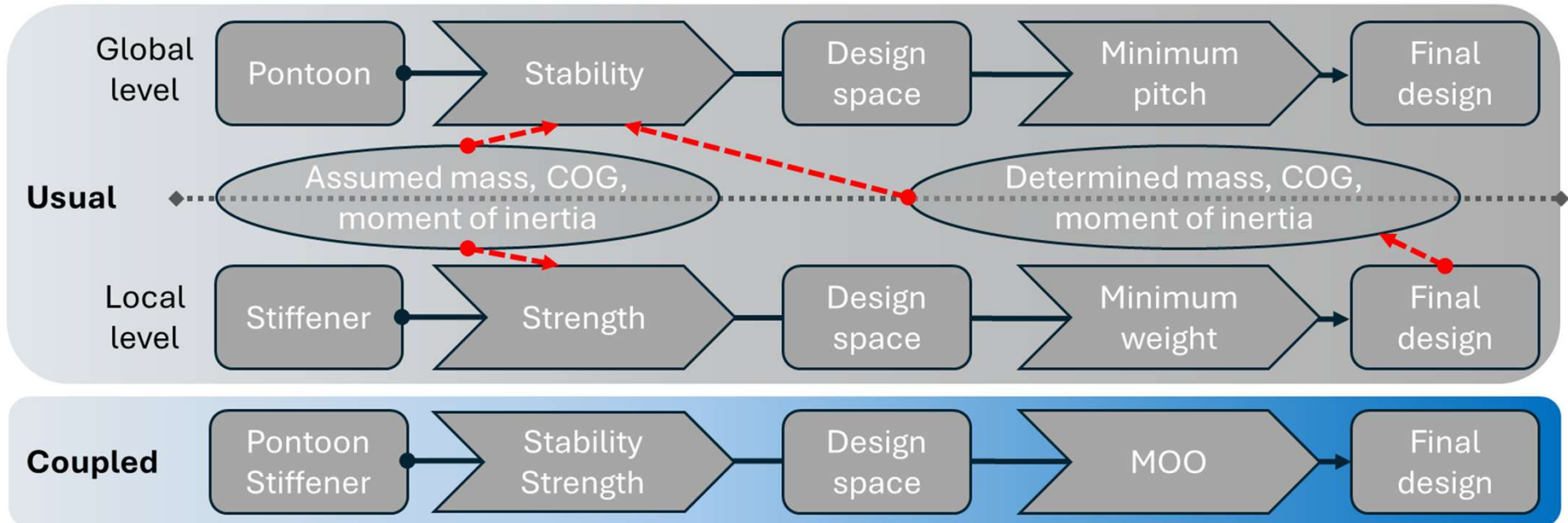
Floater deflections based on an analytical Y-frame model



Structural safety against DNV recommended practices

Local Structural Design and Integrity Analysis

- Highlight: Possibility to adopt **coupled design process**

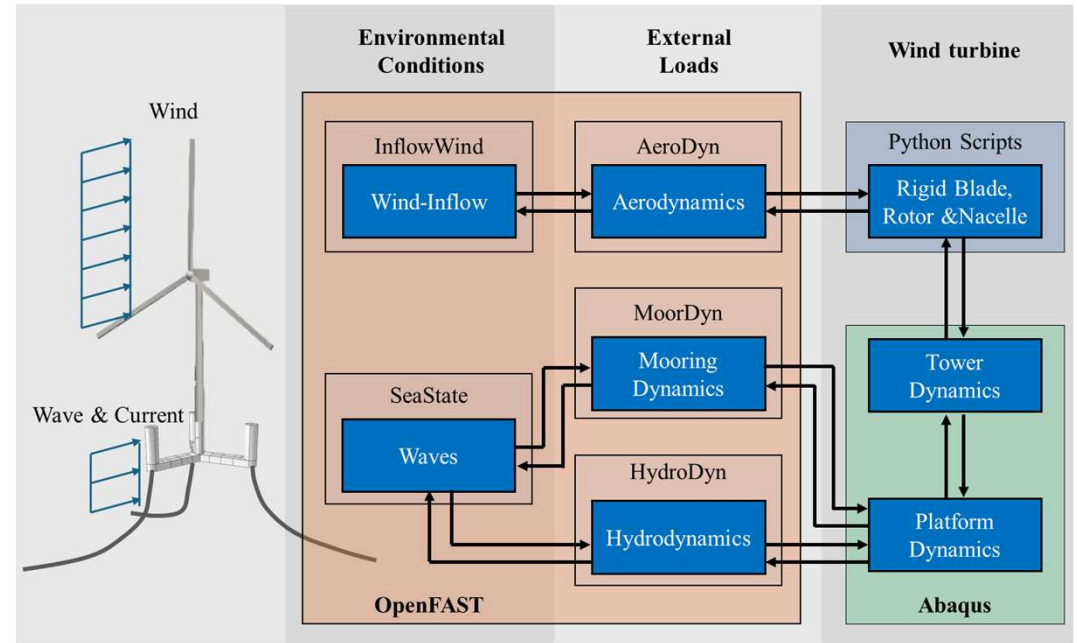
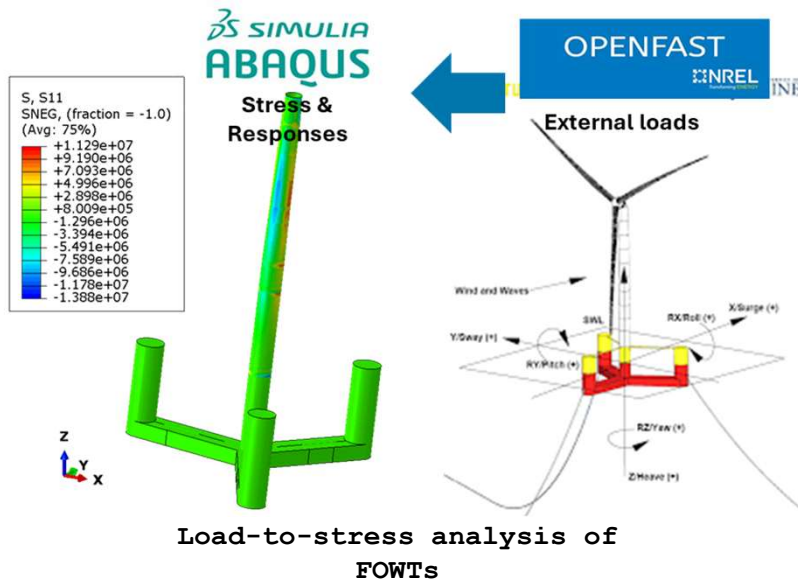


Conventional design process separated in local and global levels V.S. Coupled design process based on the developed scripts

- Progress:
 - Design space exploration and comparison
 - Development of "Strawman" local structure arrangements
 - Sensitivity analysis w.r.t utilization factors and cost

Local Structural Design and Integrity Analysis

- Focus: **Stress-level responses** for fatigue limit state evaluations and structural integrity analysis
- Methodologies:
 - **Two-way coupled analysis** incorporating FEM tools and FOWT simulators (Abaqus and OpenFAST)

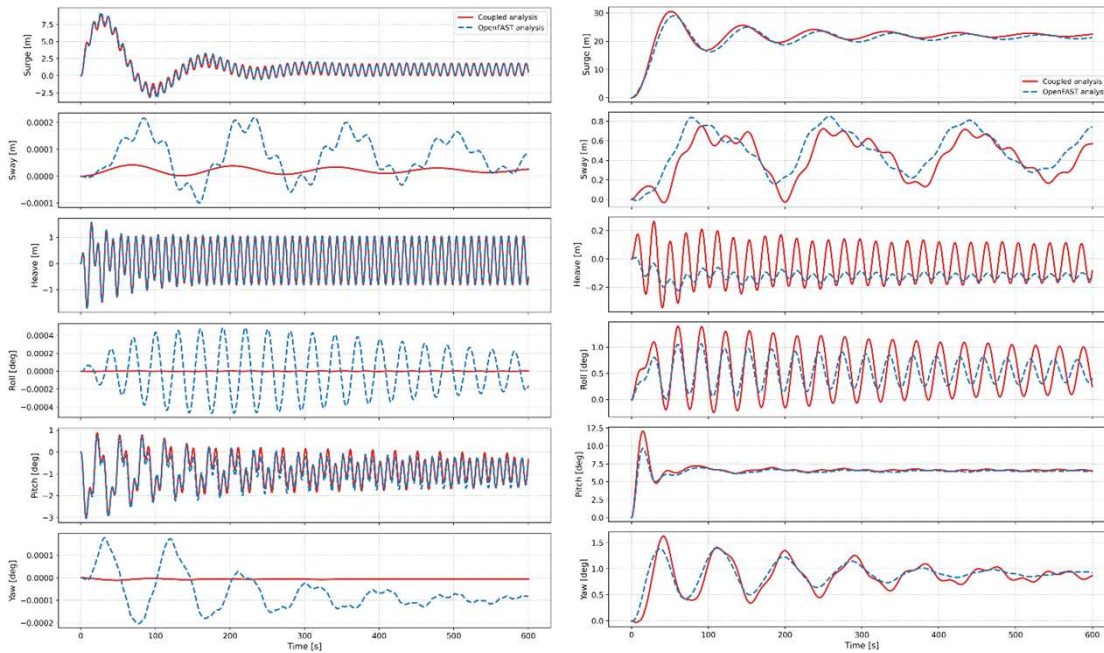


Developed framework for two-way time-domain coupled analysis

- Highlight:
 - **One-step analysis** to obtain stress responses under complex loading conditions
 - **Advanced structural models** to consider floater flexibility, geometrical & material imperfections & deteriorations

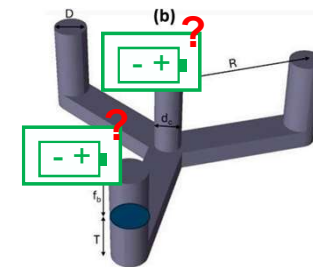
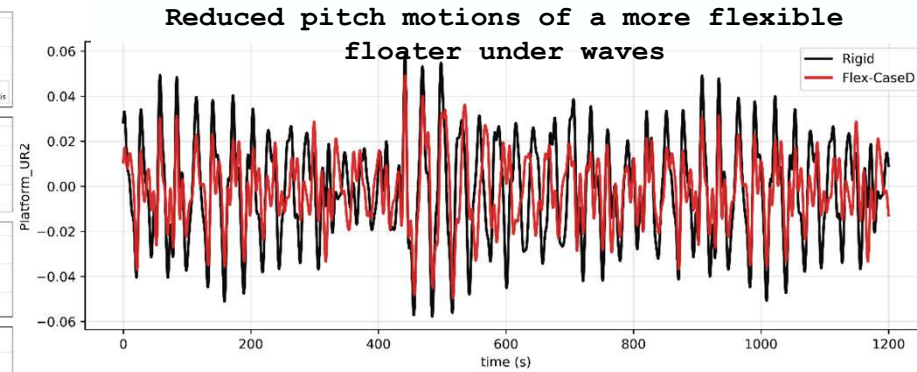
Local Structural Design and Integrity Analysis

- Progress:
 - Validation by comparing to sole OpenFAST framework
 - Investigation of how floater elasticity influences the global responses and local responses



Good agreement of motions in the wave-only simulations

Good agreement of motions in the wind-only simulations



ible configurations: (a) off-centred, (b) centred.

Potential arrangement optimization for H2 production & storage facilities

Conclusions

- Co-located wind-wave energy facilities less pause frequency and higher hydrogen production for wind-wave uncorrelated sites
- Large-scale FOWT/FWHS development requires **robust engineering tools**, and **integrated multibody/flexible-body platform analysis** is feasible
- Hydrogen integration is feasible for floating wind platforms, with **comparable extreme responses** except for increased platform pitch caused by a higher centre of gravity
- Integrated framework that **accounts for both global and local design considerations** can support exploration of **broader design space** and support **design optimization**
- Coupled framework for **one-step load-to-stress simulation** enabling direct evaluation of complex **aero-hydro-mooring-elastic interactions** and **dynamic** structural responses

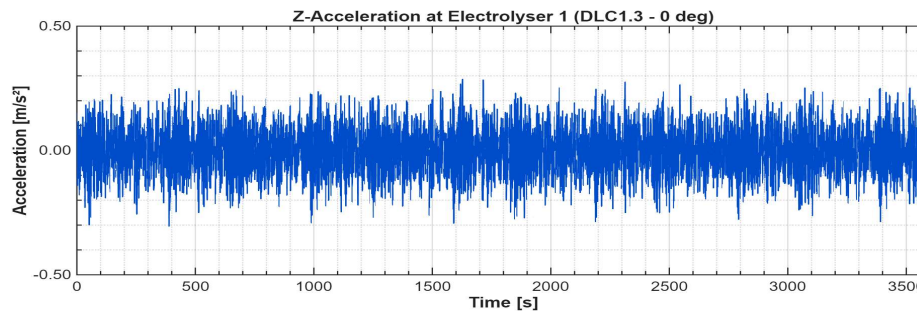
Next steps

- Development of integrated engineering model/framework for **time-domain structural analysis** for platform under various loading conditions
- Floater design space exploration considering both local and global responses
 - Open-sourced “**Strawman**” **case study** with embedded structural design for reference, verification, and validation
- Simulations using developed coupled framework to obtain stress-history
 - Investigate influence of **floater elasticity** and explore **potential optimized facility arrangements**
- Review of H2 **transportation solutions**: Material and structural selection for H2 tank



Support, Feedback and Opportunities for collaboration

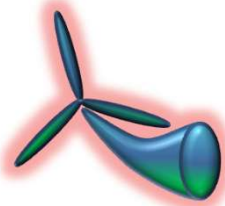
- **Data shared** by industry and academic partners can directly support the development and refinement of the tools and models
- **Benchmark studies**, together with **verification and validation cases**, can improve the accuracy, robustness, and practical applicability of the developed tools and models.
- **Collaboration** with researchers from different disciplines can enable the integration of complementary research outcomes, such as models for predicting hydrogen production based on power generation.



Thanks!
Comments/questions?

Ocean-REFuel (Ocean Renewable Energy Fuel)

Workstream2: Power to carbon free fuel



Mohamed Mamlouk
School of Engineering, Newcastle University
9th September 2025, Newcastle University



University of Nottingham
UK | CHINA | MALAYSIA



Overview

1. Membrane-less electrolyser
2. Rotating cells and MFIE
3. Electrolyzer in floating Offshore simulation
4. Questions and open discussion

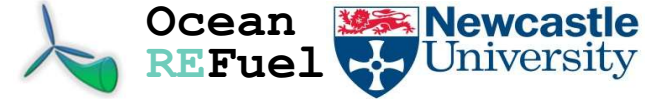
Overview

1. Membraneless electrolyser & stack modelling
2. Rotating cells and MFIE
3. Electrolyzer in floating Offshore simulation
4. Questions and open discussion



Daniel Niblett

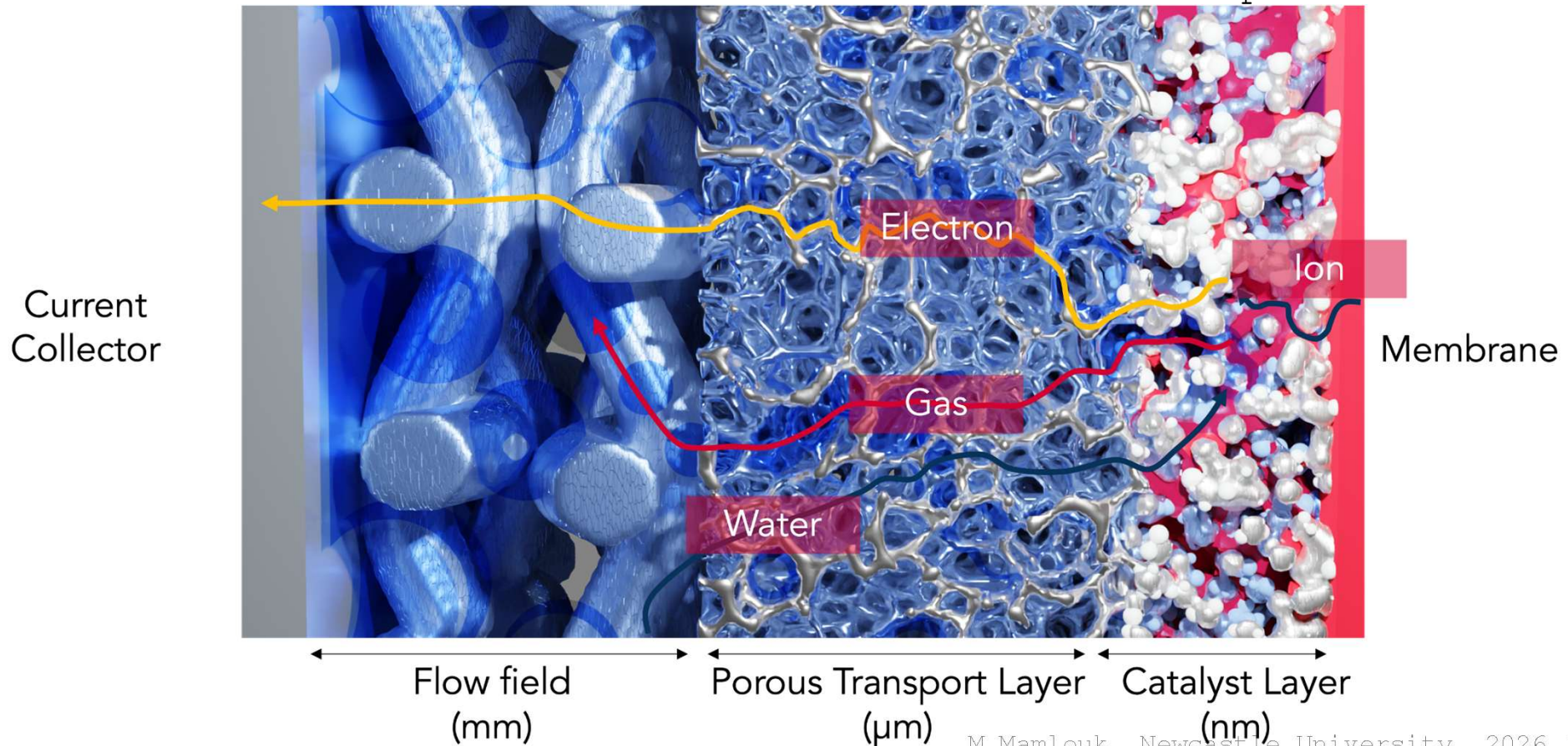
Continuing Hydrogen Research



- Dr Niblett has transitioned to his own fellowship - **£1.1M EPSRC Open Fellowship** for (ION-H2) intensifying and optimising electrolyzers – building on the success of research in Ocean Refuel.
- Past year - **£60k in extra funding** acquired (Dr Niblett PI, Prof Mamlouk Co-I) from North-east net zero accelerator and HEIF Proof-of-concept fund to continue scaling opportunity of Membraneless Electrolyser.
- Participated in **Northern Accelerator Future Founders Programme** for Membraneless Electrolyser commercialisation
- In talks with Venture Capitalists for possible commercialisation
- Scheduled talk at **All-Energy Conference** in Glasgow 14th May 2026

Insights into micro-scale system

In Alkaline and AEM, bubbles can impact performance, understanding and validating how materials and operating conditions change this is critical - details at micro-scale are difficult to capture



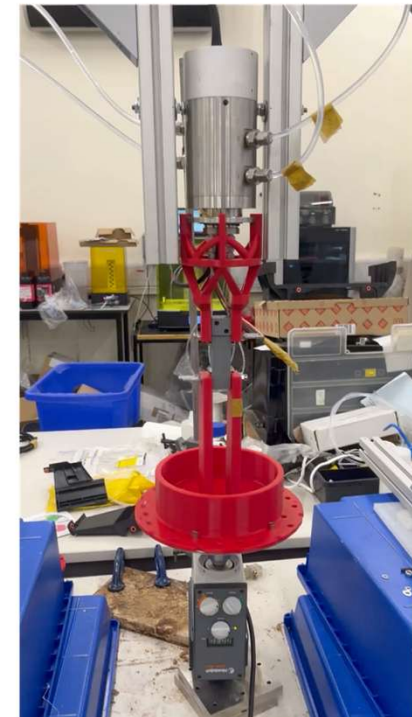
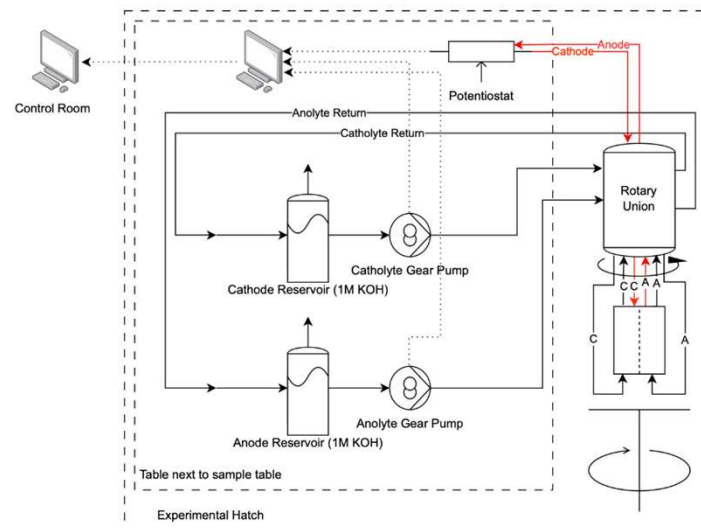
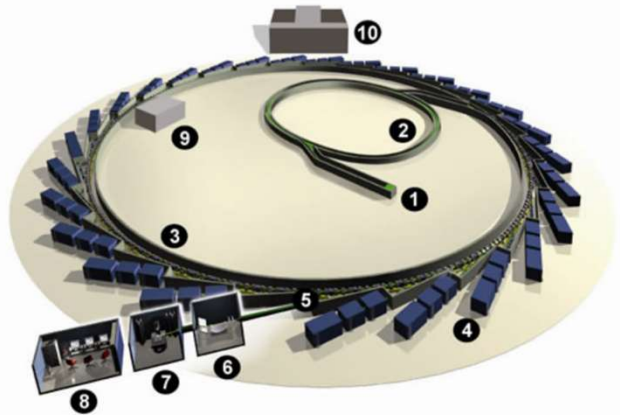
Operando X-ray Tomography (Diamond)



Ocean
REFuel



- Led proposal and team as Co-Is for 12 shifts at Diamond Lightsource Synchrotron, JEEP I-12 53 – 70 keV, Feb 2026
- 1Hz rotation, 2 tomograms (3D reconstruction) per second
 - Redesign cell to have no current collector (reduce x-ray absorption)



Operando X-ray Tomography (Diamond)

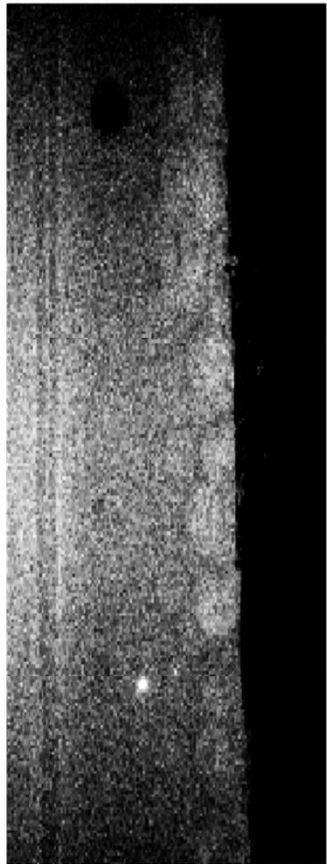


Ocean
REFuel



- 24 hour access for 4 days, 1Hz rotation continuous, live x-ray feed shown above.
- 6 researchers from Newcastle supported the experimental work as first time users of facility

Operando X-ray Tomography (Diamond)



Raw Projection
Image Adjustment

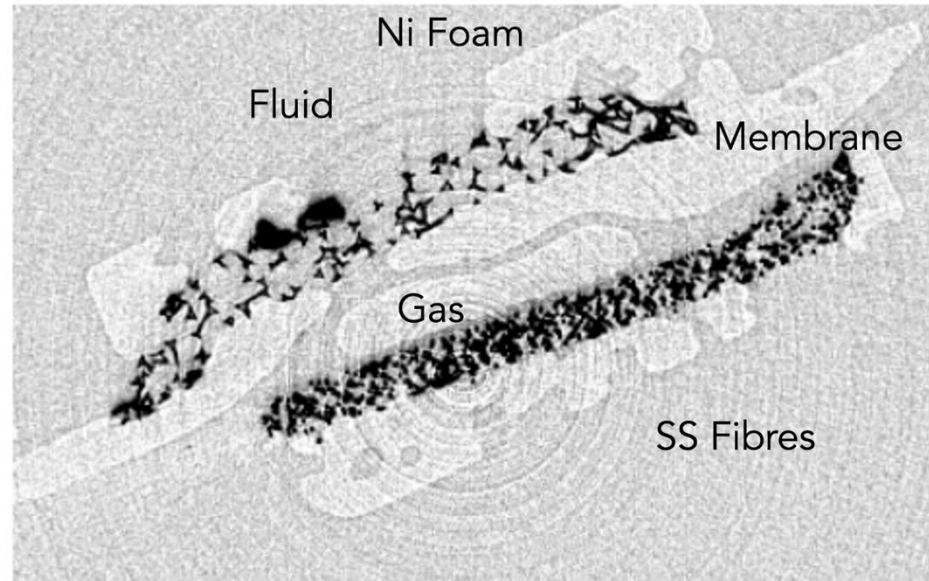
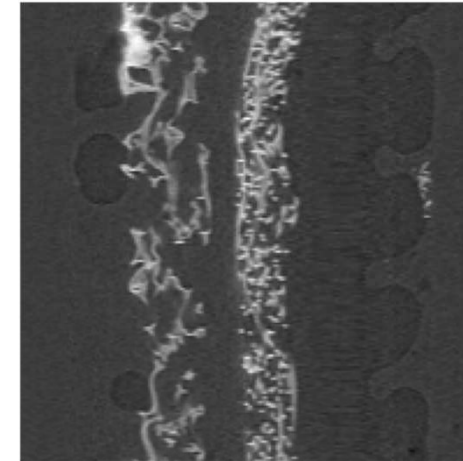
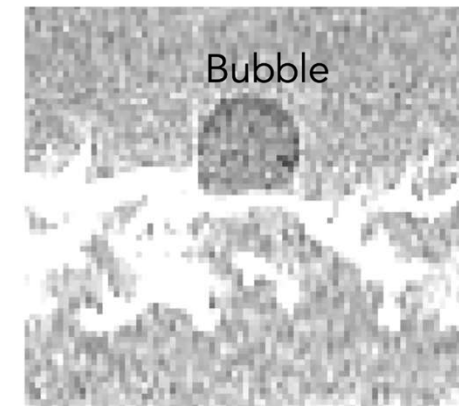


Image Reconstruction Filtered Back Projection (not cleaned)

Over 200 scans during electrolysis, each with 12000 projections (20 tomograms), 5 TB of raw data



Material and fluid distribution

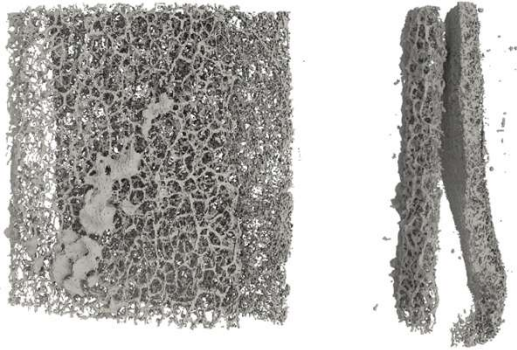


Bubble

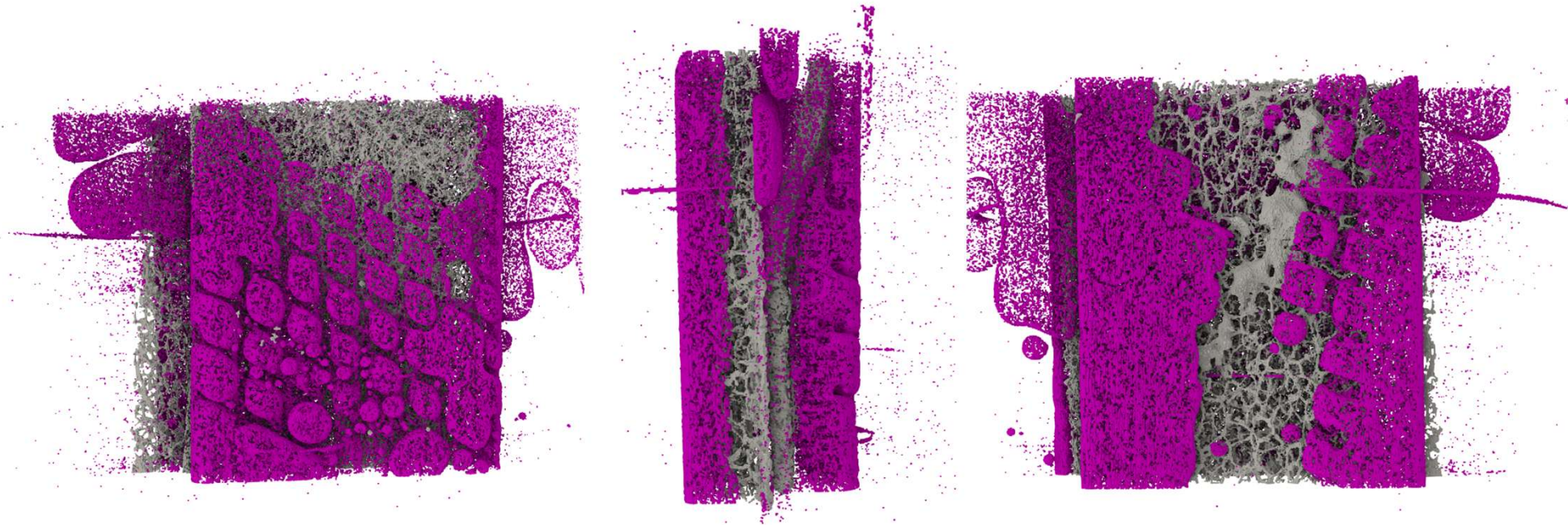
Operando X-ray Tomography (Diamond)



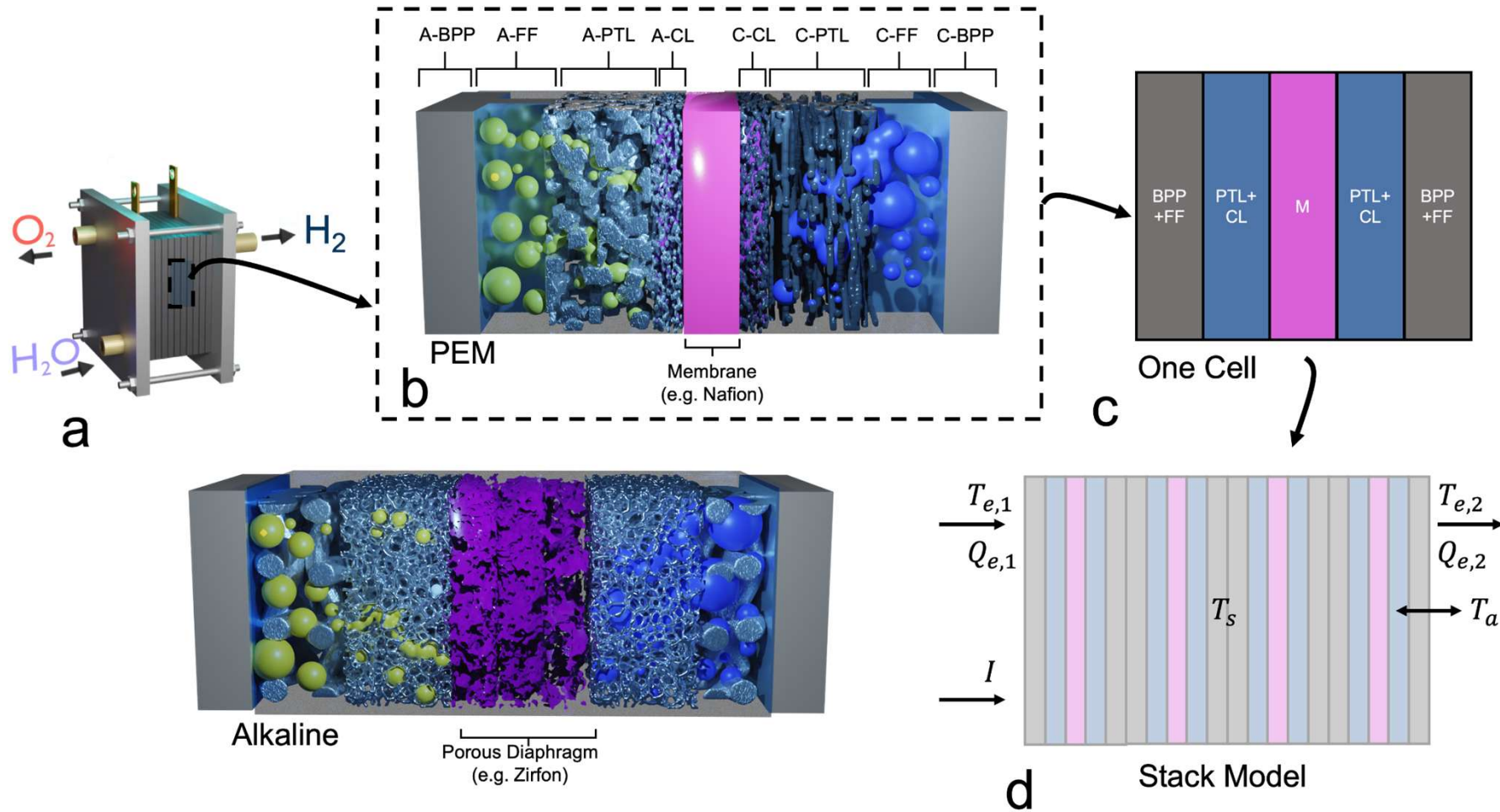
Ocean
REFuel



- Quick 3D reconstruction without cleaning or segmentation (capturing 0.5 time step.)
- Examine construction, distribution of phases, bubbles, membrane etc
- 200 scans, each with 20 3D-tomograms representing 0.5 seconds.
- Constant current and pulsing current (on/off)



Dynamic Electrolyser Stack Modelling



Dynamic Electrolyser Stack Modelling

- Previously developed 0D static electrolyser model for instantaneous hydrogen production but no dynamics considered -

<https://github.com/DNiblett/powerToElectrolysis>

$$f = N_{stacks} N_{cells} A_{cell} \left(2b \ln \left(\frac{i}{i_{0a} r_f} \right) + \frac{i\delta}{k} \right) i - P_{turbine}$$

- Extended the modelling capability to include temperature dynamics in new dynamic 0D stack model - capturing changes in potential, current, temperature, flow rates to stack (AEM, PEM, Alkaline) - <https://github.com/DNiblett/electrolyserStackModel>

Electrical Energy Conservation

$$f = \left(b_a \ln \left(\frac{j}{j_{0,a} r_f} \right) + E_{0,a} + \frac{jL}{k_{eff}} + b_c \ln \left(\frac{j}{j_{0,c} r_f} \right) \right) j A_{cell} N_{cells} - P$$

$$j_0 = j_0 (1 - 0.023 j^{0.3}).$$

$$\eta_{bubble} = \frac{2L_{PTL}}{k_e} \left(\frac{j}{1 - \alpha^3} - j \right).$$

$$W_{elec} = I(V - V_{th}) N_{cells}$$

$$Q_{gas} = \frac{j A_{cell} RT}{nF p}$$

$$Q_{g,2} = \alpha (C_1 Q_t + U_d A_e)$$

$$\frac{\partial \alpha}{\partial t} = \frac{Q_{gas} - Q_{g,2}}{V_{void}}$$

Stack temperature

$$m_s c_{p,s} \frac{\partial T_s}{\partial t} = -h_e A_e (T_s - T_e) - h_\infty A_\infty (T_s - T_\infty) + W_{elec}$$

Electrolyte/water

$$m_e c_{p,e} \frac{\partial T_e}{\partial t} = \rho_{e1} c_{p,e} Q_{e1} T_{e1} - \rho_{e2} c_{p,e} Q_{e2} T_e + h_e A_e (T_s - T_e)$$

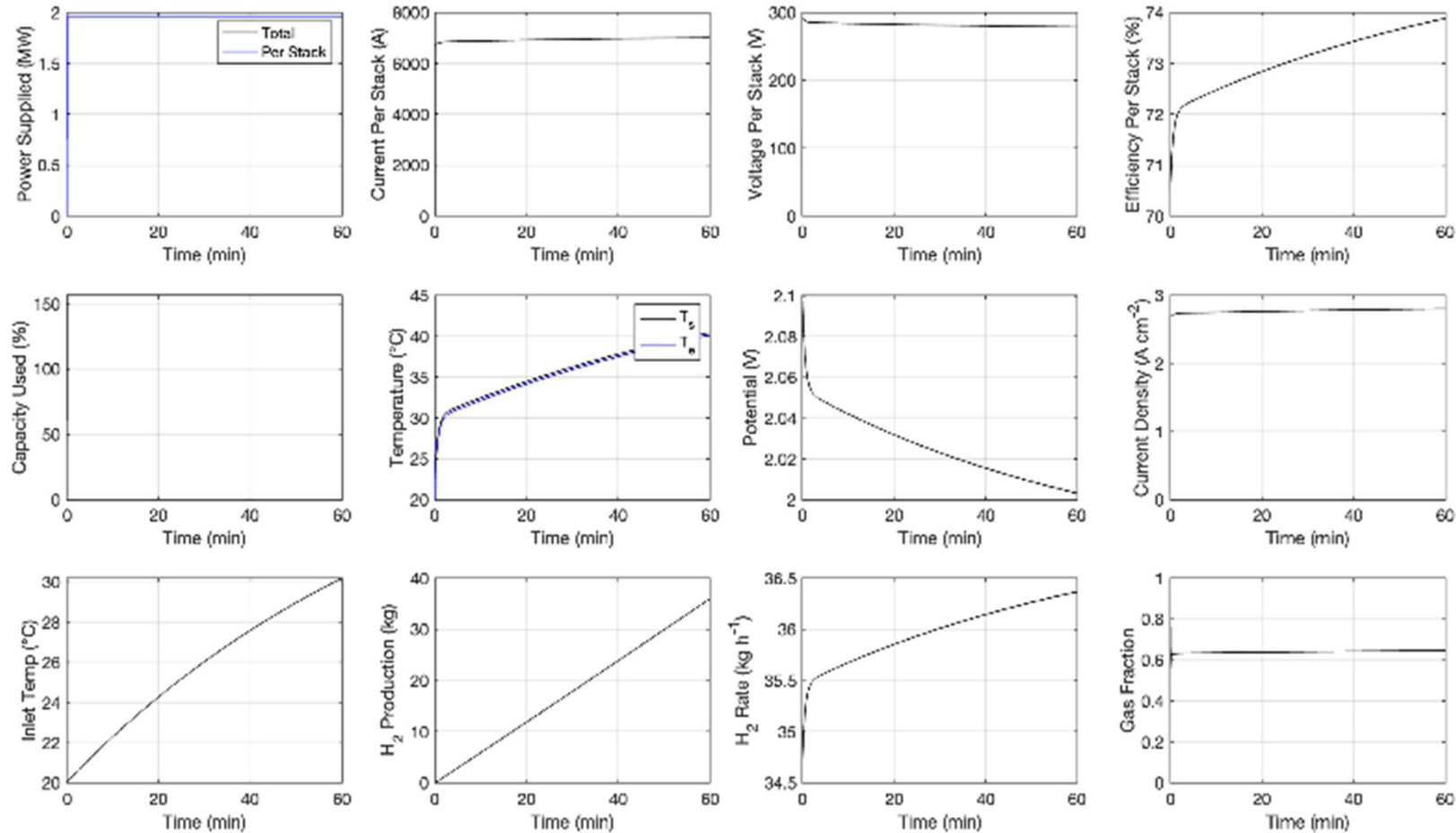
temperature

$$T^{n+1} = T^n + \frac{(-h_e A_e (T_s^{n+1} - T_e^n) - h_\infty (T_s^{n+1} - T_\infty) + W_{elec}) \Delta t}{m_s c_{p,e}}$$

$$T_{e,1} = T_{e,1} + K_p (T_{set} - T_s) \Delta t$$

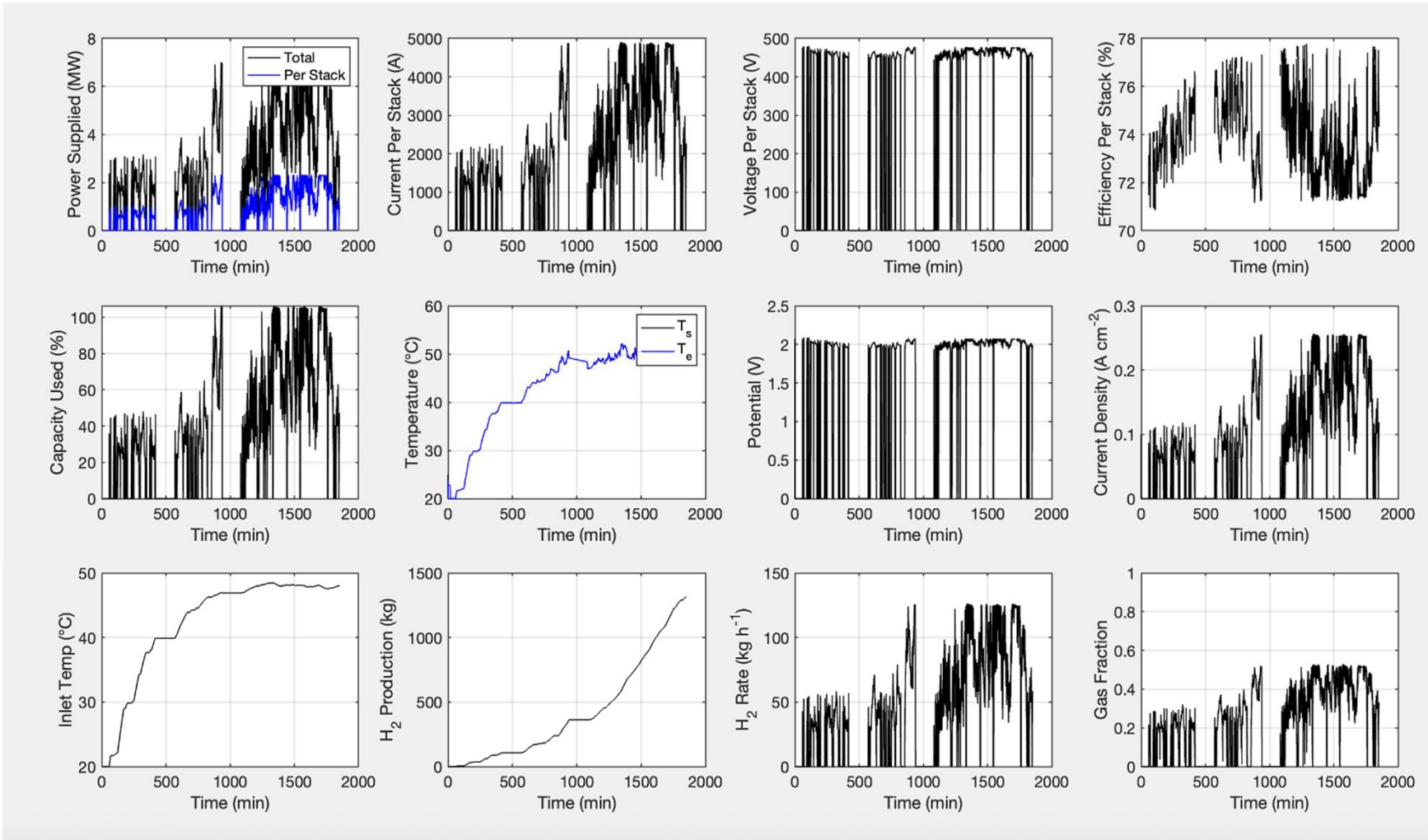
Drift flux model for 0D two-phase flow Electrolyte/water inlet temperature control loop

Dynamic Electrolyser Stack Modelling



Alkaline (1 stack) - constant power (2MW) - cold start

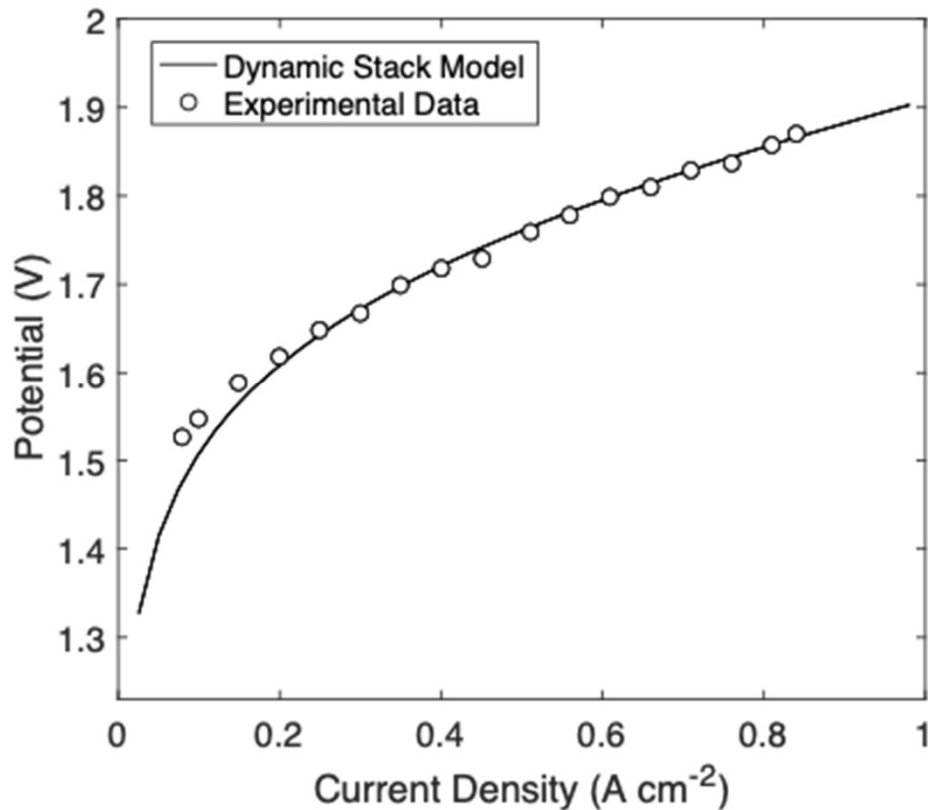
Dynamic Electrolyser Stack Modelling



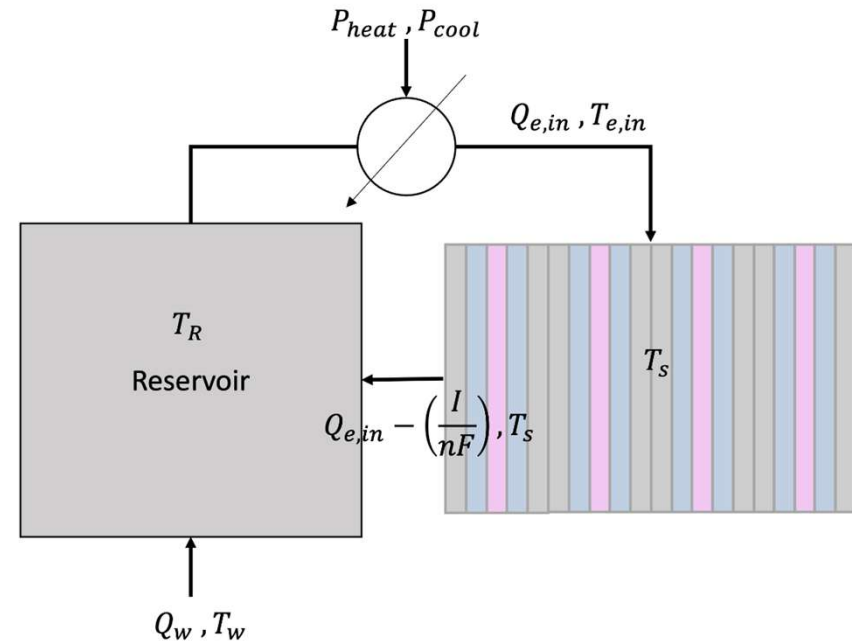
- Dynamic Temperature (difficult to reach operating set-point)
- Dynamic electrolyte temperature control challenging
- Efficiency changes with temperature (kinetics, ion transport, etc)

Dynamic Electrolyser Stack Modelling

- Next stage - validate stack model with 2kW AEM Electrolyser rig here at Newcastle (Majid + Dan collaboration)



Validated single cell AEM for 2.3kW Enapter stack



Next steps - for true dynamic validation add in solving reservoir temperature and mass balance and heater/cooler power

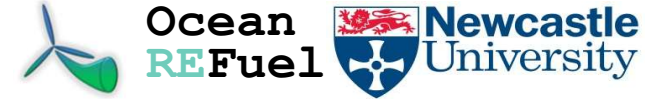
Overview

1. Overarching questions of Workstream 2
2. Membrane-less electrolyser
3. AEM based Electrolysers
4. Rotating cells and MFIE
5. Electrolyzer in floating Offshore simulation
6. Questions and open discussion



Mostafa Delpisheh

Dissemination



Coupled electrochemical-MHD modeling of magnetic-field-induced water electrolysis in acidic electrolyte, MODVAL 2026: 22nd Symposium on Modeling and Experimental. Validation of Electrochemical Energy Technologies, 10 - 11 March 2026, Lausanne Switzerland

Upcoming:

Toward offshore wind to green hydrogen: Multiphysics insights into rotation and magnetic-field induced electrolysis, ChemEngDayUK&I 2026, Birmingham, April 2026

Multi-physics modeling and experimental testing of the SDR



Ocean
REFuel



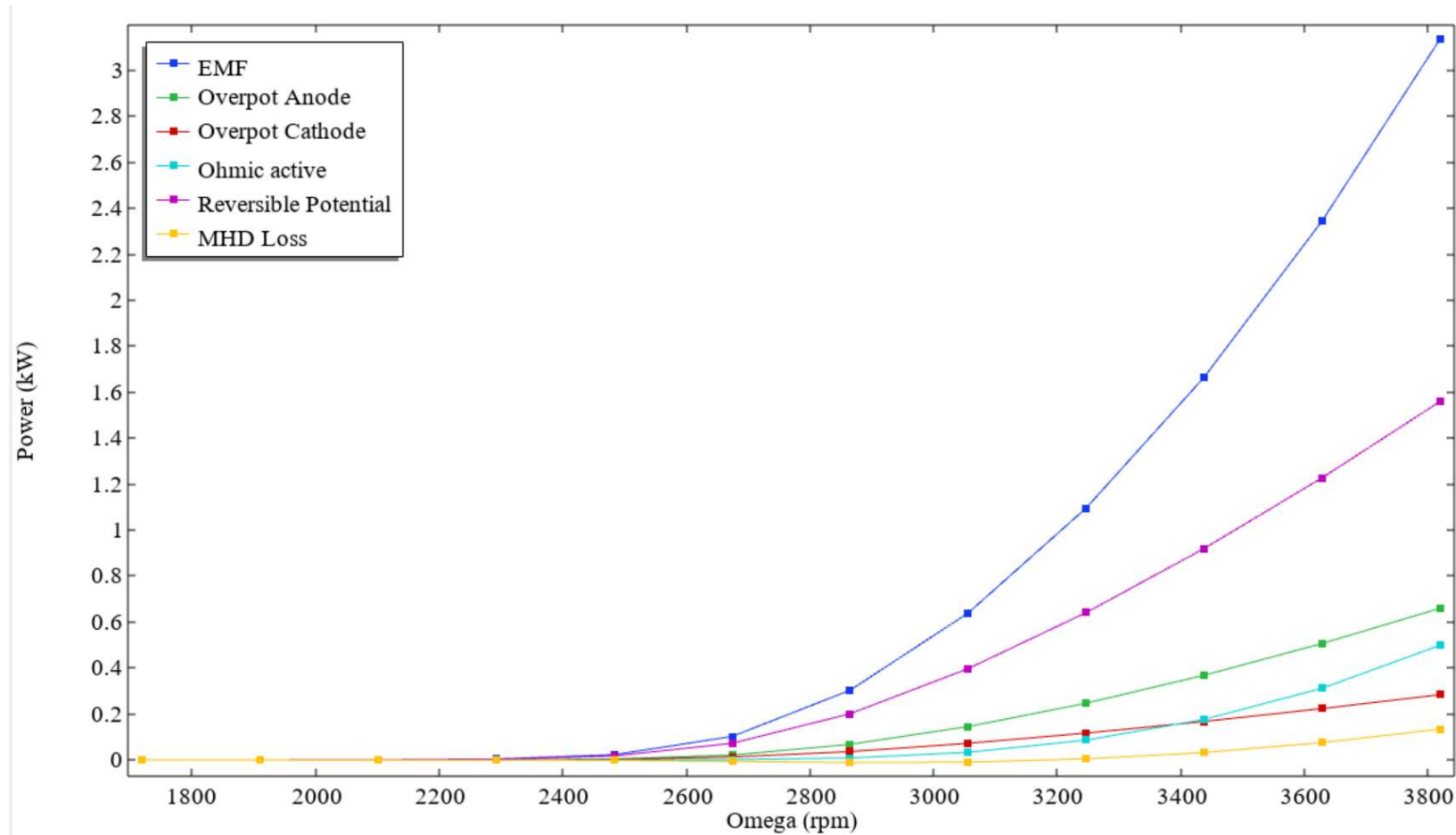
- ✓ Electromagnetism
- ✓ Magnetohydrodynamics
- ✓ Two-phase flow
- ✓ Designs exploration (alkaline)
- ✓ Experimental validation
- ✓ Tertiary Current Distribution (with transport phenomena)
- ✓ Multibody systems
- ✓ Multi-physics Coupling
- Sanity checks

Objective 1 : Electrochemical tests for multiphysics modeling input

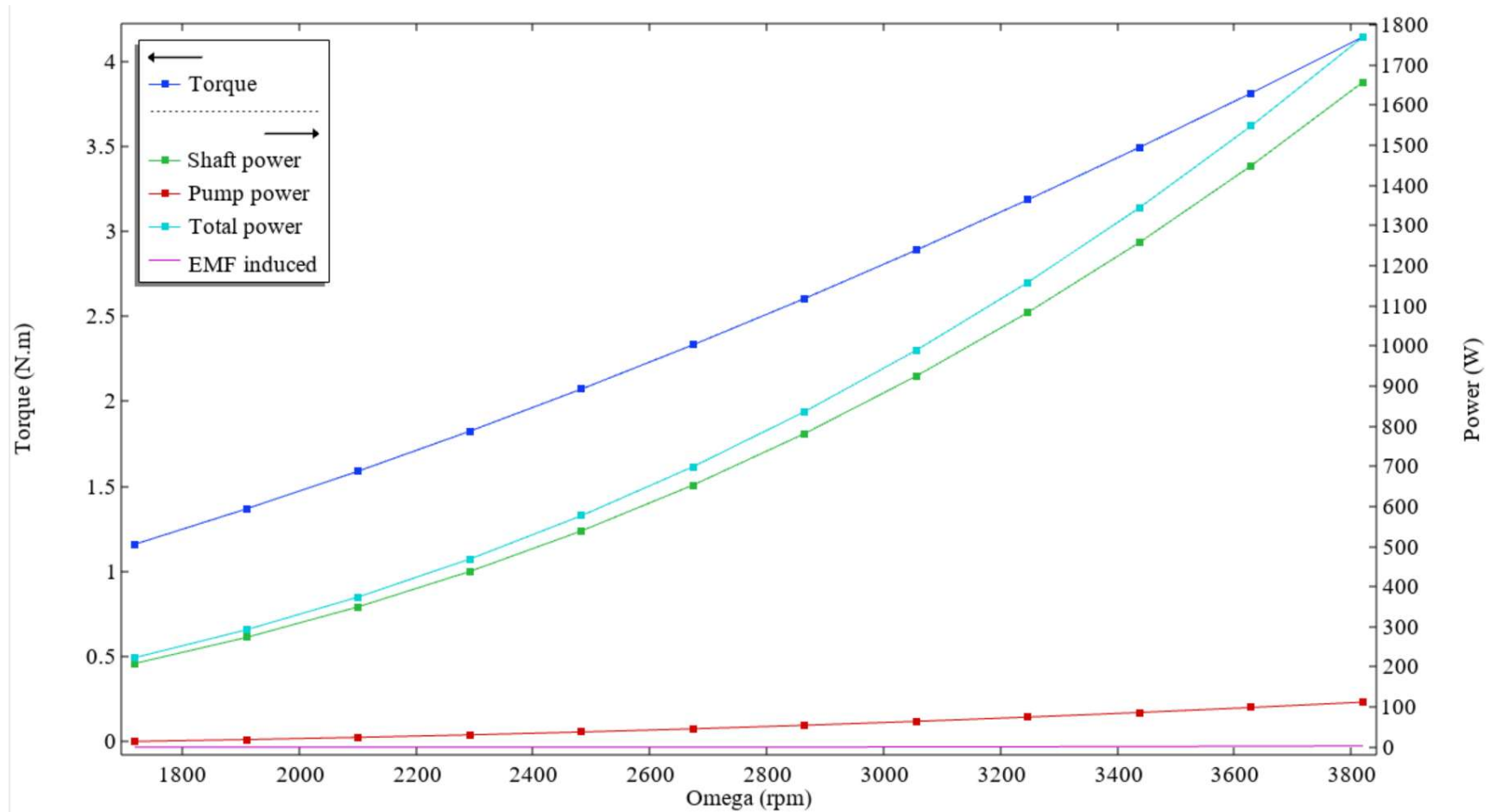
Objective 2 : Calculating the power curve vs SDR rotational speed

Objective 3 : Sanity checks on current, ion flux, power losses

Power input and losses in the system



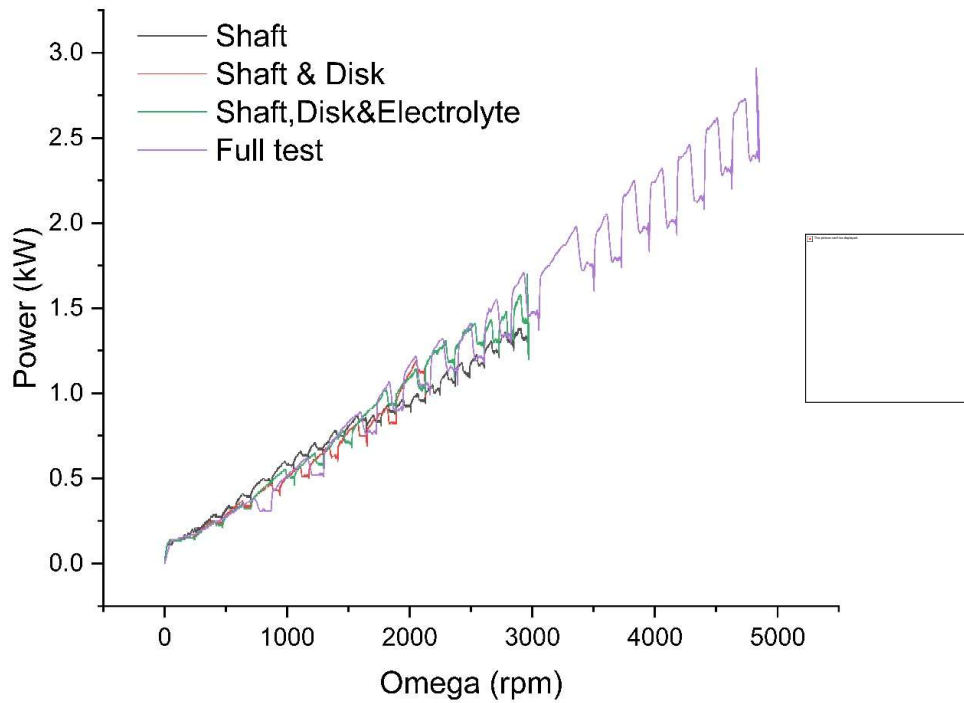
Torque & power consumption in the SDR



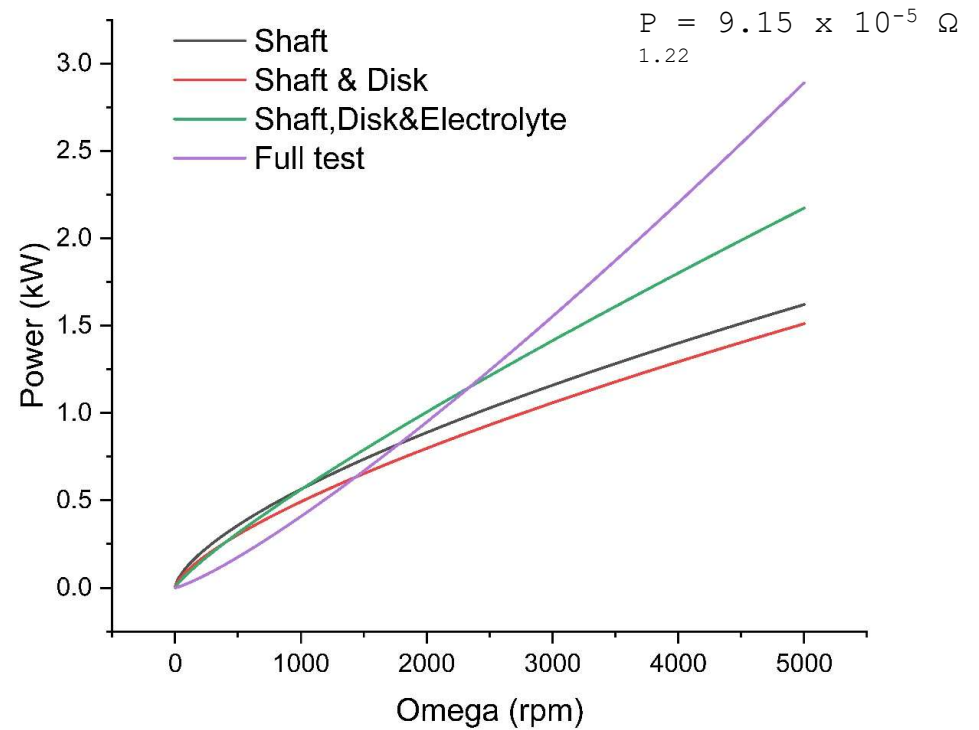
Power curve vs SDR rotational speed



Ocean
REFuel



Raw data from
electromotor drive



Curved-fitted data

Overview

1. Overarching questions of Workstream 2
2. Membrane-less electrolyser
3. AEM based Electrolysers
4. Rotating cells and MFIE
5. Electrolyzer in floating Offshore simulation
6. Questions and open discussion

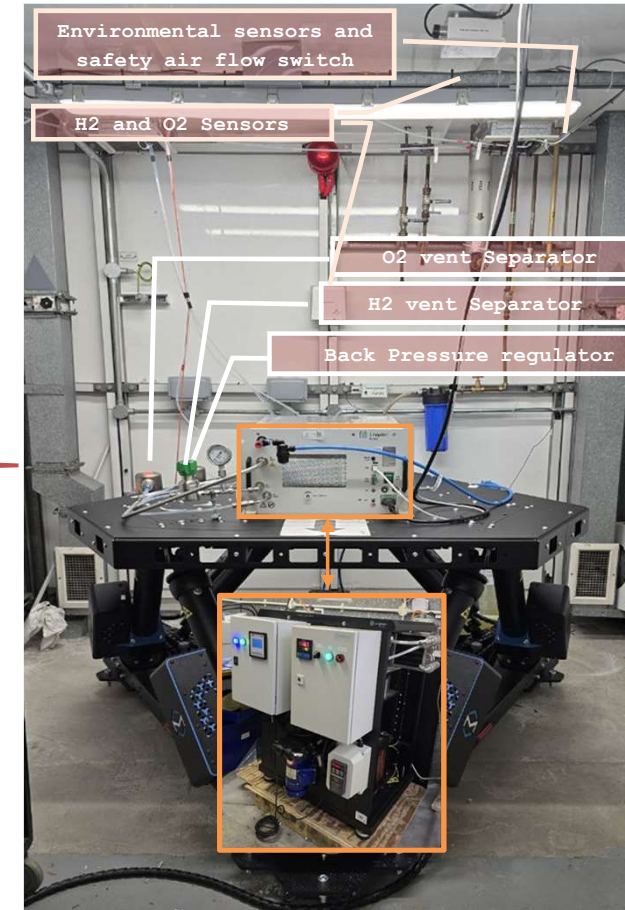
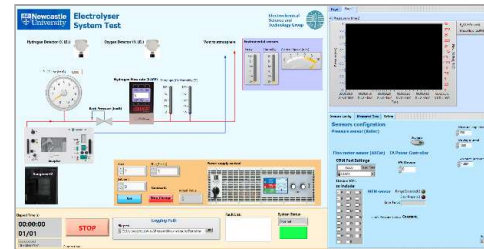


Majid Rahgoshay

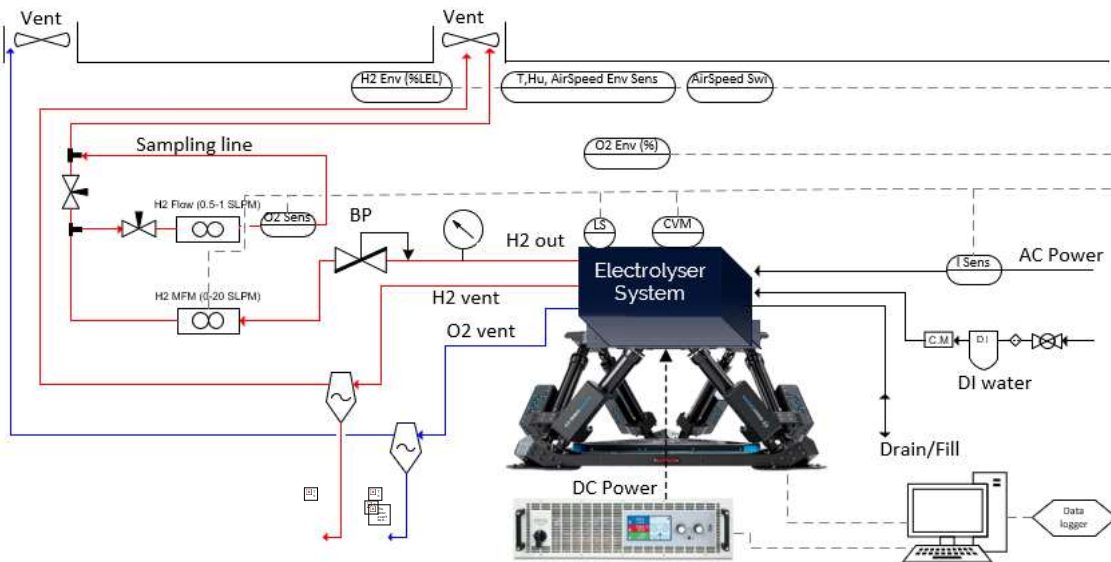
Preparing test bay

Preparing test bay for testing both electrolyser system

- Applying custom Motion profile with motion platform
- Applying custom Power profile with LabView& power supply
- Recording key parameters at 10 Hz via the NI datalogger (For steady input: 1 Hz)
- Adding Cell Voltage Monitoring system
- Adding electrolyte tank level meter
- Adding the O₂ concentration sensor for H₂ outlet line

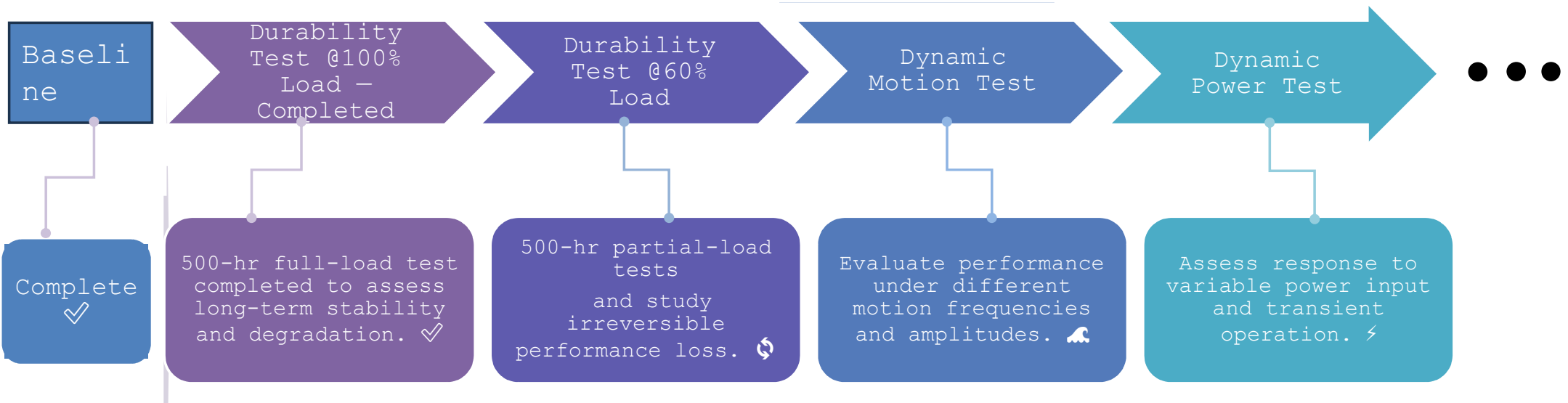


Electrolyser Test Bay P&ID



Test Plan

Completed and Planned Electrolyser Test Programme

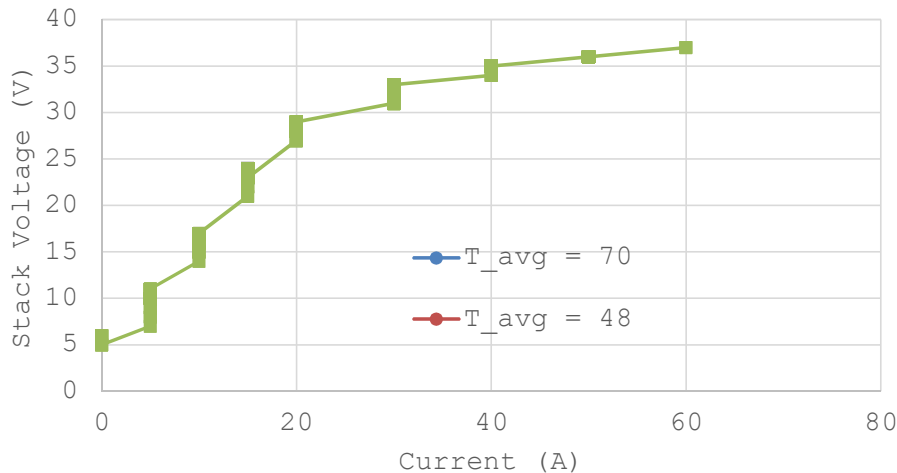


Performance Characterization



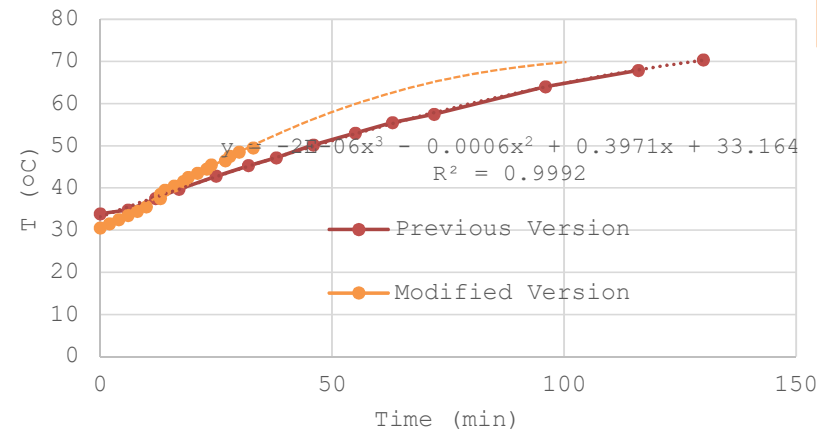
AWE atmospheric pressure (electrolyte feed on both)

- ❑ Comparing modified AWE electrolyser system to test to previous version condition:
- ❑ AEM Electrolyser testing start-up

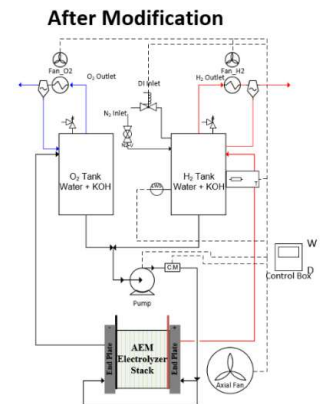


✓ Same Electrolyser Stack Performance

Temp vs time



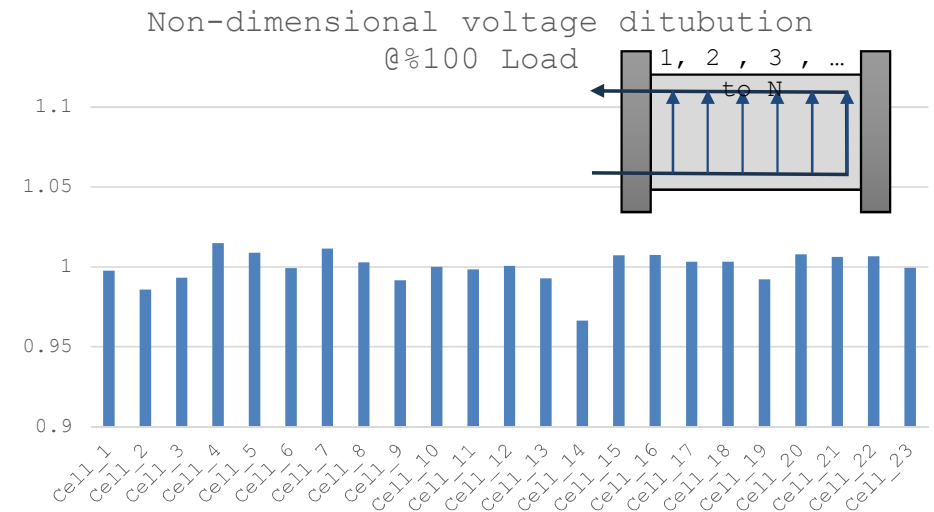
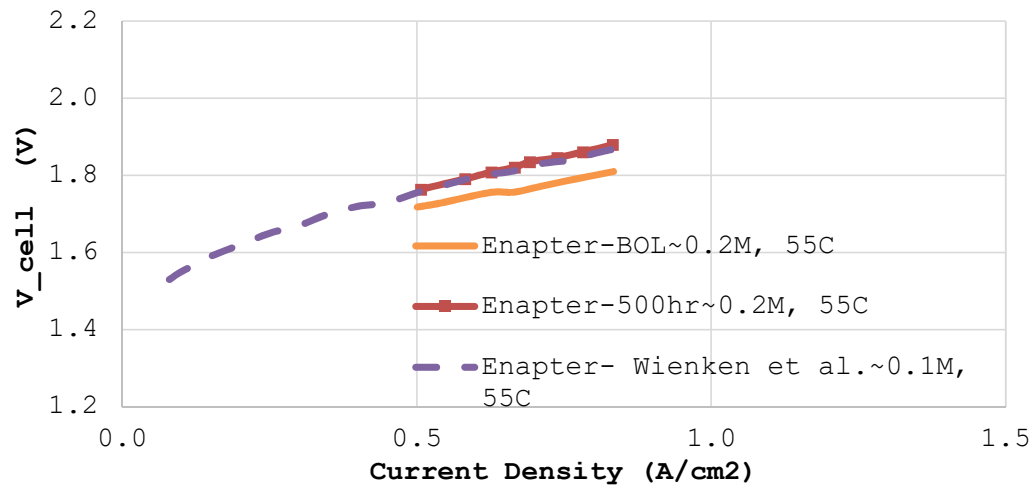
- ✓ Increasing temperature rate at start up from 0.3 °C/min to 0.4 °C/min by reducing tank size and removing heater



Performance Characterization

AEM 35 barg H₂ (electrolyte feed on Anode)

- ❑ Comparing electrolyser performance (IV curve)
- ❑ Cell Voltage deviation at normal condition



Long-Term Durability & Lifetime Testing (on normal situation)



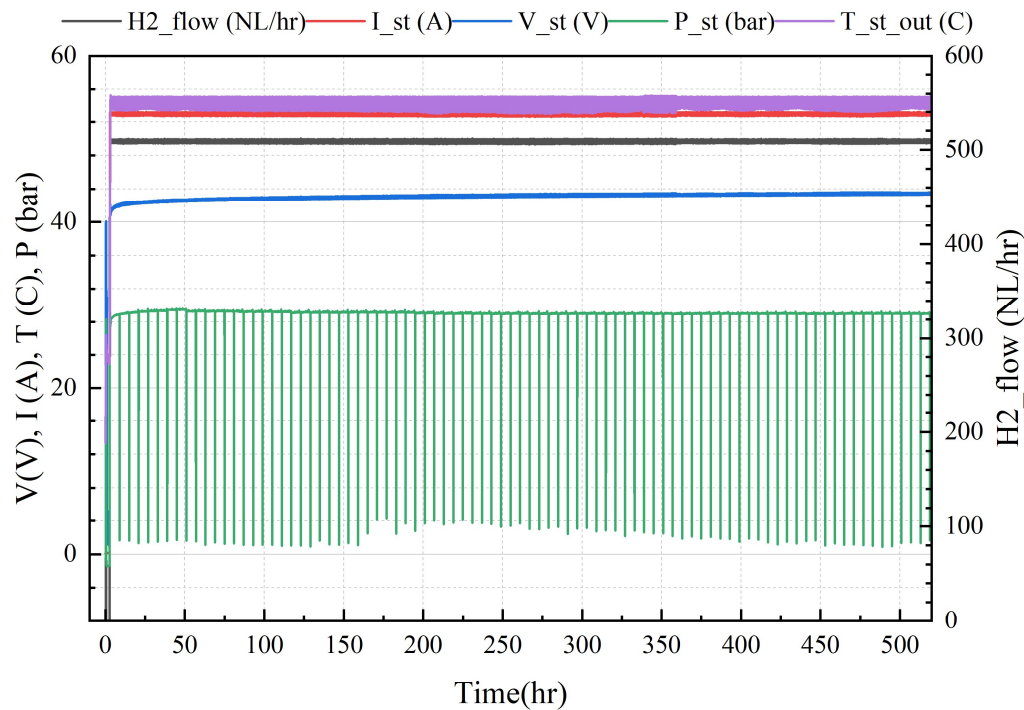
Ocean
REFuel



500 hr continues test @ 100% load

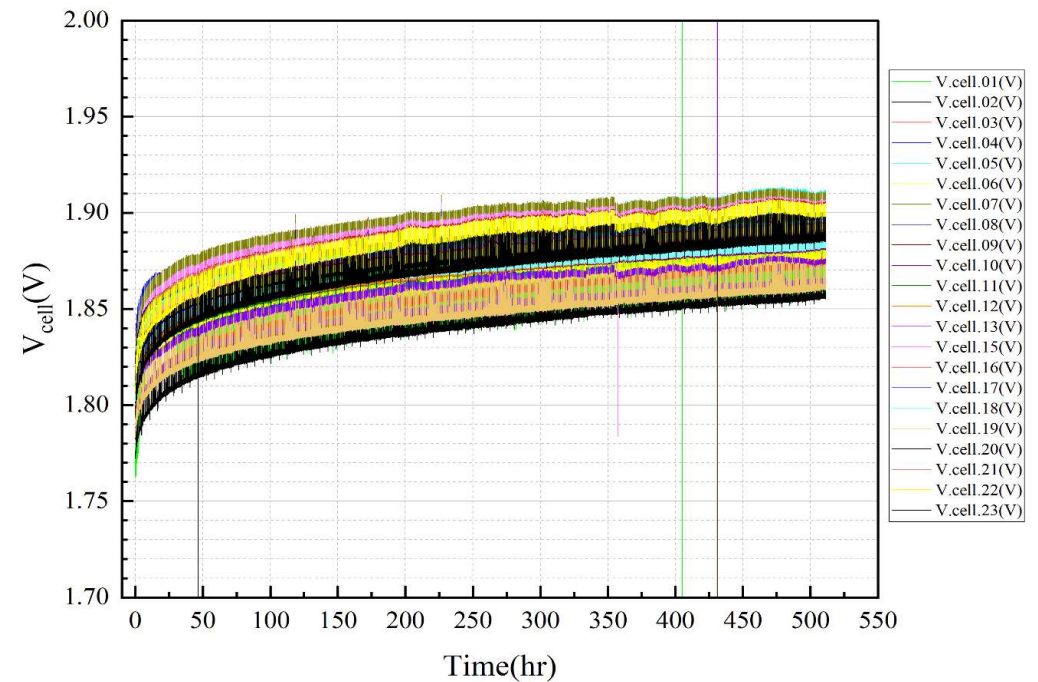
Main input and output parameters of Electrolyser system @100% load:

Hydrogen Flowrate, Stack current and Voltage, Pressure and Temperature of Stack



Individual cells voltage change at durability test:

Cell 1 to cell 23



Long-Term Durability & Lifetime Testing (on normal situation)

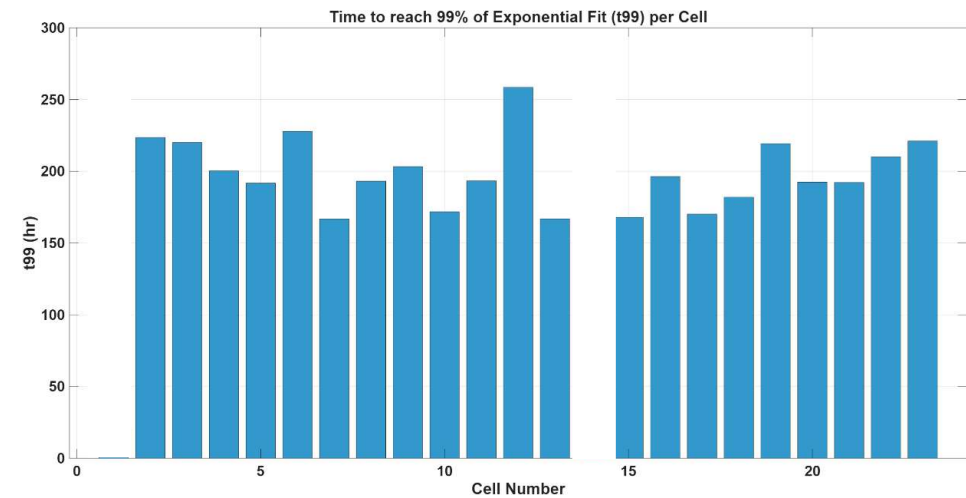
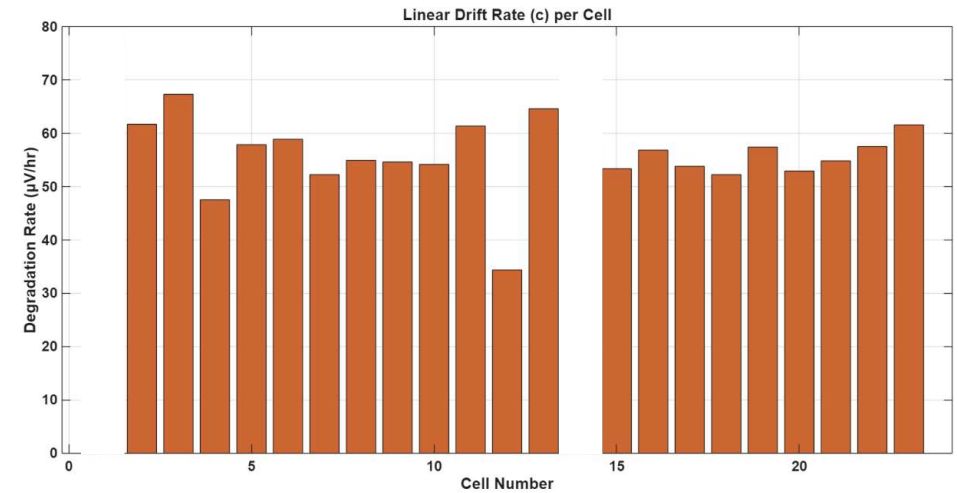
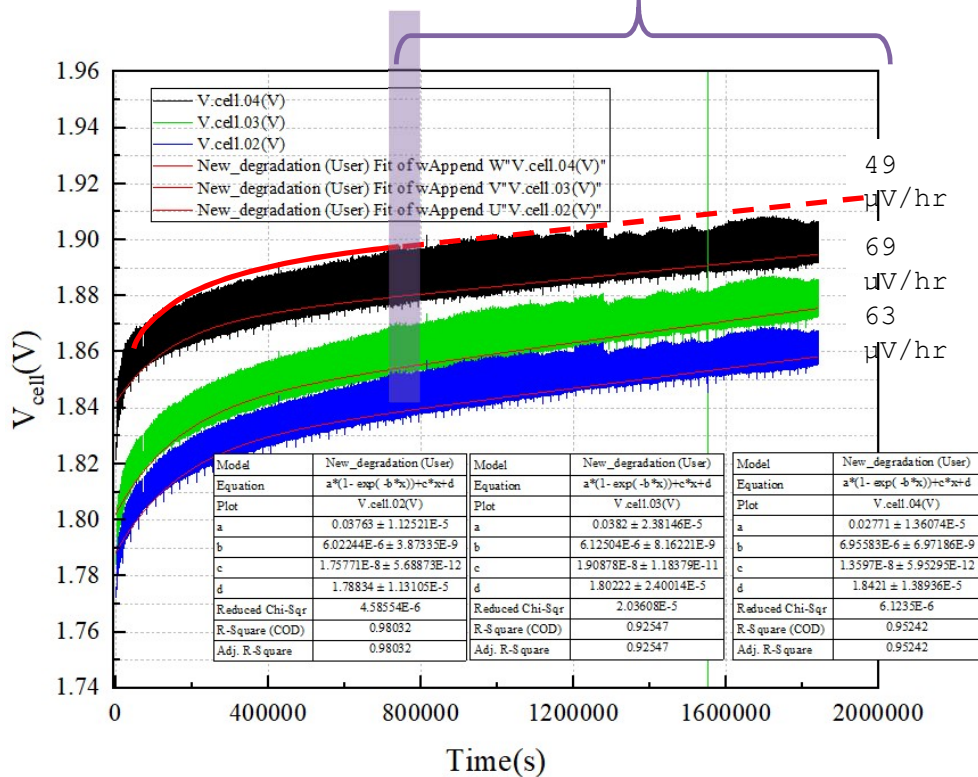


Analysing voltage degradation trend

Because no periodic recovery steps were used, c (slope) should be interpreted as the apparent long-time degradation rate under continuous operation rather than a strictly irreversible degradation rate.

$$a*(1-\exp(-b*x))+c*x+d$$

Linear Section (%99)



Test Plan-Baseline TOP Behaviour Prior to Dynamic Testing



Ocean
REFuel



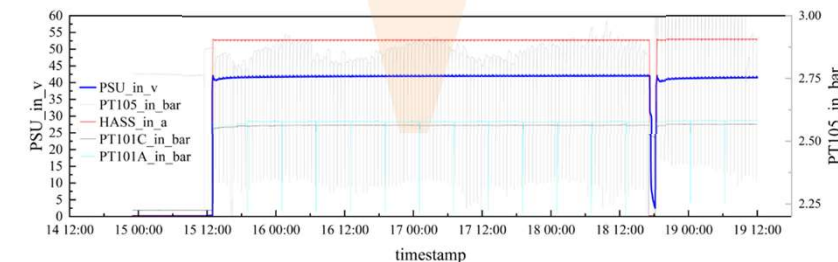
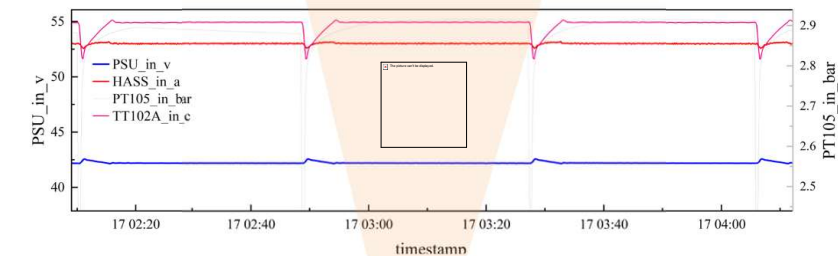
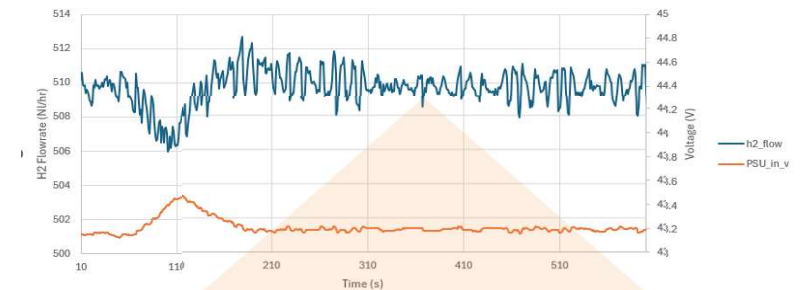
Baseline Analysis of Fluctuation and Pattern Behaviour of TOPs for Comparison with Motion-Test TOPs:

Fluctuations: Minor high-frequency fluctuations are observed in voltage and flow rate. The amplitude of fluctuation for:

- Stack voltage: **0.08%**
- H2 Flowrate: **0.4 %**

Operational Patterns: Two distinct periodic operational patterns were identified affecting system behaviour:

- **DI water feeding (~40 min):** causes small temperature fluctuations affecting stack voltage. ☐⚡
- **Hydrogen purge (~6 h):** causes noticeable changes in H₂ flow and pressure. ●📈



Test Plan -Motion Profile

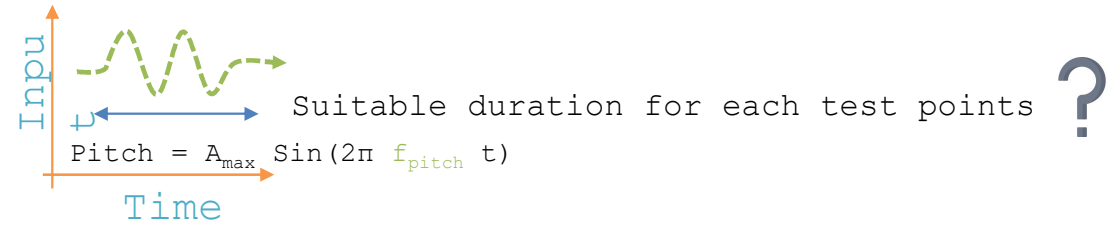
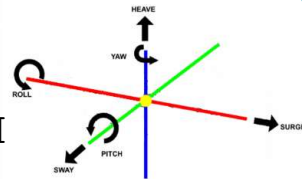
1. Test Points

Change by Scale Factor: **39**

Motion: 15 TP = 4 Amp + 11 Freq
 15 * 6 Axis = 90 Test point

Load: 2 Test point

Total TPs=2*90=180



2. Define Test Profile

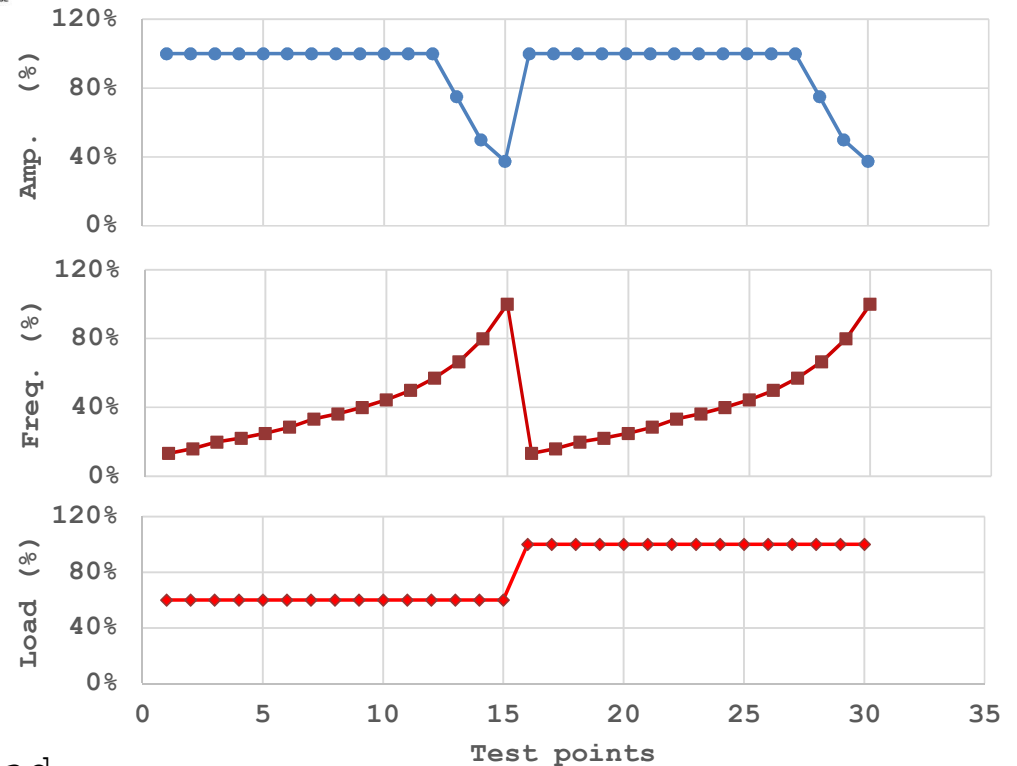
Most Stable TP → Non-Stable Situation

Motion Inputs

| | | |
|-----------|---|-----------|
| f_{min} | → | f_{max} |
| A_{max} | | f_{min} |

Sequence of test profiles:
Pitch, Roll, Heave (Z), Surge (X), Sway (Y), Yaw

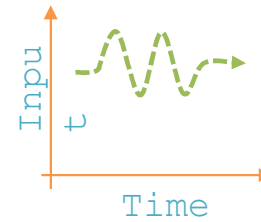
Power Input: constant 60% → to 100% Full load



Test Plan -Motion Profile

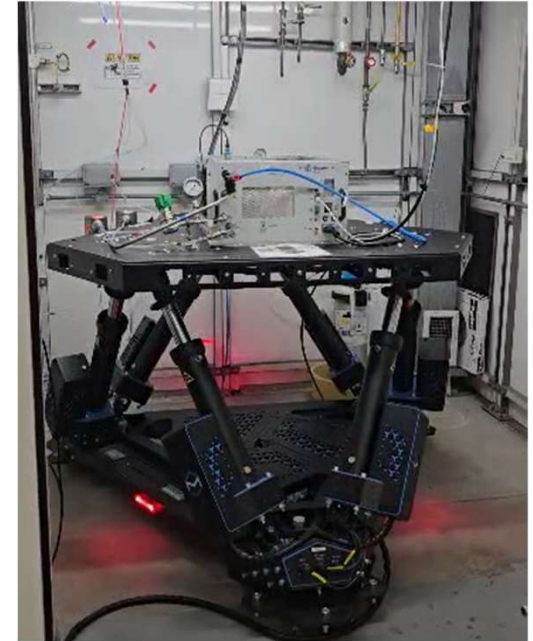
3. Perform Test

Motion: 15 TP = 4 Amp + 11 freq
 15 * 6 Axis =90 Test point
 Load: 2 Test point Total
 TPs=180

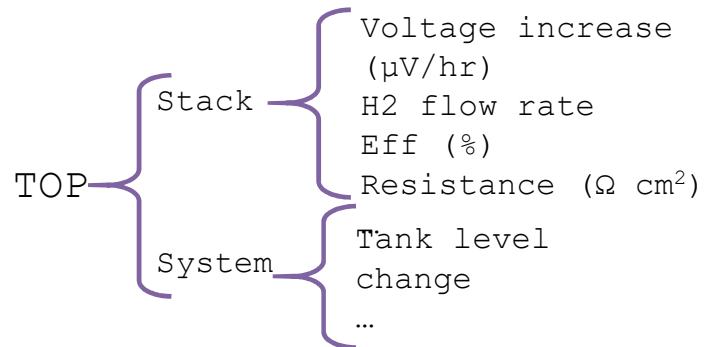


$$\text{Pitch} = A_{\max} \sin(2\pi f_{\text{pitch}} t)$$

$A_{\max} = 5 \text{ Deg}$
 $f_{\text{pitch}} = 1.6 \text{ Hz}$



4. Test Outputs



TOPs

- LabView logging (10 Hz): All individual cell voltages, stack voltage (resulting from sum of the cells voltage), tank level sensors, electrolyser power consumption and three environmental sensors are now configured to record at 10 Hz for each test point.
 - H₂ Line Parameters: For H₂ flow rate and gas humidity
 - O₂ concentration sensor in the H₂ line
- Electrolyser System Logging (1 Hz): Stack pressure, current and voltage,

Some Secondary Tops can be calculated from Primary TOPs like Efficiency

International Collaboration on Offshore Electrolyser Test Rig and Experimental Plan



Exploring synergies for offshore electrolyser deployment and motion-impact testing

University of Florence



Department of Industrial Engineering of Florence (DIEF)
European Academy of Wind Energy

- Feasibility studies including realistic offshore production
- Characterization of alkaline electrolysis, from multi-physics CFD to engineering methods
- Experimental characterization of electrolyzers

Finding synergies with OceanRefuel:

- Test rig for alkaline electrolyzer Up to 350 kW
- Alignment with durability and performance testing procedures

OPHARM1 & OPHARM2 Projects



I. Hydrogen and offshore wind: decision-support tools
(24 months | 2021-2023 | €544K)

II. Advanced analysis for offshore production of hydrogen from offshore wind
(36 months | 2023-2026 | €2,489K)

SCIENTIFIC Questions

- Networks integration
- Technology specification and Sizing
- Impact of motion on PEM electrolyser performance
- Environmental integration

- Cases definition for tests
- Simulation of movements for wind turbine and substation
- Testing 1 kW PEM electrolyser stack with simulated motion



THANKS FOR YOUR
ATTENTION

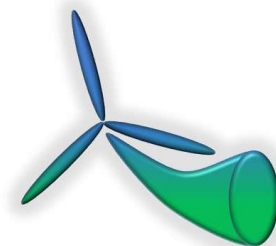


Questions and
discussion

Ocean Refuel funded by
EP/W005204/1



UK Research
and Innovation



Questions and discussion

**Ocean Refuel funded by
EP/W005204/1**



**UK Research
and Innovation**



University of
Nottingham
Energy Institute

UoN
Hydrogen Research

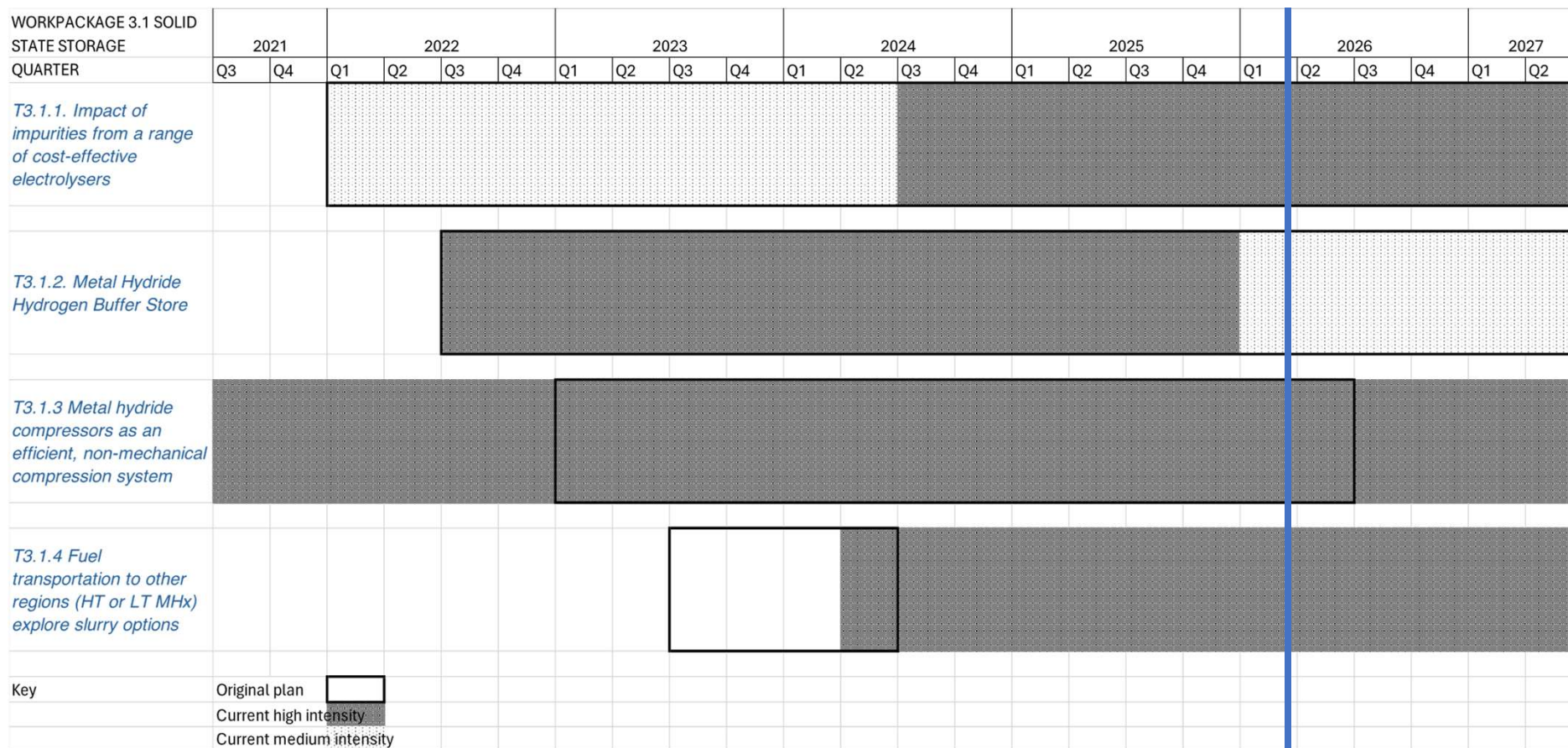
Work Stream 3.1 Update

Marcus Adams, Tugba Boynuegri, Amelia-Rose Edgley, Ramas Al Qudah,
Jorge Banuelos, Marcell Cyrille, Andrew Gray, Alastair Stuart, David Grant





Workstream 3.1 tasks



Amelia

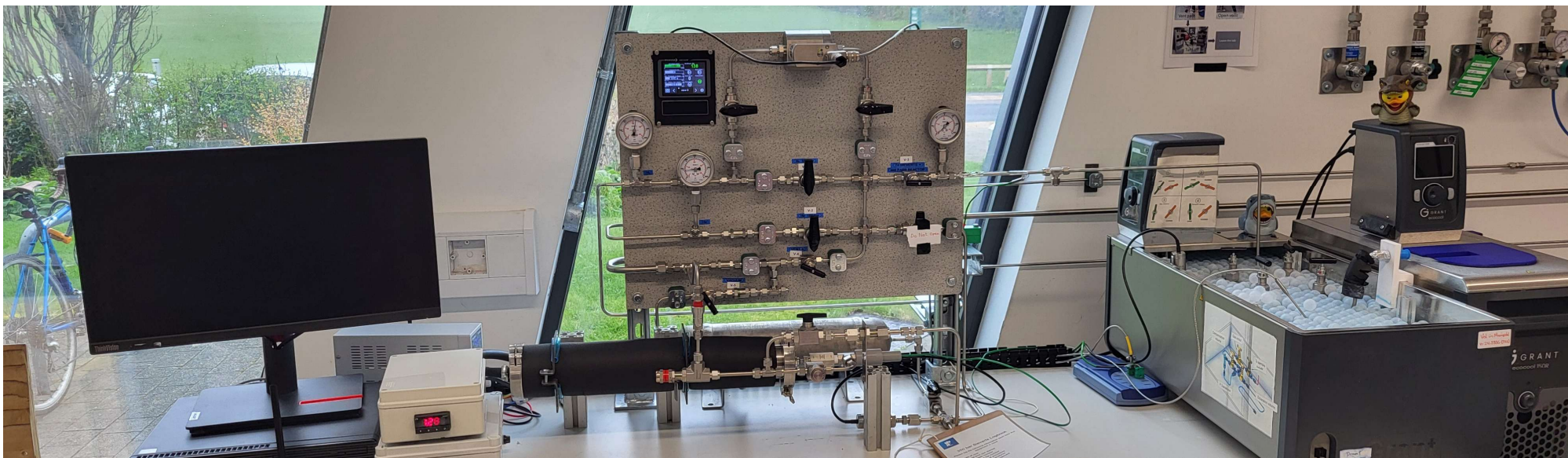
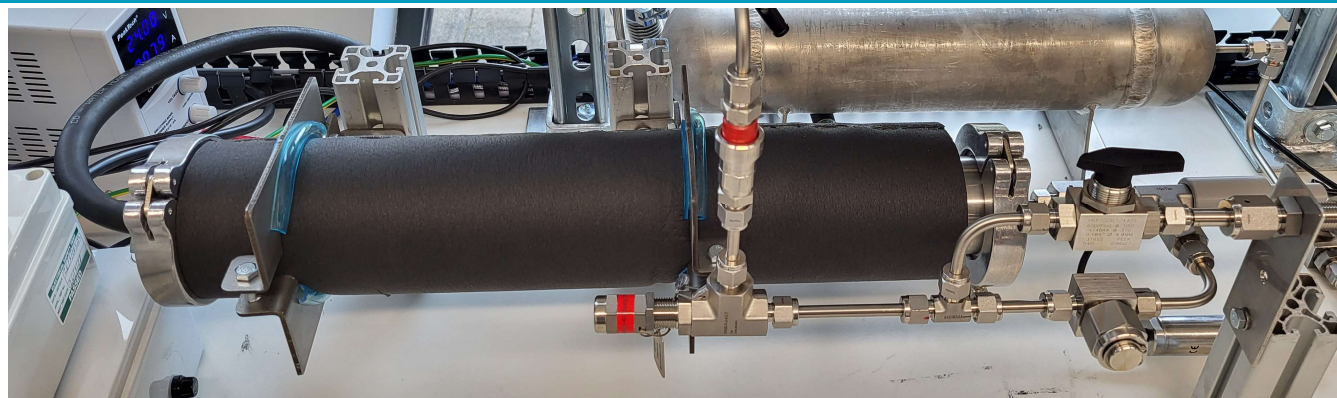


David

Tugba



- New Metal Hydride (MH) compressor built to 350 bar
- Cone and thread
- MH mass 60- 80 g

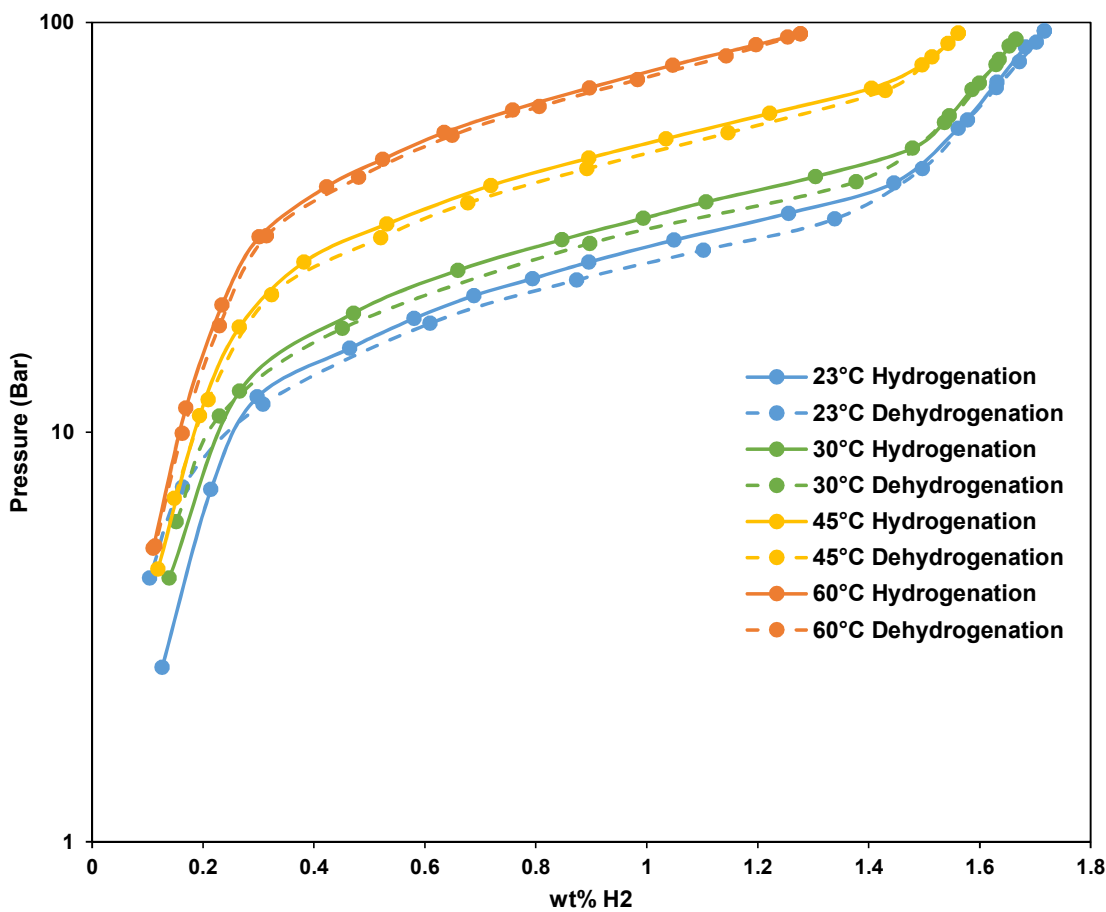




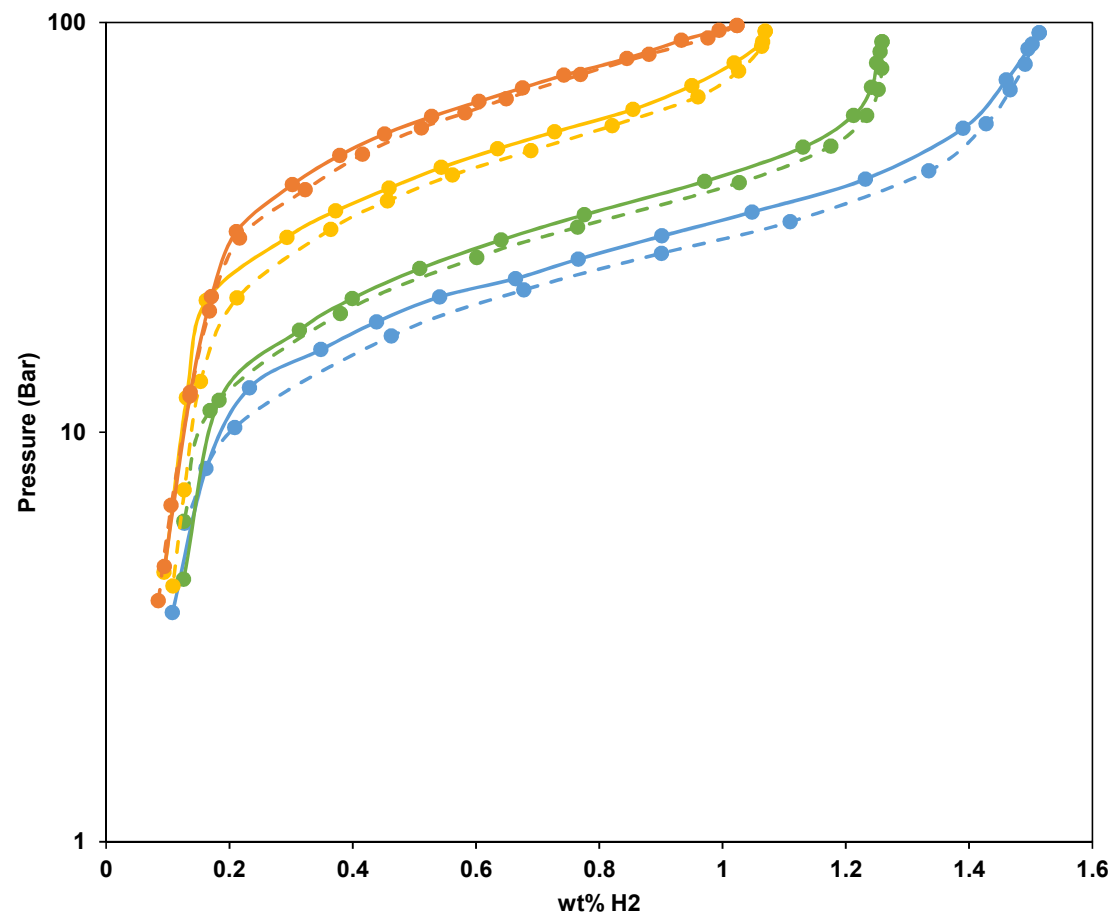
- Materials comparison completed
- Automated rig fully operational – progressing to cycling of materials
- Testing of hydrides with H₂O contaminated H₂ to determine capacity loss and potential fixes (50ppm and 100ppm to test)
- Research into pellets for both cycling and impurity



402 – $\text{Ti}_{0.77}\text{Zr}_{0.3}\text{Cr}_{0.85}\text{Fe}_{0.7}\text{Mn}_{0.25}\text{Ni}_{0.2}$

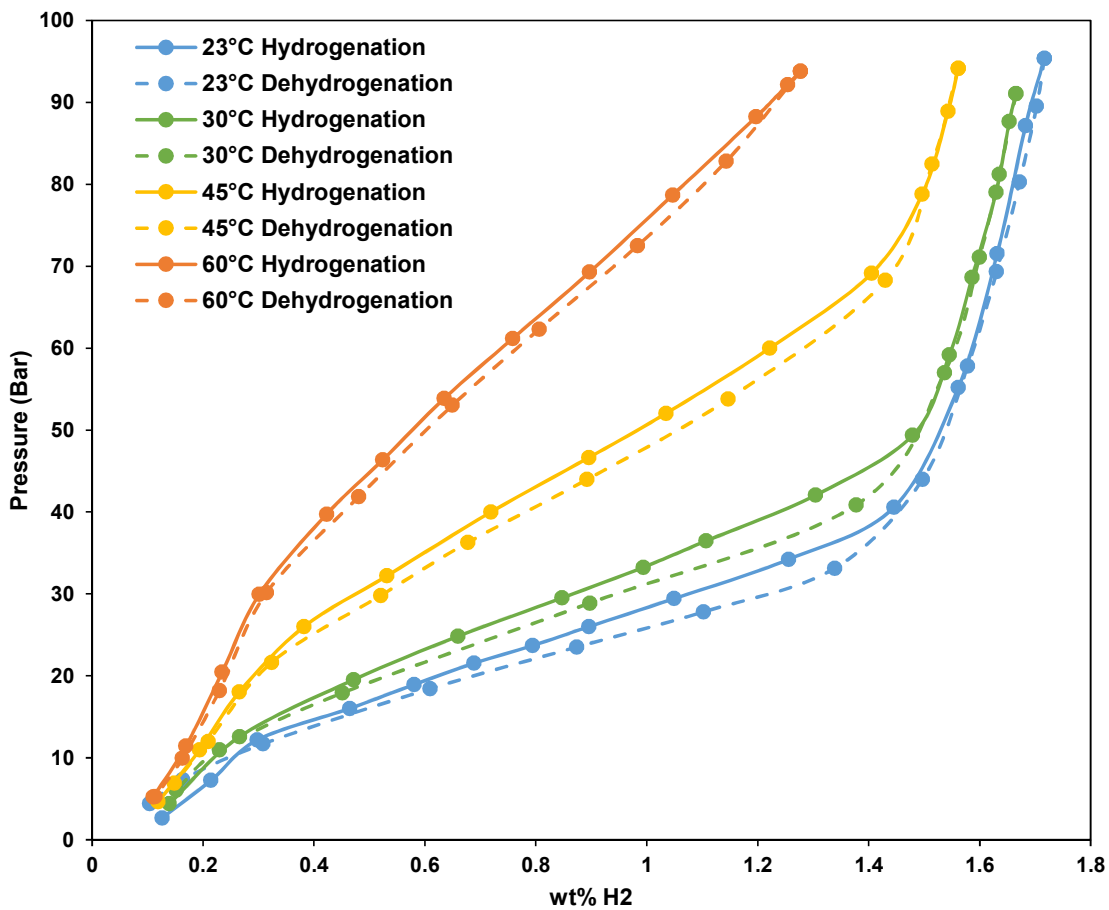


402HT – Same Composition

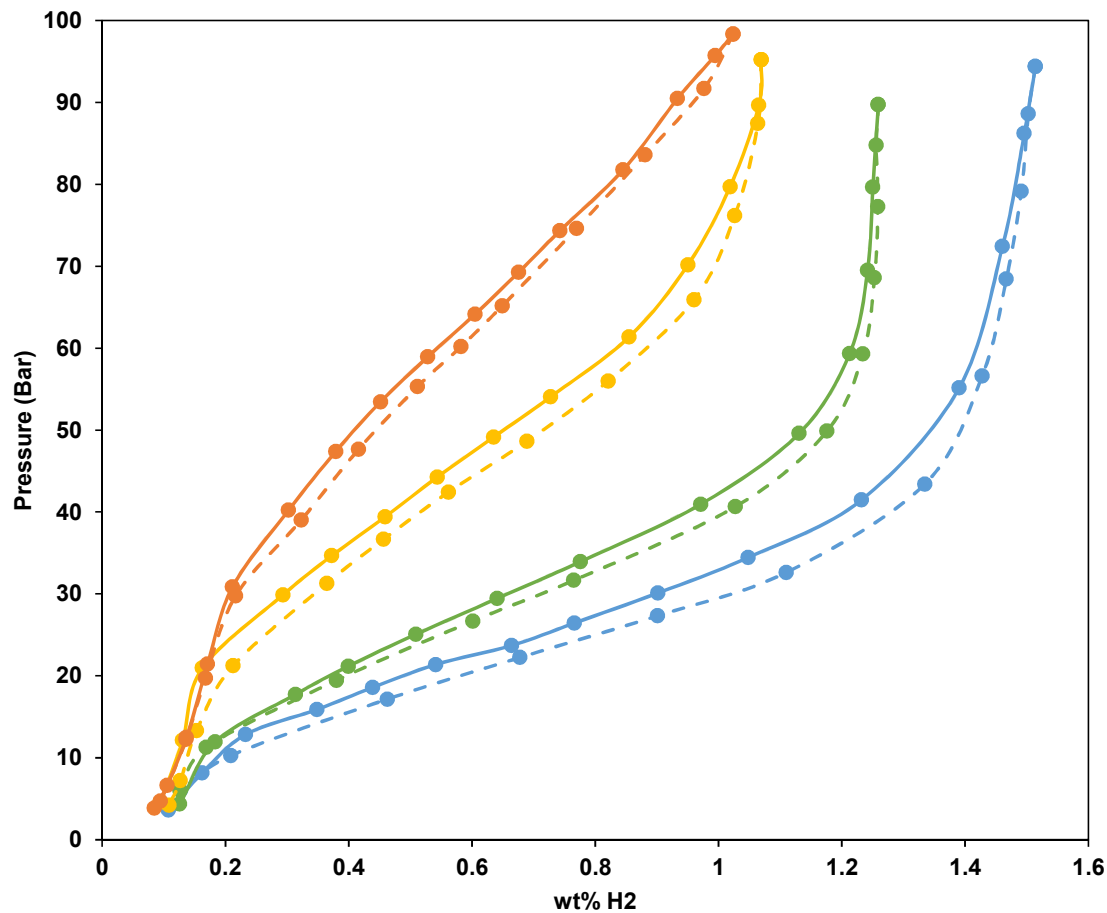




402 – $\text{Ti}_{0.77}\text{Zr}_{0.3}\text{Cr}_{0.85}\text{Fe}_{0.7}\text{Mn}_{0.25}\text{Ni}_{0.2}$

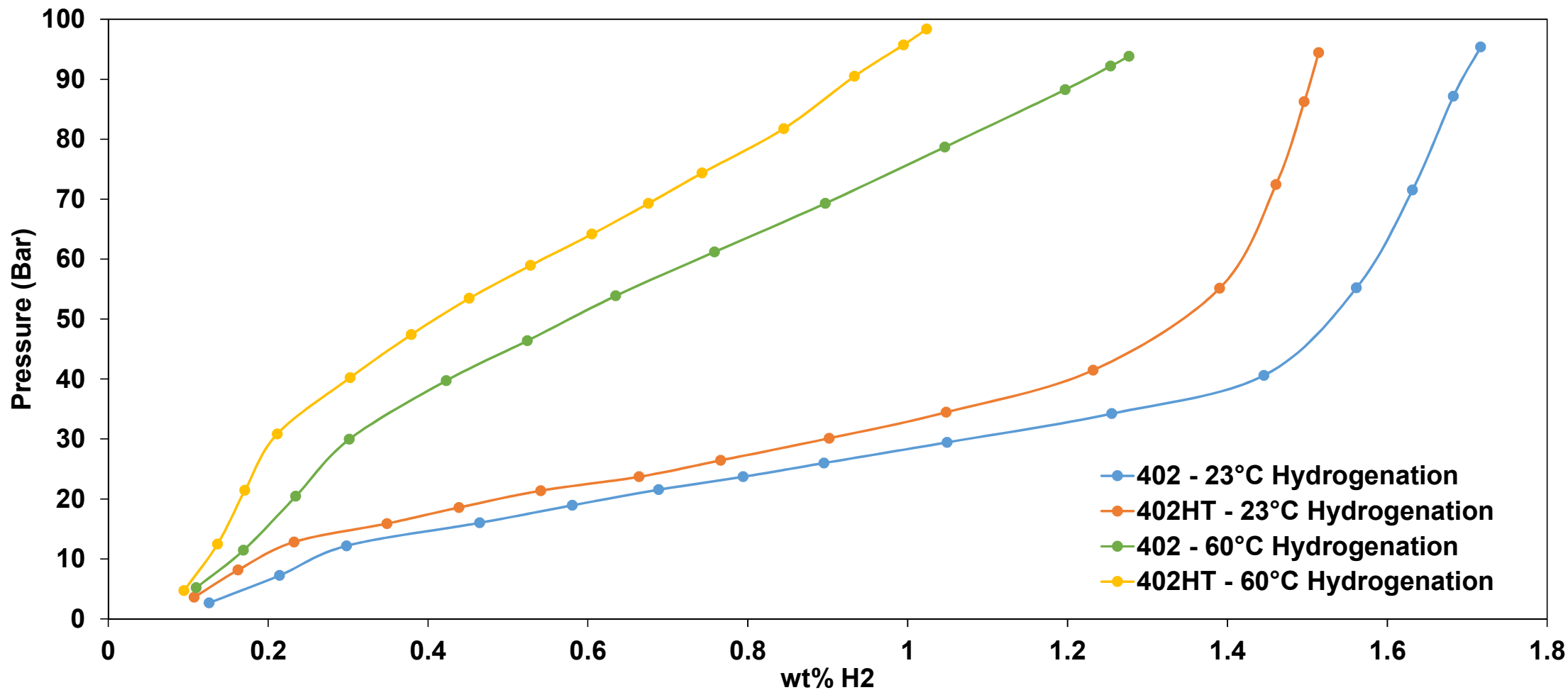


402HT – Same Composition



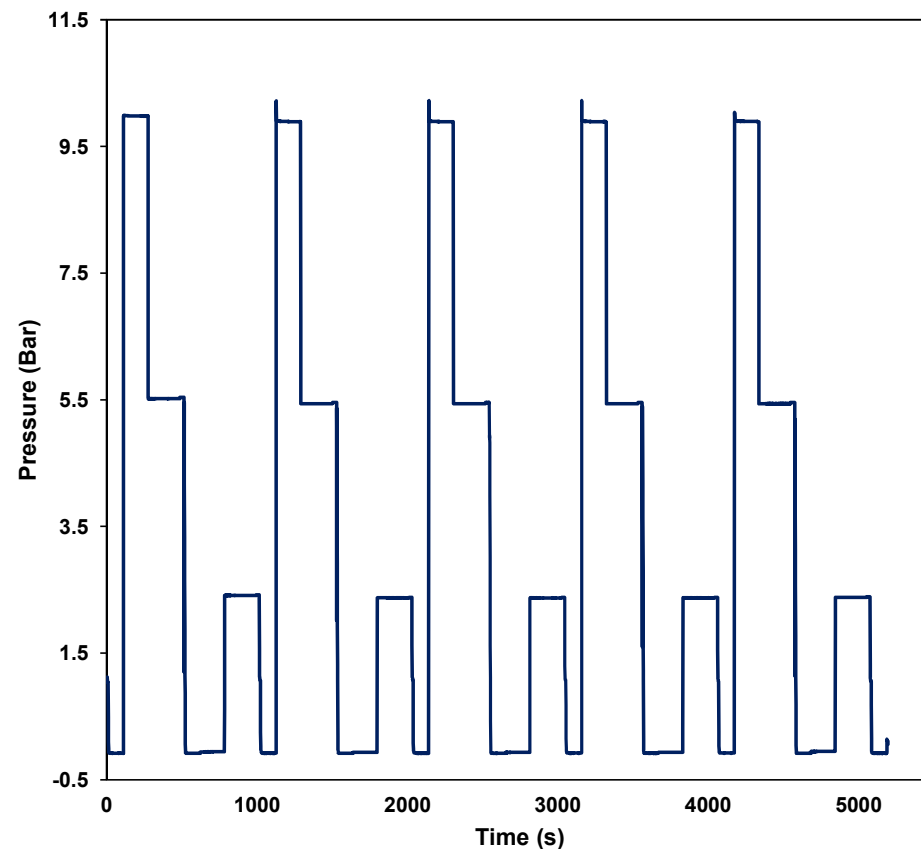
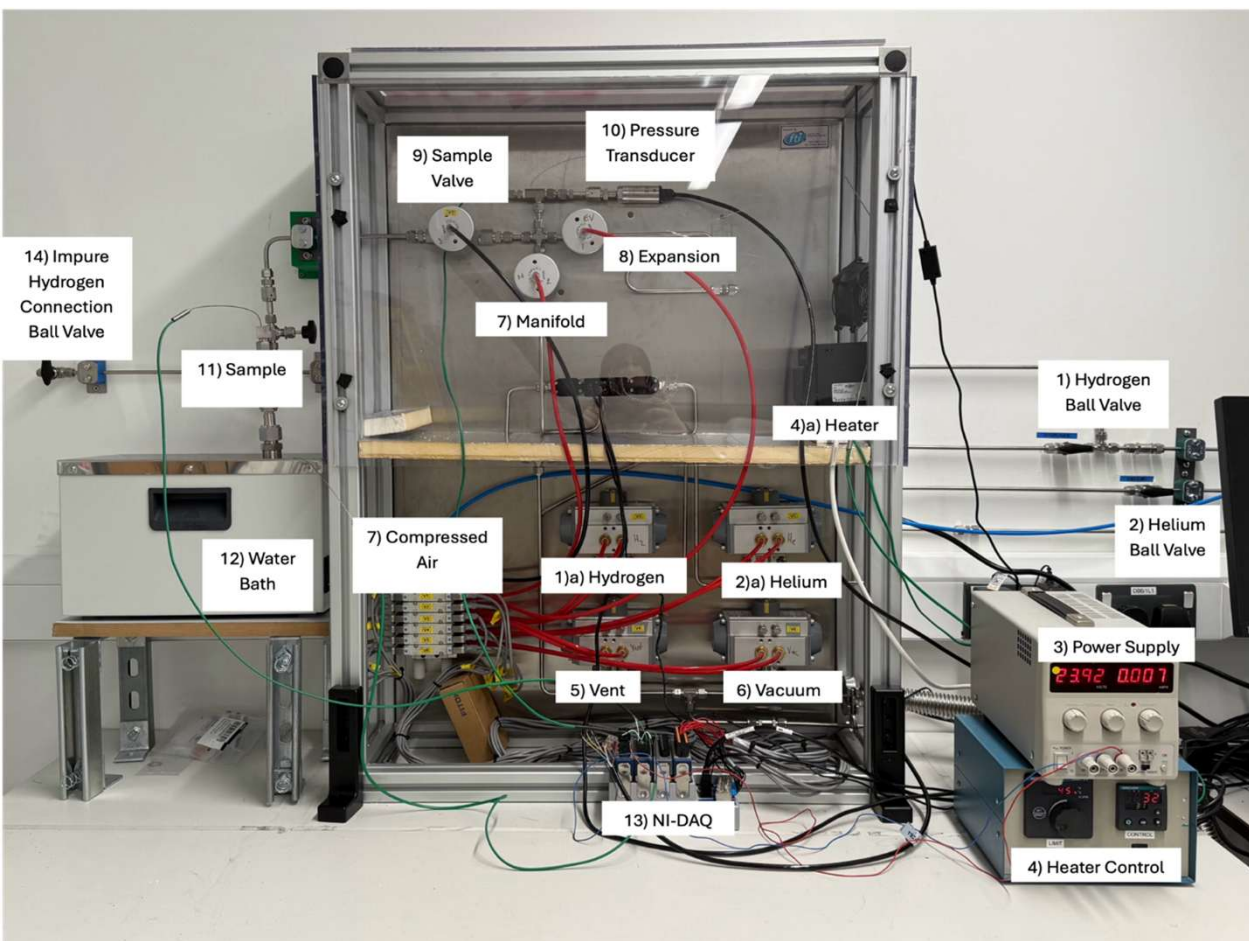


PCI Comparison





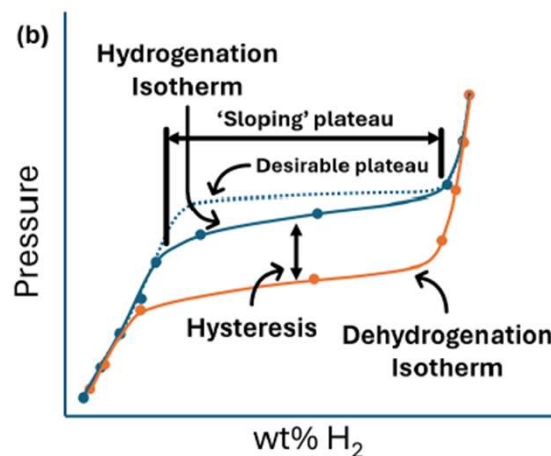
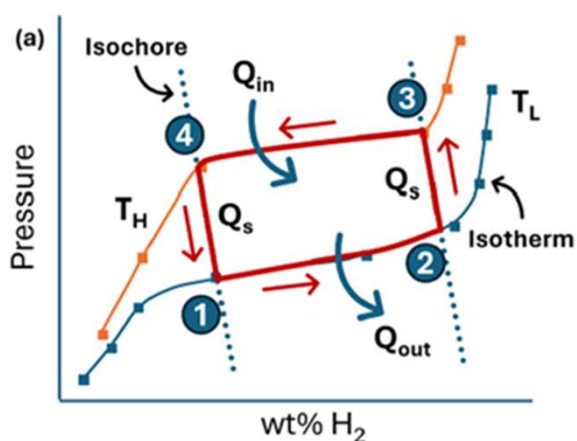
Cycling Equipment Overview





| Reactions | H ₂ (wt %) | Dehydrogenation Conditions | Rehydrogenation Conditions |
|---|-----------------------|----------------------------|----------------------------|
| (1) $3\text{NaAlH}_4 \rightleftharpoons \text{Na}_3\text{AlH}_6 + 2\text{Al} + 3\text{H}_2$ | 3.7 | 200 - 230 °C , 3-6 h | >200°C, >100 bar |
| (2) $\text{Na}_3\text{AlH}_6 + 2\text{Al} + 3\text{H}_2 \rightleftharpoons 3\text{NaH} + 3\text{Al} + 9/2 \text{H}_2$ | 1.9 | 250 - 275 °C, 10-20 h | 160-200°C , 100-150 bar |

H₂ Metal hydride Hydrogen Compressor Cycle



- 1–2: Isothermal compression for **Hydrogenation**
- 2–3: Sensible heating from TL to TH.
- 3–4: Isothermal expansion: **Dehydrogenation**
- 4–1: Sensible cooling from TH to TL.



- ✓ **Mild operating conditions**
1–3 bar, room temperature
- ✓ **Enhanced H₂ transfer**
- ✓ **Higher reaction efficiency**
- ✓ **Energy & cost savings**
Reduced pressure and heating needs
- ✓ **Option for H₂ transport in pipelines**



Dehydrogenation and re-hydrogenation of NaAlH₄

Slurry preparation

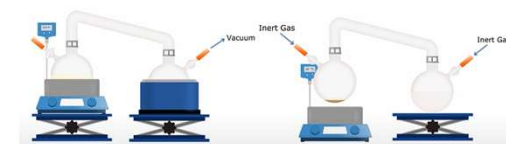
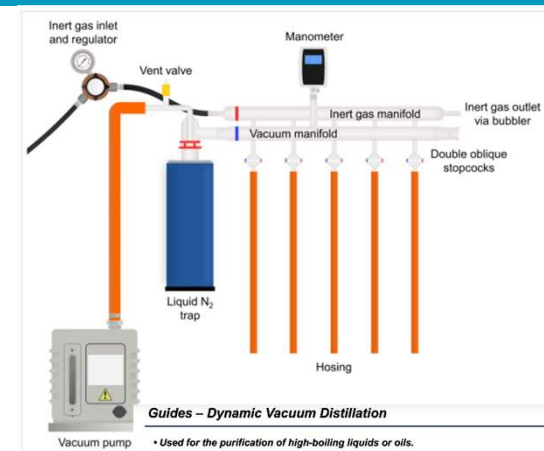
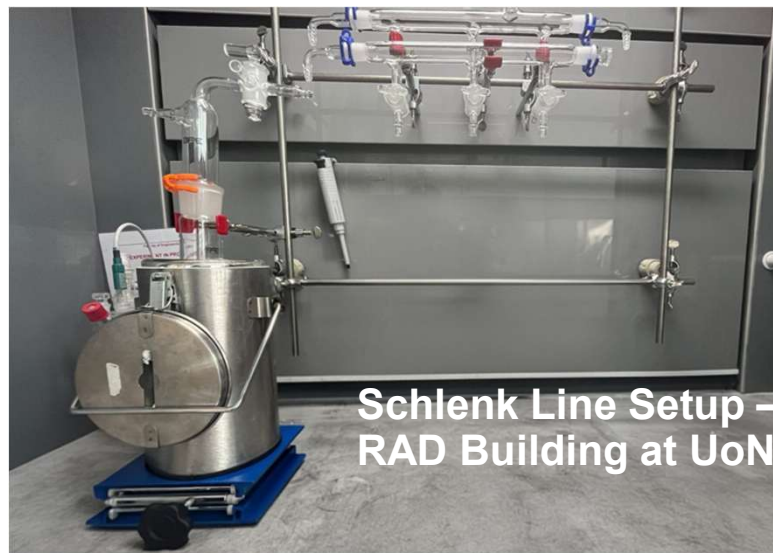
| Solvent type | Inertness | Cavitation Intensity | Approx. Cost |
|--------------|-------------|----------------------|--------------|
| FC40/PFCs | Absolute | High | \$150-80/L |
| Silicone Oil | High | Low-Medium | \$20–50/L |
| Mineral Oil | Medium | Medium | \$3–15/L |
| Glycerol | High | Very High | \$5 – 20/L |
| PEG 400 | Medium-High | Medium | \$20- 70/L |

Ultrasound Reactor

- To avoid contamination of complex hydrides from air and moisture, solvent drying is frequently applied via Schlenk line.
- Try mixture of solvents above



- Complete Schlenk Line (Sensors, pumps, glassware)



- H₂ Sorption – Desorption test in the Ultrasound Rig using synthesized NaAlH₄ in dried silicone oil, and other solvents.
- H₂ Sorption – Desorption test for Mg + Si reaction system.



University of
Nottingham
Energy Institute

UoN
Hydrogen Research

Any questions?

Comfort Break



WP4 - Ammonia, Carboniferous H₂, Overall System Optimisation

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.

This WP addresses:

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

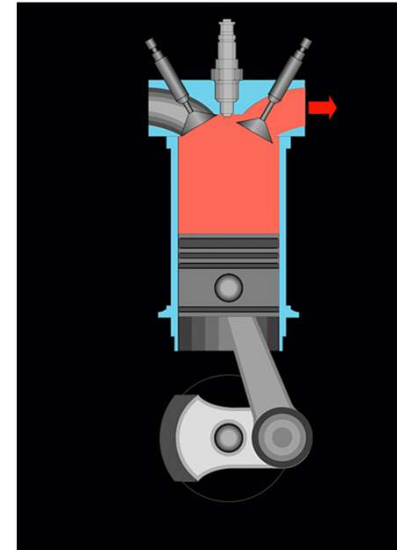
WP4.2. 'Carboniferous' Hydrogen Supply

WP4.5. Overall System Optimisation

Q3.3 TSI Engine

Fueled with NG, NH₃ and H₂ Blends

PROGRESS UPDATE



Dr M. Alnajideen
AlnajideenMI@cardiff.ac.uk



Professor A. Valera-Medina
ValeramedinaaI@cardiff.ac.uk





- Participated in the 4th SoAE (Minnesota, USA, 28 Sep–2 Oct 2025), presenting engine fuel-blend modelling, showcasing the engine setup, and disseminating the OceanREFuel project.
- A journal paper (ACS Energy & Fuels) and a Book Chapter (Springer Nature) to cover ICE fuelled NH₃/H₂ – from data presented from the previous stakeholders meeting, Nottingham 9th Sep 25.
- A review paper for Progress in Energy and Combustion Science (Elsevier, IF 37, CS 73) under review.



4th Symposium on Ammonia Energy

Whova Leaderboard Ranking







Celebrating the most active members of the community at
4th Symposium on Ammonia Energy



Rank
1







Our Progress [September 25 to March 2026]

1/2

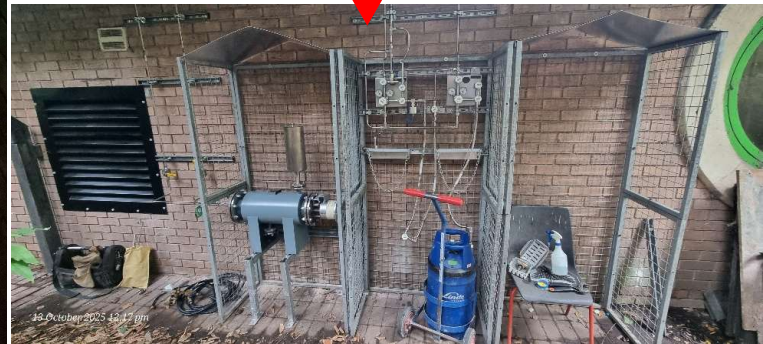
-  A new NG pipeline has been installed, tested, and certified, including a gas interlock and safety system integrated with the extraction, fire alarm, and gas detection systems, all connected to the Engine Main Control Panel; remaining work includes linking the automatic fire damper louvres in the engine room by 27 March (Styles Electrical).
-  Full $\text{NH}_3/\text{H}_2/\text{CH}_4/\text{N}_2$ fuel lines from storage cages to the engine bay have been installed, helium-tested, and certified—ready for fuelling; the storage area has been upgraded with site clearance, new plinth and wall barrier, and fuel cages.
-  Lab extraction system upgraded with new ductwork separating ventilation (louvre air extraction) from engine exhaust, preventing gas recirculation; a dedicated ambient air intake system has been installed and connected to the engine, alongside a new compressed air line to the engine room, enabling controlled AFR adjustment for upcoming tests.
-  All engine-related electrical, communication, and sensor systems have been installed, tested, and commissioned; the engine is connected to NG fuel line, and the generator is linked to a 3-phase load bank—ready for power generation.
-  Engine serviced, including replacement of oil, coolant, and fuel and air filters.
-  Engine room upgraded with fire-resistant boards, Rockwool insulation, and acoustic panels to meet ATEX Category 3 requirements; ready for GDS installation of ATEX-compliant gas detection system; air blower and CCTV to be installed for ventilation control and remote monitoring, enabling operation with the engine canopy locked by 24 April (GDS Ltd).

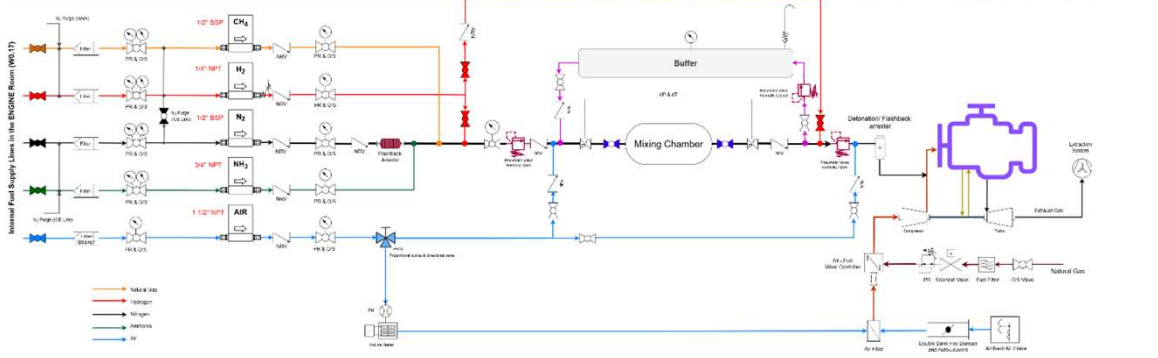
Our Progress [September 25 to March 2026]

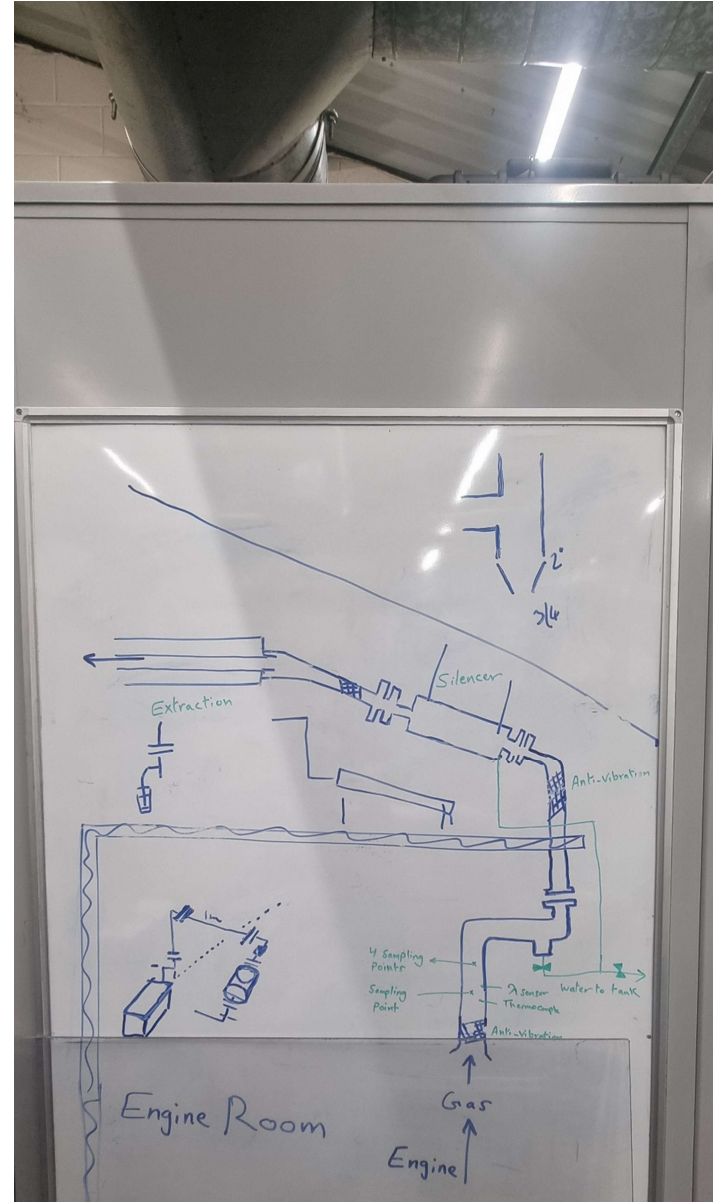
2/2

-  Engine operated at $\sim 110 \text{ kW}_{\text{th}}$ with a 32 kVA load bank; condensate in the exhaust prompted safety-driven upgrades, including water traps and drainage to an aqua ammonia-compatible tank; further upgrades to the exhaust–extraction interface are ongoing with sensors and anti-vibration joints installed, pipe lagging and gaskets being applied, and the silencer being relocated above the engine canopy in a redesigned configuration integrating water traps – by 24 April.
-  **ENGINE** is now Operational; however, completion of the upgraded exhaust–extraction connection is the immediate priority, while parallel works and controlled operation will continue, targeting completion by 15 May.
-  All MFCs acquired and calibrated; pressure regulators and internal pipeline fittings prepared, with final connections pending delivery of remaining materials by 30 April; structural supports for fuel trains, battery enclosure, and lighting are now in place.
-  Safety measures implemented, including pH meter, NH_3/H_2 leak detection (tapes and alarms), fuel line identification, and electrical labelling; all COSHH and risk assessments approved; comprehensive operating and emergency procedures (incl. DESAR and HAZOP) in preparation, with NG procedures already completed.
-  Further R&D includes acquisition of an in-cylinder pressure amplifier, replacement of the turbocharger with a catalytic converter and NH_3 cracker for CHP applications, and integration of an H_2 electrolyser for fuel supply—aligned with OceanREFuel, AgriCHP, and EPSRC Critical Mass for real-world testing in relevant environments.
-  **NOTE:** Two incidents last year led to temporary lab closure: (1) hydrogen leak from the main H_2 cylinder manifold (component replaced), and (2) fallen trees impacting the roof close to fuel lines; both issues have now been fully resolved.

Canolfan Rhagoriaeth ar Dechnolegau Amonia
Centre of Excellence on Ammonia Technologies











[Run video](#)

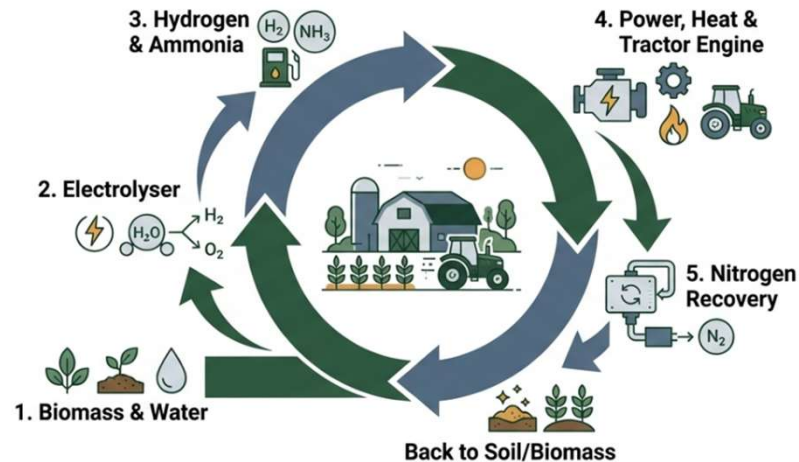


AgriCHP Clean Farm Energy
Circular Economy in Rural Wales

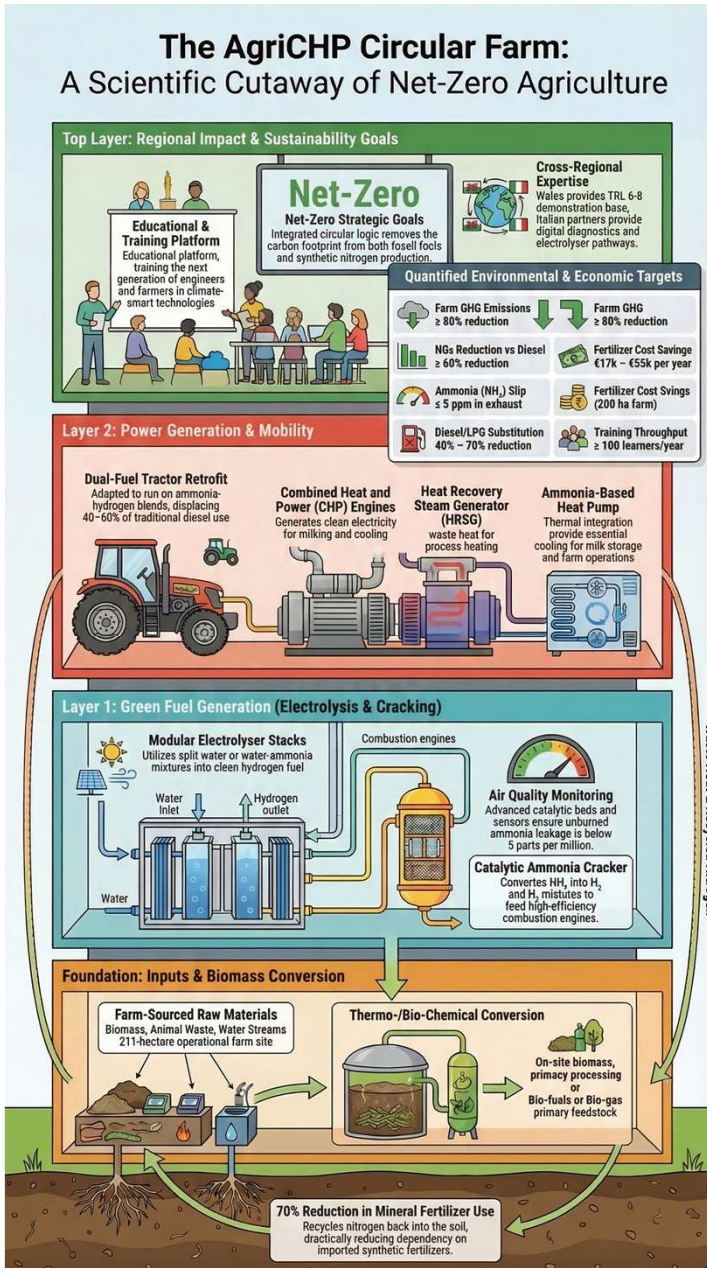
Awarded

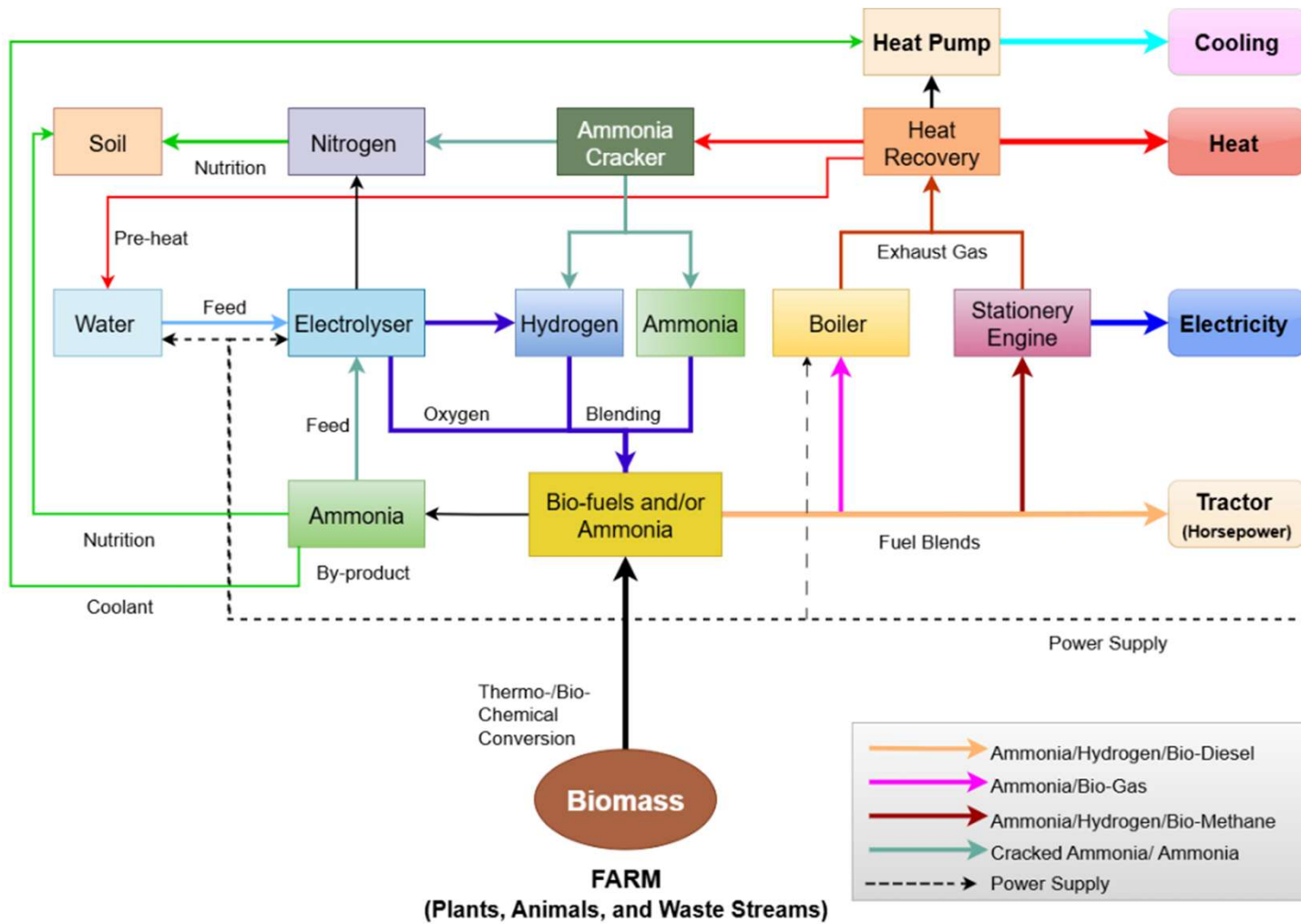
- AgriCHP-Clean-Farm-Energy project is a pioneering circular economy initiative designed to redefine the agricultural energy landscape. TRL 6 to 8.
- Moving beyond the limitations of standalone renewables, AgriCHP establishes a "first-of-its-kind" integrated system where on-site biomass, water, and waste streams are converted into a suite of high-value utilities.
- This project is not merely as a technical assembly, but as a holistic "closed-loop" model that empowers farms to become self-sustaining energy hubs.

Closing the Loop: Zero Waste, Total Energy Autonomy



Every byproduct becomes a feedstock. The system generates renewable NH₃/H₂, replaces fossil diesel, and recycles exhaust nitrogen directly into agricultural fertiliser.





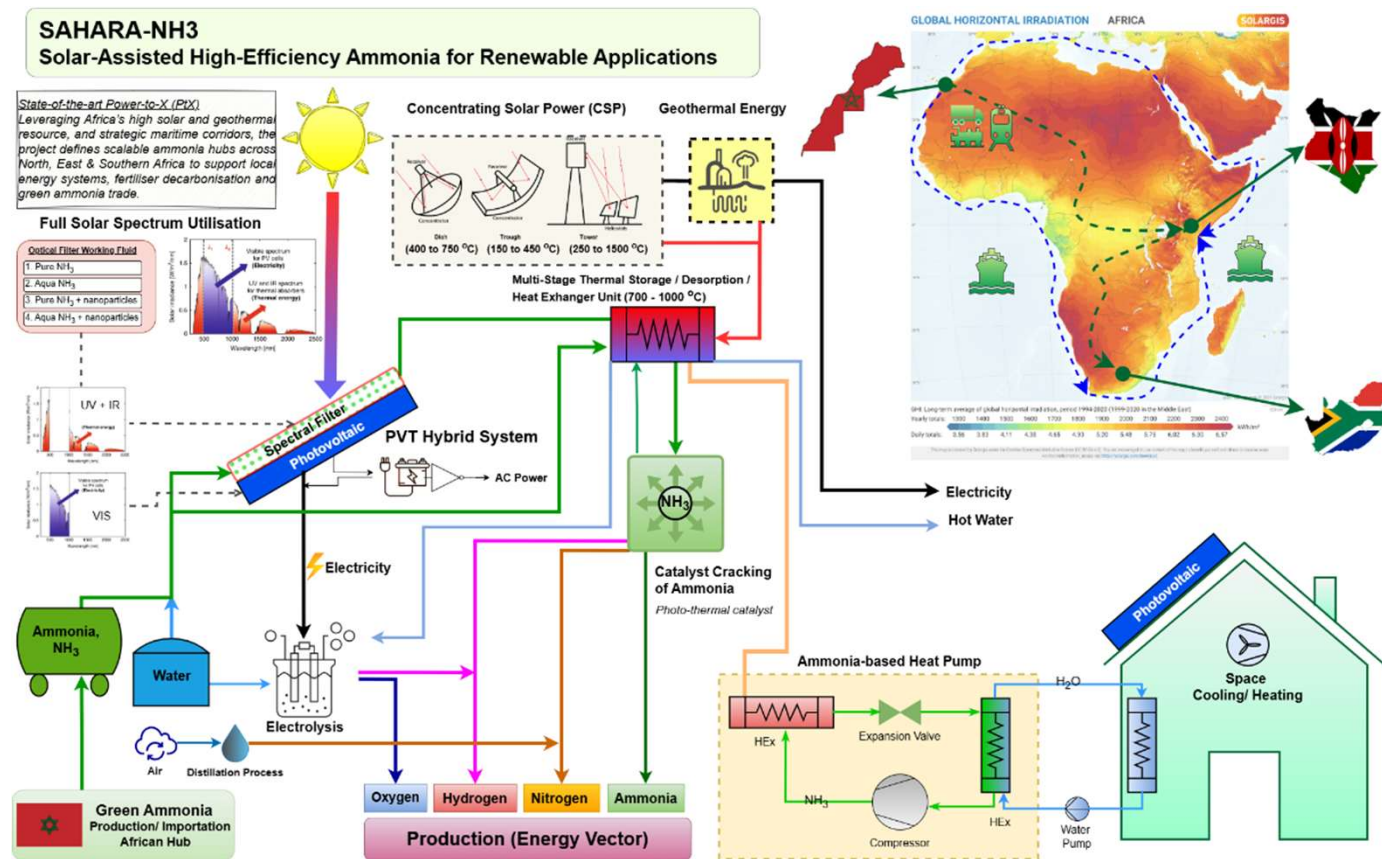
"To enable energy-self-sufficient, net-zero farms through integrated circular energy and nutrient flows, delivering reliable power, heat, cooling and fertiliser on site while building skills and industrial capacity across regions"

SAHARA-NH3: Solar-Assisted High-Efficiency Ammonia for Renewable Applications

- The overall objective of SAHARA-NH3 is to develop, model and experimentally validate an integrated, solar-assisted ammonia-based energy concept that maximises energy recovery across the renewable-to-end-use value chain.
- The project enables the decentralised production and co-utilisation of hydrogen, heat and residual ammonia to deliver electricity, heating, cooling and fertiliser-relevant services in off-grid and weak-grid African contexts.

United Kingdom (TRL 2-6); Morocco (TRL 3-5); Italy (TRL 4-5); Kenya (TRL 3-5); South Africa (TRL 4-6); and Germany (TRL 1-3).

UK will be funded by UKRI



Under Review



Latest Publications (Sep 25 to date)



Article
Effect of Illumination Colour on the Growth and Energetic Properties of *Chlorella vulgaris* for Bioenergy Applications

Pawel Czyzewski ¹, Przemyslaw Matuszak ¹, Marcelina Malecka ¹, Joanna Jojka ¹, Ahmad M. S. H. Al-Moftah ^{2,3}, Hao Shi ^{2,4,*}, Mohammad Alnajideen ^{2,*} and Agustin Valera-Medina ²

- ¹ Institute of Thermal Engineering, Poznan University of Technology, 60-965 Poznan, Poland; pawel.czyzewski@put.poznan.pl (P.C.); joanna.jojka@put.poznan.pl (J.J.)
- ² College of Physical Sciences and Engineering, Cardiff University, Cardiff CF24 3AA, UK; al-moftaha@cardiff.ac.uk (A.M.S.H.A.-M.); valeramedina1@cardiff.ac.uk (A.V.-M.)
- ³ Qatar National Research Fund (QNRF), Qatar Foundation, Doha P.O. Box 5825, Qatar
- ⁴ Cambridge CARES, University of Cambridge, 1 Create Way, Singapore 138602, Singapore
- * Correspondence: hao.shi@cares.cam.ac.uk (H.S.); alnajideenmi@cardiff.ac.uk (M.A.)



Energy
Volume 330, 1 September 2025, 136735



Modeling and optimization of ammonia/hydrogen/air premixed swirling flames for NOx emission control: A hybrid machine learning strategy

Hao Shi ^{a,b}, Zebang Liu ^a, Syed Mashruk ^a, Mohammad Alnajideen ^a, Ali Alnasif ^{a,c}, Jing Liu ^d, Agustin Valera-Medina ^a



Fuel
Volume 422, 15 October 2026, 139162



Full Length Article
Comparative numerical study of premixed and non-premixed burners for an ammonia-fueled micro gas turbine

Mohsen Fatehi ^a, Mohammad Alnajideen ^b, Massimiliano Renzi ^a, Agustin Valera Medina ^b

- ^a Free University of Bolzano, NOI Techpark-Bruno Buozzi St.,1, Bolzano 39100, BZ, Italy
- ^b Cardiff University, College of Physical Sciences and Engineering, Cardiff CF243AA, Wales, UK



Fuel
Volume 403, 1 January 2026, 136746



Full Length Article
Exploring the potential of ammonia as a fuel: Advances in combustion understanding and large-scale furnace applications ☆

Sven Eckart ^{a,b}, Ernesto Salzano ^{b,c}, Andreas Richter ^d, Mohammad Alnajideen ^e, Agustin Valera-Medina ^e, Krishna Prasad Shrestha ^f, Ahmed Yasiry ^{g,h}, Jinhua Wang ^h, Florian Bauer ⁱ, Chunkan Yu ^j, Hartmut Krause ^a, Gianmaria Pio ^c



Fuel
Volume 407, Part C, 1 March 2026, 137462






Full Length Article
Numerical investigation of combustor inlet temperature effects on emissions and performance in non-premixed ammonia-fueled micro-gas turbines



Mohsen Fatehi ^a, Mohammad Alnajideen ^b, Jacopo Carlo Alberizzi ^a, Massimiliano Renzi ^a, Agustin Valera-Medina ^b

April to May, 2026



Complete Installation & Infrastructure

-  Modify exhaust-duct connection
-  Install water traps, aqua ammonia tank, heated sampling line
-  Apply pipe lagging & integrate DAQ sensors




Fuel & Safety Systems

-  Finalise internal fuel train integration
-  Install gas monitoring, CCTV & HSE alarm systems

Engine Commissioning & Testing



-  Continue operation on CH₄ for benchmark validation
-  NH₃-CH₄ blends testing: June 2026

Funding & Dissemination



-  Submit Horizon funding application and KTP/CDT
-  Finalise and submit pending papers (x6)
-  A Dissemination Plan has been discussed with Mark.

June 2026 - Onwards

Transition towards AgriCHP-focused implementation and demonstration (TRL 6-8) in a real-world application

-  Mo continues voluntary support for OceanREFuel
-  Align with AgriCHP objectives to deliver our system-level contribution, supporting the OceanREFuel project.

R&D Development

-  Implement in-cylinder optical diagnostics
-  Integrate the engine with the NH₃ cracker, heat pump system, H₂ electrolysis, biomass boiler, and NO_x nutrient loop for fertiliser production.

Engagement & Collaboration

-  You are invited to visit our LAB upon engine readiness.
-  You are welcome to visit AgriCHP demonstration site in Wales (early next year).
-  We are keen to support you in upcoming funding calls.



Canolfan Rhagoriaeth ar Dechnolegau Amonia
Centre of Excellence on Ammonia Technologies

Thank you



5th SYMPOSIUM on
AMMONIA ENERGY

**3rd LATAM MEETING ON GREEN
AMMONIA AND POWER-to-X**

September 28th - 30th, 2026 | Santiago, Chile

R G **9th Rostock Large Engine Symposium**
The Future of Large Engines IX
M T October 13-14, 2026 • Yachthafenresidenz Hohe Düne



University of
Nottingham
UK | CHINA | MALAYSIA



Engineering and
Physical Sciences
Research Council



School of Engineering
Ysgol Peirianeg





WP4.2 – ‘Carbonaceous’ H₂

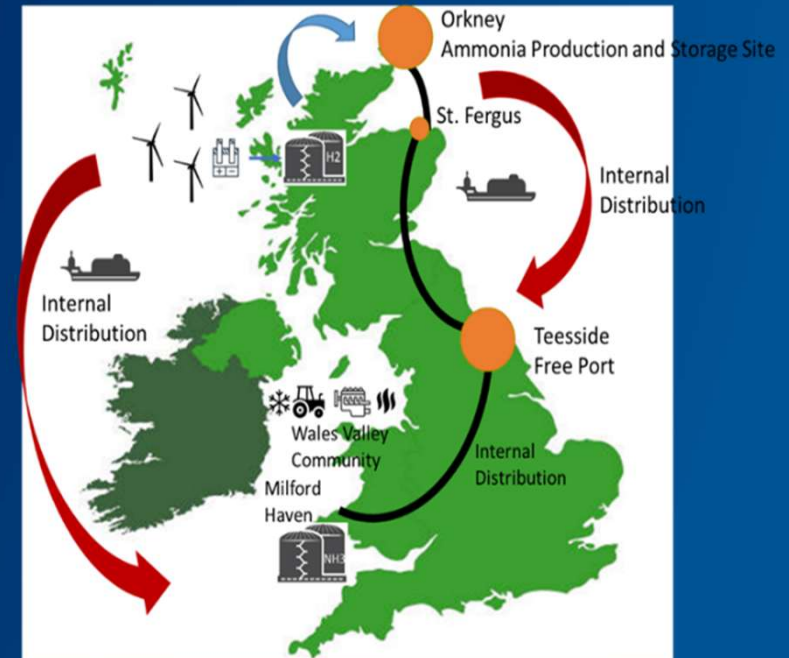


H₂-based systems may be able to move to 100% initially but other scenarios may favour the use of intermediate (high) blends in early operation.

Most likely in regions with one main gas feeder.

What range of operation is possible for burners designed/optimized for one gas, when operated on a different blend.

Previous work is on low H₂ percentages. We are exploring the higher ranges



Robin Irons and Haiqin Zhou

Ocean REFuel

WP4.5. OVERALL
SYSTEM OPTIMISATION

STRAWMAN CASE STUDY

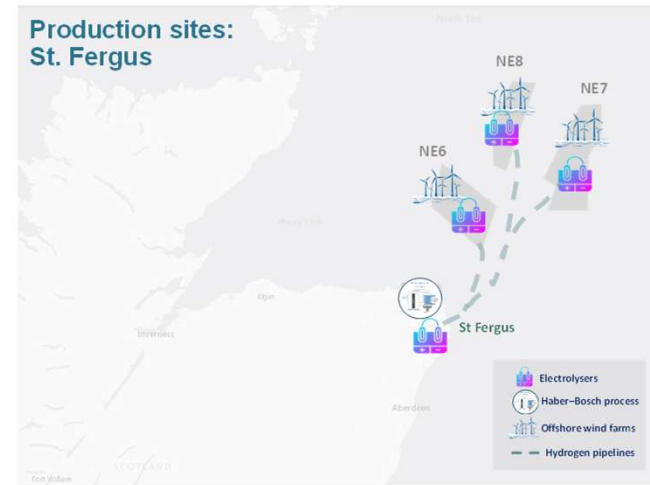
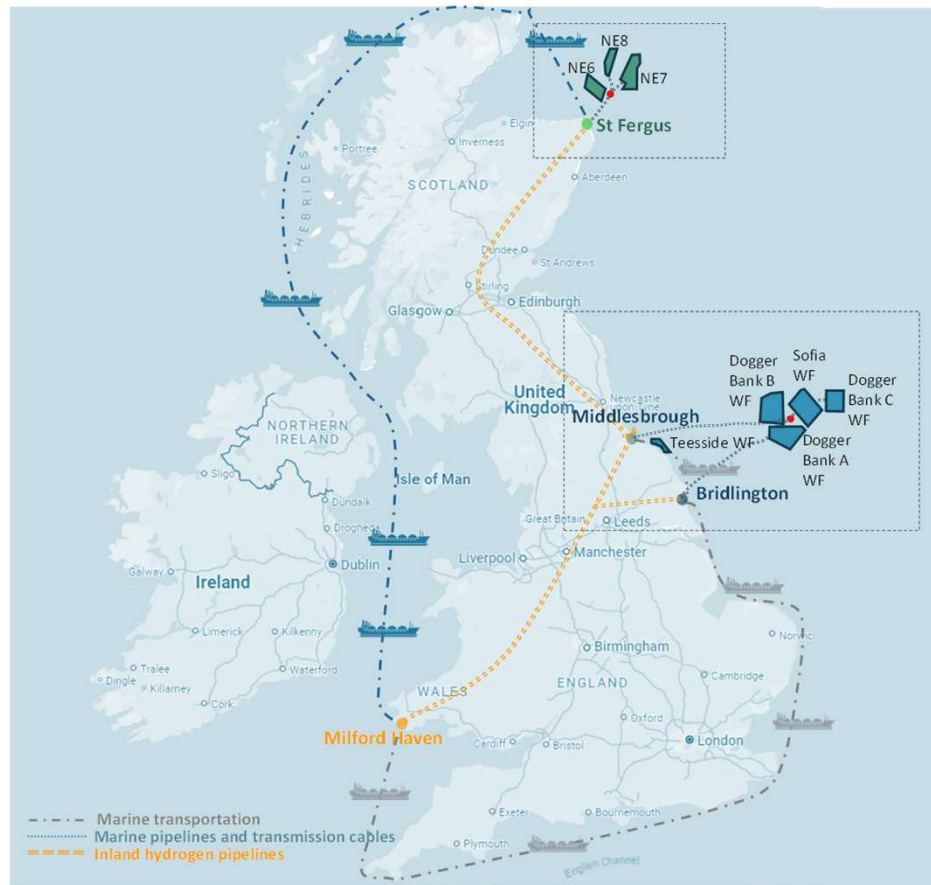


Figure 1. UK North Sea offshore wind-hydrogen system configuration. The map shows offshore wind developments across three corridors connecting to St Fergus, Bridlington, and Middlesbrough. Marine transportation routes (dashed blue) indicate seaborne transport pathways. Marine pipelines and transmission cables (dotted blue) represent subsea infrastructure. Inland hydrogen pipelines (dashed orange) connect hubs to Milford Haven. Insets detail production sites near St Fergus (floating platforms) and Teesside (fixed foundations). Symbols indicate electrolysers (purple), and offshore wind farms (grey turbines)

Updates to the previous work

- **Temporal Resolution Upgrade**

Previous model used a single average representative month (730 hours) derived from a 1 GW generic wind from a previous project

New model operates at full-year hourly resolution (8,760 time steps), capturing seasonal variability and realistic capacity factor distributions

Wind power conversion script was entirely rewritten to process ERA5 reanalysis wind-speed data for each of the six wind farms separately, using site-specific power curves

- **Model Scale**

In the range of 9.6 million constraints and 5.5 million variables following the temporal resolution upgrade

Solved on the Imperial College London HPC cluster using GAMS with CPLEX solver

- **Results**

Final results are not significantly changed relative to the 730-hour runs

The revised model now rests on a substantially more robust and reproducible methodological foundation, strengthening the credibility of all reported LCOH and LCOA values

Sensitivity with respect to Configurational Decisions: Results Table

| Scenario | Wind Platform Technology | Electrolysis Location | Offshore-to-Shore Energy Transmission | Ammonia Synthesis Location | Storage Technology at Coastal Terminal | Terminal-to-Demand Transport Infrastructure | Life Span | Levelised Cost (£/kg) | Levelised Cost (£/MJ) |
|----------|--------------------------|-----------------------|---------------------------------------|------------------------------|--|---|-----------|-----------------------|-----------------------|
| #1 | Fixed + Floating | Onshore Terminal | Electricity via Marine Cable | No conversion | Compressed H ₂ in Salt Caverns | Inland H ₂ Pipeline to Milford Haven | 15 | 12.243 | 0.1020 |
| #2 | Fixed Bottom Only | Offshore Platform Hub | H ₂ via Marine Pipeline | No conversion | Compressed H ₂ in Salt Caverns | Inland H ₂ Pipeline | 15 | 8.813 | 0.0734 |
| #3 | Fixed Bottom Only | Offshore Platform Hub | H ₂ via Marine Pipeline | No conversion | Liquefied H ₂ Cryogenic Storage | Seaborne Ship Transport | 15 | 7.790 | 0.0649 |
| #4 | Floating Only | Offshore Platform Hub | H ₂ via Marine Pipeline | No conversion | Compressed H ₂ in Salt Caverns | Inland H ₂ Pipeline | 15 | 11.700 | 0.0975 |
| #5 | Floating Only | Offshore Platform Hub | H ₂ via Marine Pipeline | No conversion | Liquefied H ₂ Cryogenic Storage | Seaborne Ship Transport | 15 | 10.545 | 0.0879 |
| #6 | Fixed + Floating | Offshore Platform Hub | H ₂ via Marine Pipeline | No conversion | Compressed H ₂ in Salt Caverns | Inland H ₂ Pipeline | 15 | 9.205 | 0.0767 |
| #7 | Fixed + Floating | Offshore Platform Hub | H ₂ via Marine Pipeline | No conversion | Liquefied H ₂ Cryogenic Storage | Seaborne Ship Transport | 15 | 8.699 | 0.0725 |
| #8 | Fixed + Floating | Turbine-Integrated | H ₂ via Marine Pipeline | No conversion | Compressed H ₂ in Salt Caverns | Inland H ₂ Pipeline | 15 | 8.883 | 0.0740 |
| #9 | Fixed + Floating | Turbine-Integrated | H ₂ via Marine Pipeline | No conversion | Liquefied H ₂ Cryogenic Storage | Seaborne Ship Transport | 15 | 8.360 | 0.0697 |
| #10 | Fixed + Floating | Offshore Platform Hub | NH ₃ via Marine Pipeline | Offshore Haber-Bosch Process | Cryogenic Ammonia Storage | Seaborne Ship Transport | 15 | 1.562 | 0.0840 |
| #11 | Fixed + Floating | Onshore Terminal | Electricity via Marine Cable | Onshore Haber-Bosch Process | Cryogenic Ammonia Storage | Seaborne Ship Transport | 15 | 1.979 | 0.1064 |
| #12 | Fixed + Floating | Turbine-Integrated | NH ₃ via Marine Pipeline | Offshore Haber-Bosch Process | Cryogenic Ammonia Storage | Seaborne Ship Transport | 15 | 1.458 | 0.0784 |

Table 2. Levelised cost of delivered energy for offshore wind-hydrogen system configurations. All costs normalized to energy content (£/MJ) using lower heating values of 120 MJ/kg for hydrogen and 18.6 MJ/kg for ammonia. Life span represents weighted average component lifetime across system infrastructure. Scenarios #1-9 deliver hydrogen through compressed gaseous or liquefied pathways. Scenarios #10-12 deliver ammonia synthesized via Haber-Bosch process from offshore or onshore hydrogen production.

Sensitivity with respect to Configurational Decisions: Key Findings

- **Wind Foundation Technology**

Floating platforms impose a consistent 33–35% cost premium over fixed-bottom equivalents (S4 vs. S2: 11.700 vs. 8.813 £/kg; S5 vs. S3: 10.545 vs. 7.790 £/kg), representing the single highest-impact binary decision in the configuration space — unrecoverable by any downstream optimisation of electrolysis location, storage pathway, or transport mode.

- **Electrolysis Location**

Turbine-integrated electrolysis (S9, 8.360 £/kg) achieves lower cost than any mixed-fleet offshore hub configuration, demonstrating that eliminating both marine cables and centralised platforms outweighs the electrolyser scale penalty, though distributed units incur compressor costs approximately three times higher than any other hydrogen configuration.

- **Storage and Transport Mode**

Liquefied H₂ seaborne transport consistently outperforms compressed H₂ inland pipeline delivery across all electrolysis location categories by 5.5–12% (S3 vs. S2, S7 vs. S6, S9 vs. S8), because at UK North Sea distances inland pipeline capital cost exceeds the combined cost of liquefaction and marine shipping.

- **Hydrogen vs. Ammonia**

Hydrogen delivers a consistent energy-equivalent cost advantage of 4.3–12.5% over ammonia in every structurally paired comparison — offshore hub (S6 at 0.0767 vs. S10 at 0.0840 £/MJ), onshore terminal (S1 at 0.1020 vs. S11 at 0.1064 £/MJ), turbine-integrated (S9 at 0.0697 vs. S12 at 0.0784 £/MJ) — though ammonia infrastructure offers strategic offsets through ambient-pressure storage and established global shipping

Sensitivity with Respect to Economic Parameters: Tornado Diagrams

Scenario#1 (Baseline= 12.243 £/kg H₂)

| | | |
|--|--------|--------|
| Power Infrastructure CAPEX & OPEX (75%-125%) | 10.324 | 14.949 |
| Project Lifetime (10-20 Years) | 10.858 | 16.442 |
| Discount Rate (6%-10%) | 10.956 | 13.874 |
| Electrolzer Efficiency (50-60 kWh/kg) | 11.034 | 13.675 |
| Wind Turbine CAPEX & OPEX (75%-125%) | 11.410 | 13.077 |
| Wind Capacity Factor (85%-115%) | 11.600 | 13.115 |
| Inland H2 Pipeline CAPEX & OPEX (75%-125%) | 12.080 | 12.406 |
| Onshore Electrolyzer CAPEX & OPEX (75%-125%) | 12.106 | 12.389 |

Scenario#3 (Baseline= 7.790 £/kg H₂)

| | | |
|---|-------|-------|
| Project Lifetime (10-20 Years) | 6.968 | 9.558 |
| Discount Rate (6%-10%) | 7.029 | 8.594 |
| Wind Turbine CAPEX & OPEX (75%-125%) | 7.180 | 8.399 |
| Wind Capacity Factor (85%-115%) | 7.371 | 8.356 |
| Marine H2 Pipeline CAPEX & OPEX (75%-125%) | 7.596 | 7.984 |
| Offshore Electrolyzer CAPEX & OPEX (75%-125%) | 7.632 | 7.948 |
| Offshore Compressors CAPEX & OPEX (75%-125%) | 7.633 | 7.947 |
| Offshore Platform Civil CAPEX & OPEX (75%-125%) | 7.689 | 7.890 |

Scenario#9 (Baseline= 8.360 £/kg H₂)

| | | |
|--|-------|--------|
| Project Lifetime (10-20 Years) | 7.496 | 10.216 |
| Discount Rate (6%-10%) | 7.560 | 9.204 |
| Electrolzer Efficiency (50-60 kWh/kg) | 7.601 | 9.120 |
| Wind Turbine CAPEX & OPEX (75%-125%) | 7.669 | 9.052 |
| Offshore Compressors CAPEX & OPEX (75%-125%) | 7.822 | 8.898 |
| Wind Capacity Factor (85%-115%) | 7.946 | 8.920 |
| WT Electrolyzer CAPEX & OPEX | 8.155 | 8.565 |
| Marine H2 Pipeline CAPEX & OPEX (75%-125%) | 8.258 | 8.462 |

Scenario#12 (Baseline= 1.458 £/kg NH₃)

| | | |
|---|-------|-------|
| Project Lifetime (10-20 Years) | 1.309 | 1.777 |
| Wind Turbine CAPEX (75%-125%) | 1.347 | 1.569 |
| Discount Rate (6%-10%) | 1.365 | 1.668 |
| HB NH3 Synthesis Efficiency (85%-95%) | 1.390 | 1.533 |
| Wind Capacity Factor (85%-115%) | 1.397 | 1.539 |
| NH3 Processing, Storage & Shipping (75%-125%) | 1.416 | 1.499 |
| WT Electrolyzer CAPEX & OPEX (75%-125%) | 1.425 | 1.490 |
| Marine NH3 Pipeline CAPEX & OPEX (75%-125%) | 1.456 | 1.459 |

Figure 2. Tornado sensitivity diagram showing the influence of key techno-economic parameters on the levelised cost of hydrogen or ammonia for representative configurations.

Parameters are ranked by their impact on the baseline levelised cost when varied across their uncertainty range. Results show that financial parameters – project lifetime and discount rate – rank among the top three drivers across all four scenarios. In Scenario 1, power infrastructure capital and operating expenditure is the second-ranked driver, reflecting the dominance of marine transmission costs in that configuration. Wind farm capital costs and capacity factor

Sensitivity with Respect to Economic Parameters: Key Findings

- **Cross-Scenario Pattern**

Financial parameters — project lifetime and discount rate — rank among the top three cost drivers in every configuration irrespective of architecture, with wind farm performance consistently in the upper half of every tornado diagram, while configuration-specific infrastructure components generate comparatively narrow sensitivities and no individual parameter perturbation reverses the relative cost ordering across configurations.

- **Configuration-Specific Findings**

Power infrastructure CAPEX+OPEX ranks second in Configuration 1 (swing 4.625 £/kg), reflecting marine cable dominance; electrolyser efficiency rises to third in Configuration 9 due to loss of economies of scale in turbine-integrated units; and Haber-Bosch synthesis efficiency enters as a new fourth-ranked driver in Configuration 12, while the marine ammonia pipeline is essentially insensitive across its full range.

Cost Breakdown: Stacked Bar Chart

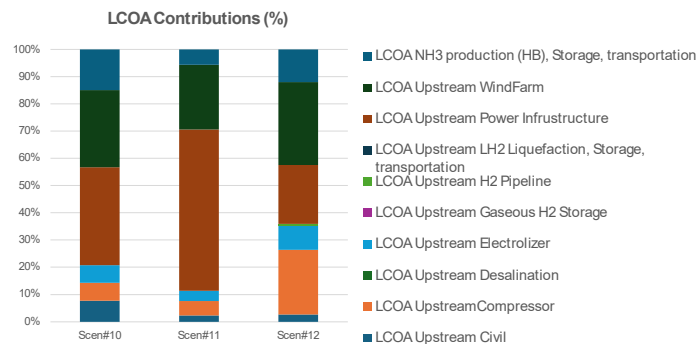
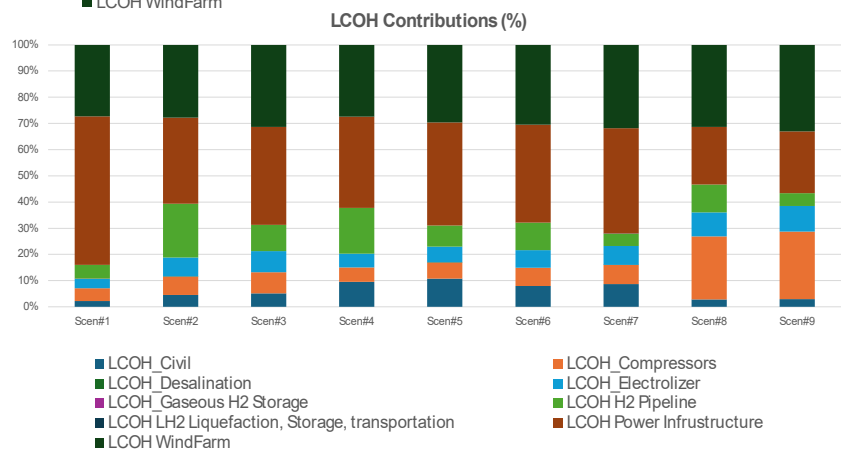
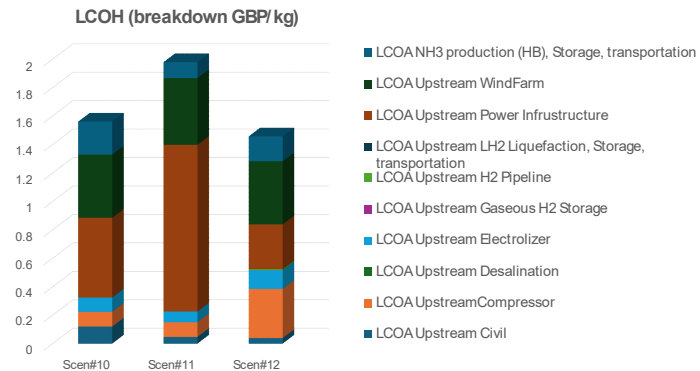
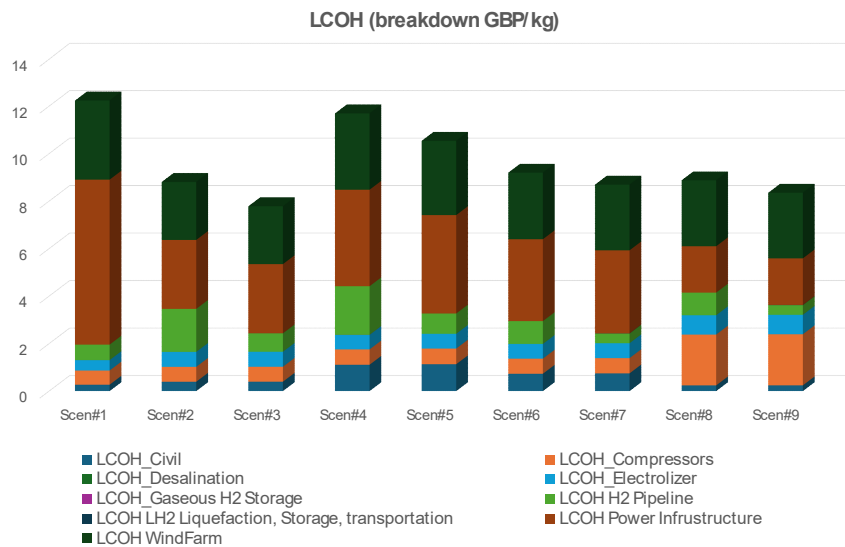


Figure 3. Cost distribution across system components for all twelve offshore wind-to-hydrogen and ammonia configurations. Stacked bars show the contribution of wind farm capital costs, electrolyser capital costs, balance of plant, transmission infrastructure, storage, and ammonia synthesis to the total levelised cost (£/kg or £/MJ) for each scenario. Scenarios are ordered by increasing levelised cost. Fixed-bottom and

Cost Breakdown: Key Findings

- **Wind Farm as Universal Cost Floor**

Wind farm CAPEX+OPEX is the single largest cost component across all twelve configurations without exception, establishing that system-wide cost reductions are more sensitive to offshore wind capital cost reduction, installation learning rates, and capacity factor improvements than to incremental gains in any downstream processing or logistics component.

- **Power Infrastructure as Primary Differentiator**

Three distinct tiers are identifiable — marine cable configurations (S1, S11) where power infrastructure is comparable to or exceeds wind farm costs; floating-only configurations (S4, S5) elevated by foundation premiums alone; and all fixed or mixed-fleet pipeline configurations at the lowest tier — with this three-tier structure being the primary mechanism explaining the broad cost spread across the configuration set.

- **Ammonia Cost Structure**

Each ammonia configuration's cost distribution is dominated by its inherited upstream hydrogen production cost rather than the Haber-Bosch or logistics layer, implying that efforts to reduce ammonia delivery costs should target the same upstream interventions — foundation type, transmission architecture, and wind resource — that govern hydrogen pathway

Key Observations and Concluding Remarks

- **Principal Findings**

Fixed-bottom offshore platform hubs with liquefied hydrogen seaborne transport establish the economic benchmark at 0.065 £/MJ (7.79 £/kg H₂), yet the six most economical hydrogen configurations cluster within a narrow band of 0.065–0.077 £/MJ, confirming that multiple technology pathways can achieve commercial viability and that site-specific optimisation should govern configuration selection over prescriptive mandates.

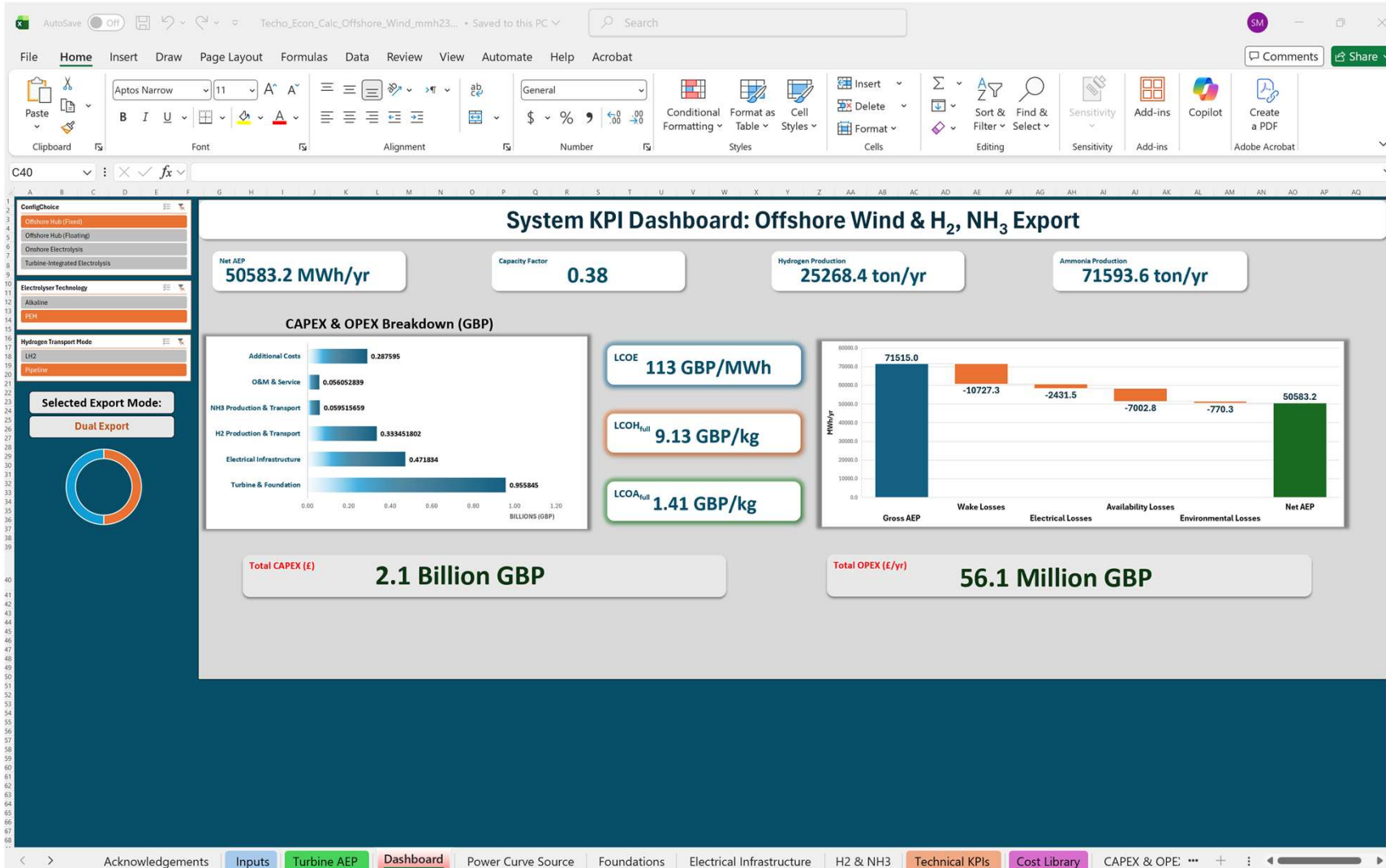
- **Challenging the Centralisation Paradigm**

Turbine-integrated distributed electrolysis proves competitive at 0.0697 £/MJ — only 7% above the optimal offshore hub — demonstrating that transmission infrastructure savings can offset electrolyser scale penalties at UK North Sea distances, while floating platforms impose an irrecoverable 33–35% cost premium that no downstream optimisation can compensate.

- **Policy and Investment Priorities**

Offshore wind capital cost reduction and floating platform standardisation are the highest-priority technology development targets across all configurations; policy should adopt performance-based incentives over prescriptive technology mandates, and ammonia investment should prioritise upstream wind and foundation costs rather than Haber-Bosch capital reductions, as the latter contributes comparatively little to the total cost spread.

Excel Calculator: Dashboard Visual



Excel Calculator: Technical Modules and Use Case Findings

- **Tool Overview**

An Excel screening tool developed to evaluate the full value chain of offshore wind-to-hydrogen and ammonia systems across four electrolysis configurations (Offshore Hub Fixed, Offshore Hub Floating, Onshore Electrolysis, Turbine-Integrated), covering turbine performance, electrical infrastructure, hydrogen production, liquefaction or pipeline transport, Haber-Bosch synthesis, ammonia storage, and seaborne shipping through a unified CAPEX/OPEX/levelised cost dashboard.

- **Key Technical Modules**

Wind energy yield is estimated using the IEA 15 MW reference power curve with a Weibull wind distribution, loss factors, and site-specific water depth logic that automatically assigns foundation type (monopile, jacket, gravity, or floating semi-submersible); electrical infrastructure is sized from first principles including inter-array cables, export cables, offshore substation transformers, GIS bays, and reactive power compensation; hydrogen production is modelled for both PEM and Alkaline electrolyzers at 80% load fraction, with downstream options for pipeline compression, liquefaction (11.8 kWh/kg), boil-off gas management, and LH₂ or NH₃ seaborne shipping; the Haber-Bosch loop uses a 15% per-pass conversion with recycle and purge, an ASU sized to stoichiometric N₂ demand, and catalyst sizing via Gas Hourly Space Velocity.

- **Key Use Case Findings**

Fixed-bottom foundations achieve LCOH of 9.13 £/kg and LCOA of 1.41 £/kg NH₃ versus 12.09 £/kg and 1.96 £/kg for floating — a ~32–42% premium consistent with the MILP framework findings; turbine-integrated electrolysis delivers marginally lower levelised costs (8.63 £/kg, 1.32 £/kg NH₃) than the offshore fixed hub by eliminating electrical transmission losses; PEM outperforms Alkaline on a full-chain basis (9.13 vs. 9.88 £/kg) despite higher CAPEX, due to superior hydrogen yield; and LH₂ transport produces a slightly lower LCOH (8.94 £/kg) than pipeline (9.13 £/kg) at 3,000 nautical miles, while a blended NH₃/H₂ custom export mode maintains near-identical levelised costs to full ammonia export — confirming that mixed carrier strategies offer market flexibility without significant cost penalty.

Inland hydrogen transport and storage modelling

IMPERIAL COLLEGE LONDON – OCEAN-REFUEL

MARCH, 2026

A solid blue horizontal bar spanning the width of the slide at the bottom.

Outline

- Problem statement
- Modelling approach
- Case study description
- Case study results

Problem statement

Given are:

- Hydrogen and carbon dioxide storage locations in the UK and cost related datasets
- Hydrogen and carbon dioxide transport pipelines and cost related datasets
- Selected technologies for hydrogen production and their corresponding cost
- Projected hydrogen demand per sector in the UK

Design an optimal (low-high infrastructure) hydrogen production, transport, storage and use network for the UK, in order to satisfy hydrogen demand by 2035.

Modelling approach

- Overview of modelling approach
- Hydrogen transport and storage model
- Key inputs
- Time discretisation
- Space discretisation

Modelling approach

Overview of modelling approach

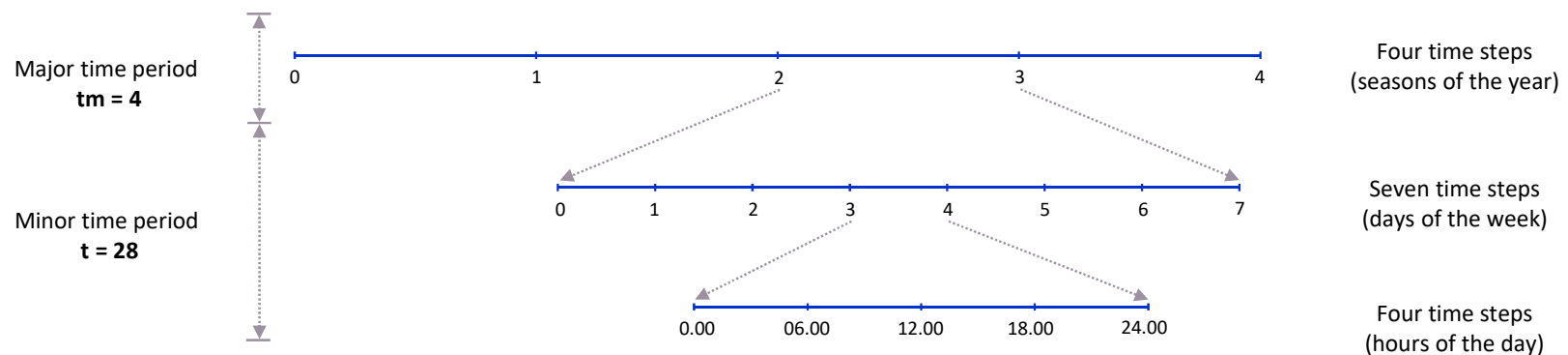
- The approach integrates a Resource-Task Network (RTN) modelling structure with fine-grained spatial and temporal discretisation, enabling the analysis of infrastructure investments, operational strategies, and policy impacts in a cohesive and data-driven manner.



Time discretisation

Temporal discretisation of planning horizon

- The annual demand horizon is discretised into four segments, each representing season of the year – autumn, winter, spring, and summer as shown below.
- Each season is further discretised into seven segments or days of the week, and finally each day is discretised into four segments or six-hour interval.



Space discretisation

Spatial discretisation of geographical map

The analysis considers the UK geographical map, which is discretised into zones to reflect:

- Industrial clusters, such as Teesside, Humber, Grangemouth, and Merseyside, which are early focal points for hydrogen deployment.
- Renewable generation zones, particularly offshore wind development areas in the North Sea and Scottish waters.
- Transport corridors, including existing natural gas pipeline networks that could be repurposed for hydrogen.
- CO₂ storage basins, e.g. offshore saline formations in the North Sea and East Irish Sea, critical for blue hydrogen pathways.

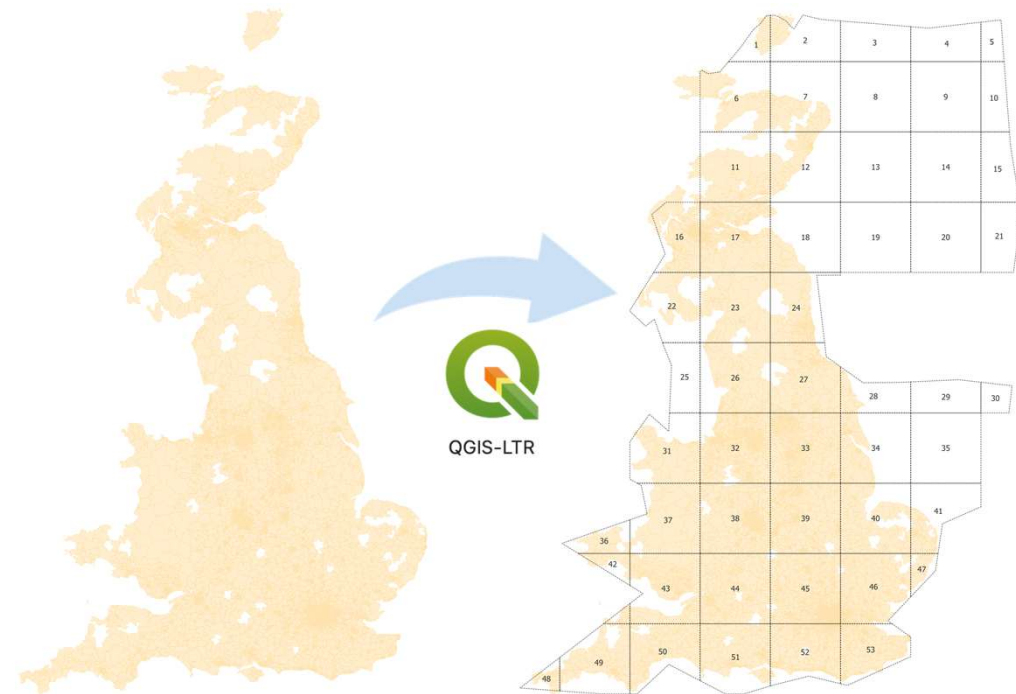
Spatial discretisation ensures:

- Modelling of inter-regional hydrogen flows, enabling analysis of pipeline and shipping infrastructure.
- Assessment of regional disparities in production costs, resource availability, and infrastructure requirements.
- Identification of bottlenecks or synergies in the national hydrogen system.

Space discretisation

Spatial discretisation of geographical map

- For modelling purposes, the entire UK geography is discretised in to 53 zones/cells.
- Distance between two cells can be calculated considering the Euclidean distance between adjacent cells.
- Depending on the geographical location, cells can contain various type of infrastructure such as
 - salt cavern for hydrogen storage,
 - depleted gas field for storage of captured CO₂,
 - existing transport pipelines,
 - blue and green hydrogen production, and
 - lastly hydrogen demand - industrial, transport, and power.
- The discretisation is carried out using an open sources software named QGIS 3.40.

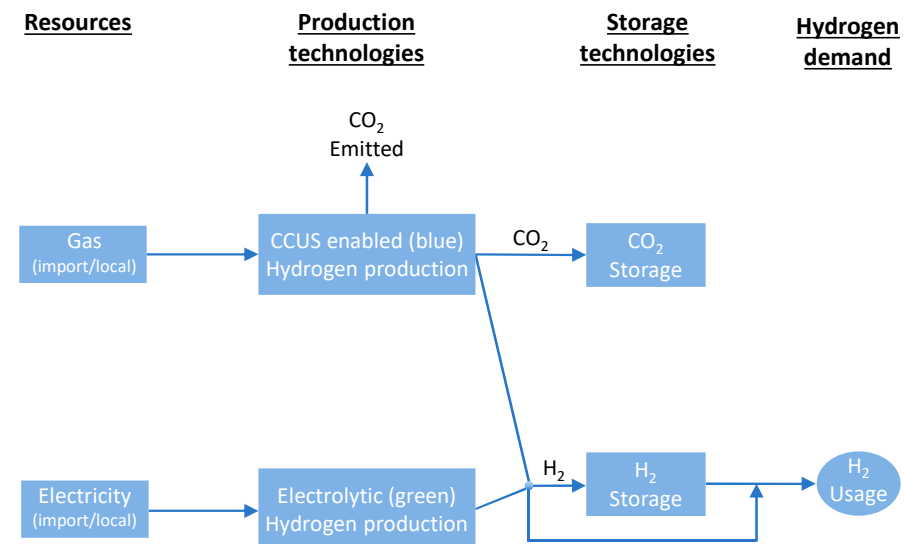


Hydrogen transport and storage model

Overview of resources-task network for hydrogen transport and storage

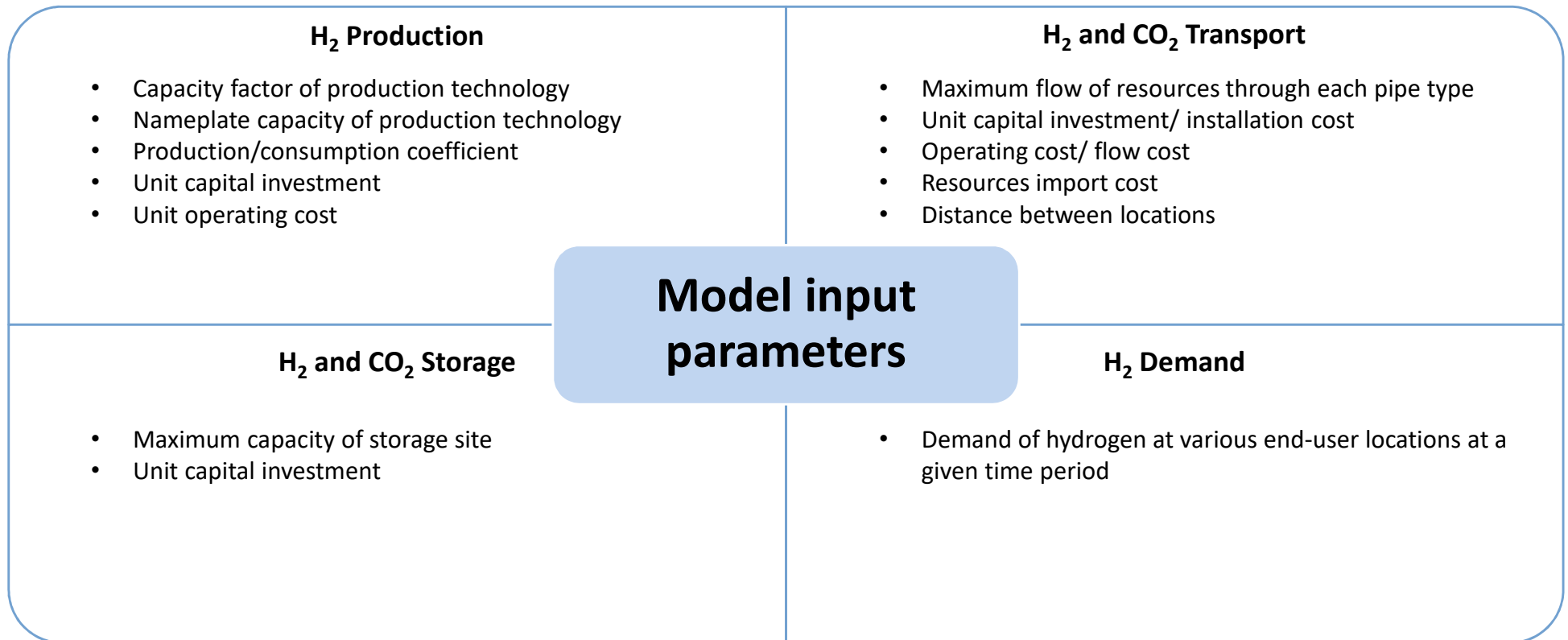
- **Generic RTN-H₂ transport & storage model**
- **The model comprises**
 - H₂ & CO₂ storage locations and their installation cost
 - H₂ & CO₂ transport pipelines and related cost
 - Technologies for H₂ production and related cost
 - GHG related to production and transport technologies
 - Imported resources
 - Hydrogen demand
- **Optimisation-based model (MILP)**
 - **Objective function:** total cost
 - **Constraints:** technology balance in each cell, production rate constraint in each cell, resource balance for each cell, flow constraint between cells, etc.
 - **Decision variables:** production rate of technology, number of technology installed, inventory of resource, flow of resource between entities, imported resource, etc.

Hydrogen production, transport, storage and use network



Key inputs

Case study information required by proposed model



Case study

- Case study description
- Representative case study results
- Case study results – key findings

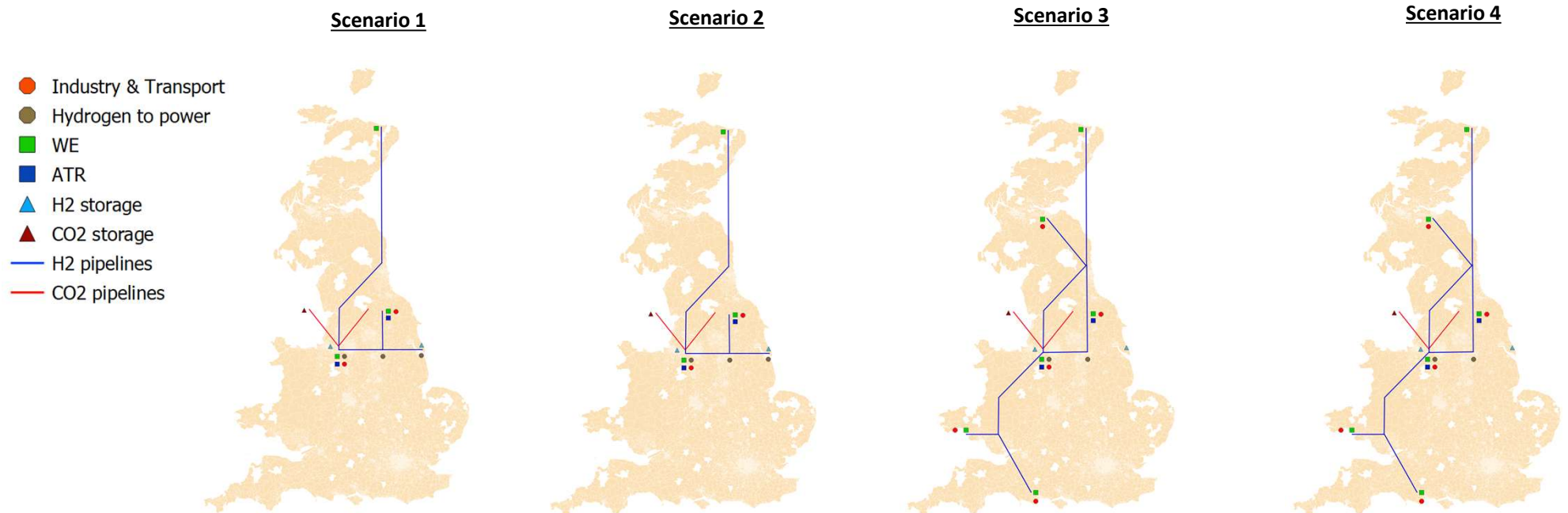
Case study description

Overview of hydrogen demand, production, and storage levels in eight scenarios

| Scenario | Industrial + Transport Demand | Power Generation Demand | Green H ₂ via Electrolysis | Blue H ₂ via ATR | Salt Cavern Storage |
|----------|-------------------------------|-------------------------|---------------------------------------|-----------------------------|---------------------|
| 1 | Low | High | High | Low | Low |
| 2 | Low | High | High | Low | High |
| 3 | High | Low | High | Low | High |
| 4 | High | Low | High | Low | Low |
| 5 | Extra Low | Extra Low | Extra Low | Low | Low |
| 6 | High | Low | Low | High | High |
| 7 | Low | High | Low | High | High |
| 8 | Low | High | Low | High | Low |

Representative case study results

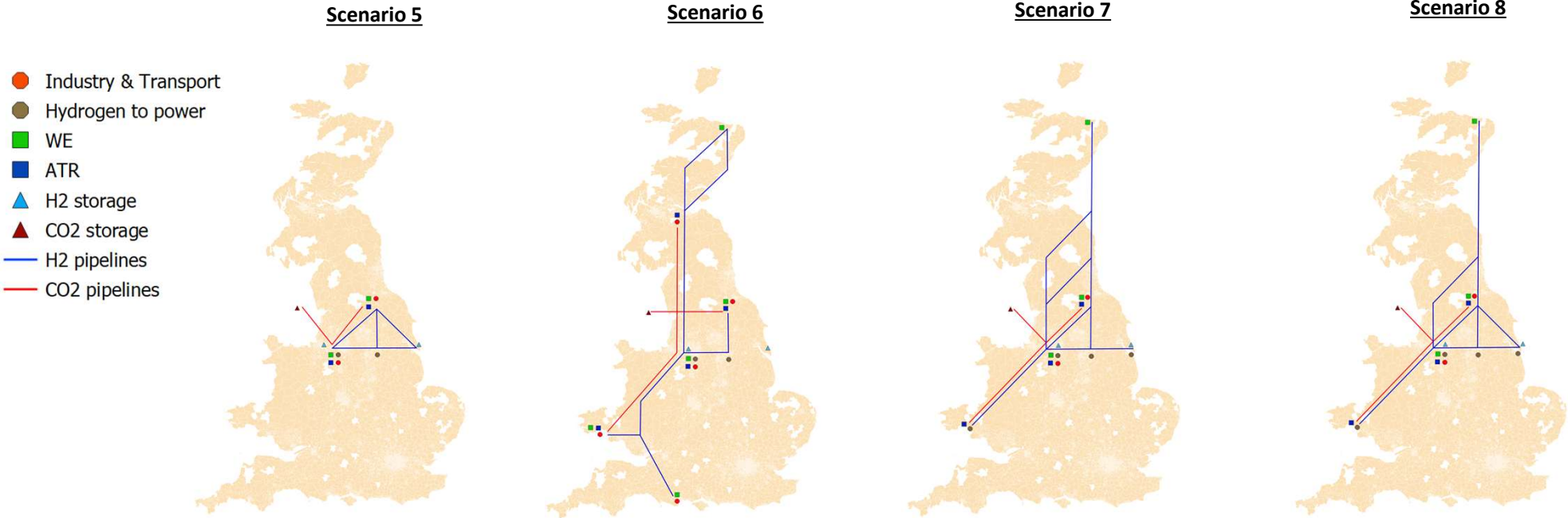
Optimal network structure



Levelised cost of hydrogen (LCOH) in range of 4-5 £/kg

Representative case study results

Optimal network structure

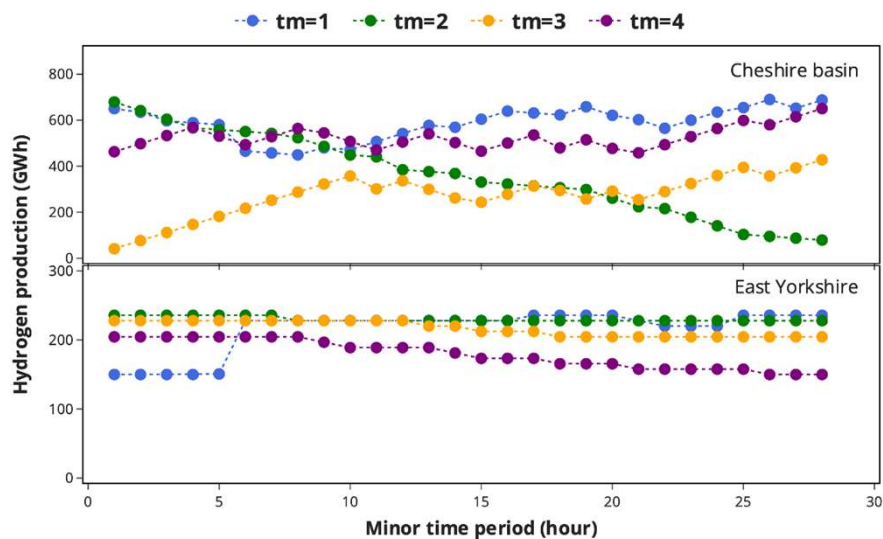


Levelised cost of hydrogen (LCOH) in range of 4-5 £/kg

Representative case study results

Sample profile of hydrogen inventory at storage sites

Scenario 1



Case study results – key findings

Hydrogen-to-Power (H2P) drives storage requirements

- Across all scenarios, **hydrogen storage activation/utilisation strongly correlates with the presence and scale of H2P demand.**
- This supports the strategic role of **seasonal storage** in balancing intermittent renewables with dispatchable power.
- *Policy steer:* Long-duration hydrogen storage should be **co-developed alongside large-scale H2P rollout**, particularly in East Yorkshire and Cheshire, where geology is suitable for salt caverns.

Hydrogen demand structure impacts network design

- Scenarios with high industrial demand (e.g., Scenario 3) show dense network layouts around five clusters.
- In contrast, high H2P scenarios (Scenarios 1, 2, 7, 8) require **storage and dispatch planning** rather than broader cluster coverage.
- *Design principle:* Hydrogen networks must be **demand-led**:
 - For industry, focus on **regional clustering**.
 - For power, ensure **strategic storage and grid coupling**.

Thank you

Cross Cutting Themes

Economic Modelling

Public Perception of technologies

LCA and System Metrics



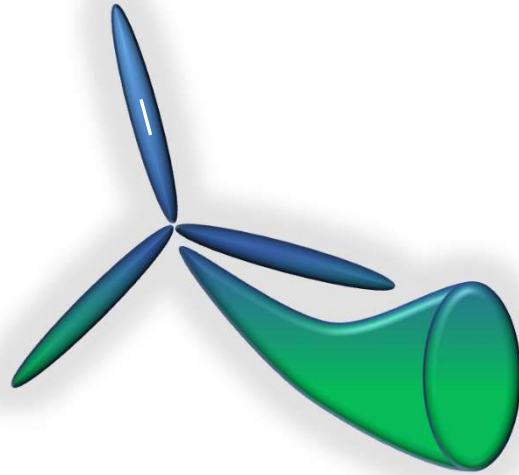
UNIVERSITY of STRATHCLYDE
CENTRE FOR
ENERGY POLICY



UNIVERSITY OF
BATH



Engineering and
Physical Sciences
Research Council



Ocean-REFuel (Ocean Renewable Energy Fuel)

"Next generation Renewable Ocean Energy"

Cross-cutting themes Policy/Economic Modelling & Public Perceptions



University of
Nottingham
UK | CHINA | MALAYSIA

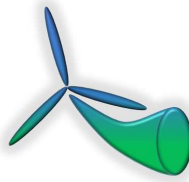


UNIVERSITY OF
BATH



UNIVERSITY of STRATHCLYDE
CENTRE FOR
ENERGY POLICY

Economic Modelling: Shetland case study



- Exploring how potential harnessing Shetland's extensive wind power and marine energy resources may impact the prosperity and sustainability of the local economy and affect the lives and livelihoods of its residents.
- Main focus over last 6 months: how Shetland's **Sullom Voe Terminal might transition from oil and gas processing to the production of low carbon fuels including green hydrogen**, starting with focus on a counterfactual 'do nothing' scenario (capacity being freed up)
- Main stakeholder support on developing scenarios from Shetland Islands Council and Veri Energy, with data input from Wood Mackenzie
- Collaborating with the **Public Perceptions team in investigating how understanding of economy-wide impacts may impact public attitudes to green energy developments**

Shetland project objective

To use CEP's expertise in developing and applying dynamic economy-wide **scenario simulation** frameworks – here our **Shetland Economy Model (SEM)** – to generate **evidence** to inform **policy decision-making** and **strategy development** (local, devolved and national), **business planning** and building consensus around economic **narratives**.



Example: 'Do Nothing' at the Sullom Voe Terminal

Policy Brief Hundreds of jobs at risk from inaction at Sullom Voe

By Karen Turner, Abdoul Karim, Antonios Katris and Paulina Gonzalez-Martinez

Taking no action to transition the Sullom Voe Terminal could ultimately cost 234 jobs across the Shetland economy by 2036, climbing to 402 by 2050.

Avoiding another Grangemouth or Mossmorran requires urgent action now.

Summary

What happens to Shetland's economy and local employment in a 'do nothing' scenario at the Sullom Voe Terminal ('SVT')?

Our research investigates the impact on jobs and income generation at the terminal site and across the local supply chain if oil processing activity winds down without action to transition to low-carbon fuel production. Our analysis uses our Shetland Economy Model ('SEM') and industry projections of the decline of oil and gas extraction activity in the East and West of Shetland oil fields.

A short-term boost could be delivered if the Clair oil field is extended but, even in that scenario, 340 jobs are at risk across the Shetland economy

Our results show that SVT and the local Shetland supply chain may experience a short-term boost in activity if BP's plans to unlock more reserves via the 'Clair South' development are progressed (though the longer-term outlook points to a sharp decline from the late 2030s, resulting from cessation of production from East of Shetland fields). We estimate that this will cost the Shetland economy a total of 340 full-time equivalent ('FTE') jobs by 2050 and £25 million per annum in local income generation (Shetland's gross regional domestic product, GRDP), assuming SVT continues to operate on a steady pathway of decline.

If the Clair extension does not go ahead, almost 250 jobs could be lost by the mid-2030s

The outlook is more acute if current regulatory and fiscal headwinds, such as the continuation of the UK Energy Profits Levy ('EPL'), prevent the Clair field extension from going ahead. In this scenario, our findings indicate that 80 FTE jobs will be lost at SVT from 2036, compounded by further 154 job losses across other local sectors as supply chain requirements and worker incomes decline. By 2050 (assuming SVT continues to operate on this steeper path of decline), total job losses across the local economy rise to 402 by 2050, while Shetland's GRDP falls by an estimated £30 million per annum.

Urgent action is required to unlock a pathway to a just transition for Shetland

The message is clear; without early planning and investment in new low-carbon fuel production and other replacement activity at SVT (which could also include extending Scotland's carbon capture and storage capacity), the cost of inaction to the Shetland economy and local communities extends well beyond the terminal gates. A timely transition is necessary, both to avoid skilled workers and their families from leaving the islands and unlock new economic opportunities. A key catalyst our research points to is the shift from export-focused fossil fuel processing to the production of low-carbon fuels in ways that sustain high-quality jobs and income generation, while meeting more of Shetland's energy requirements locally.

In conclusion, even in the best-case scenario, in which BP extends Clair production via SVT, 340 Shetland jobs will be lost and £24 million will be wiped from the local economy by 2050.

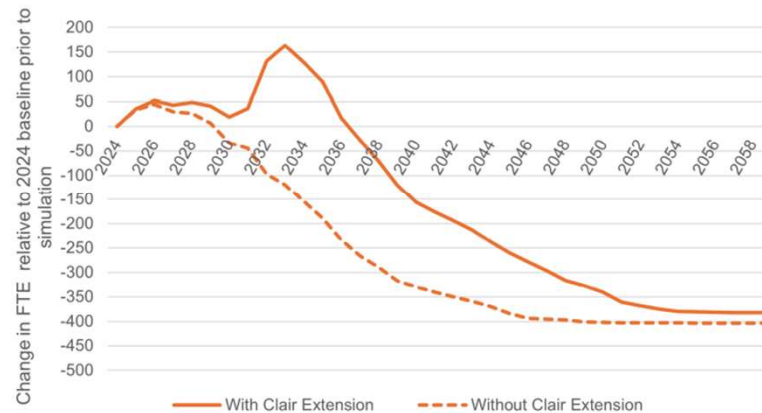
NEXT STEPS

Read our second policy brief investigating how proposed low-carbon fuel production at SVT would change the picture reported.

Two scenarios using Wood Mackenzie data

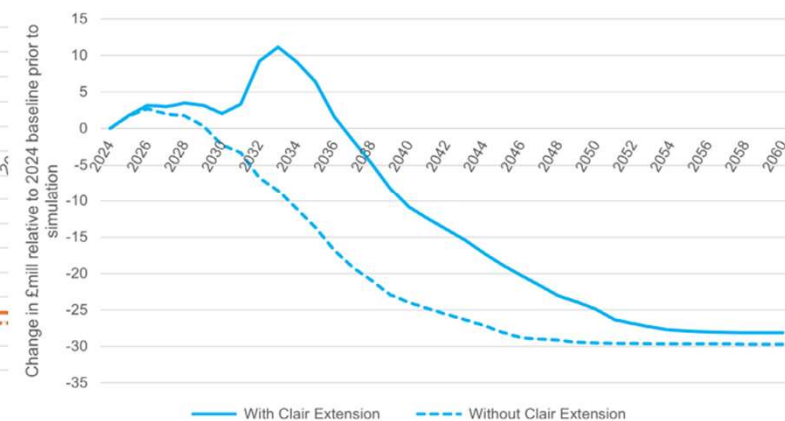
- With Clair extension – boost then decline
- Without Clair extension – steady steeper decline
- Hundreds of jobs at risk but frees up industry and supply chain resources in remote island economy context

Figure 2: Dynamic impact on total employment ('FTE') across the Shetland economy associated with the projected decline in oil processing activity at SVT



Source: CEP's simulation using SEM.

Figure 4: Dynamic impacts on the trajectory of Shetland's GRDP (£ million, 2024 prices) associated with the projected decline in oil processing activity at SVT



Source: CEP's simulation using SEM.



Example: 'Do Something' at the Sullom Voe Terminal

Policy Brief

An early shift to low-carbon fuel production at the Sullom Voe Terminal ('SVT') could provide the backbone for a successful transition of the Shetland economy

By Karen Turner, Abdoul Karim, Antonios Katris and Paulina Gonzalez-Martinez

Phase 1 of planned low-carbon fuel ('LCF') production at SVT could alone mitigate the risk to jobs across the Shetland economy from the projected decline in oil processing activity and boost the islands' GDP by at least £2.8 million per annum.

Summary

Could Veri Energy's proposed Phase 1 of low-carbon fuel production mitigate job losses and local GDP leakage associated with the projected decline in oil processing activity at SVT, thereby helping avoid another Grangemouth or Mossmorran? We investigate this question using our Shetland Economy Model ('SEM') to conduct scenario simulations informed by a combination of local authority data and industry projections. In a [linked CEP policy brief](#) we present findings showing that, particularly if current regulatory and fiscal headwinds, such as the continuation of the UK Energy Profits Levy ('EPL'), prevent the Clair oilfield extension going ahead, 234 full-time equivalent ('FTE') jobs (80 at SVT and 154 across the local supply chain) would be lost across the Shetland economy by the mid-2030s. Job losses would rise over time to up to 402, and Shetland's gross regional domestic product ('GRDP') would fall by up to £30 million per annum.

Early action on a transition to low-carbon fuel production at SVT would save up to 350 jobs across Shetland in the 2030s and would limit long-term job losses to a maximum of 55.

When we reran our scenario simulations introducing the proposed deployment of Phase 1 LCF production at SVT, we find that there is likely to be a short-term boost to employment across Shetland; a net loss of 34 jobs associated with reduced oil processing activity at SVT becomes a net gain of 269 jobs as deployment of the LCF Phase 1 project begins in 2030. Moreover, 240 of these jobs would be located beyond the terminal's gates, in sectors such as construction, services, ports and harbours, and renewable power feeding LCF Phase 1 production at SVT.

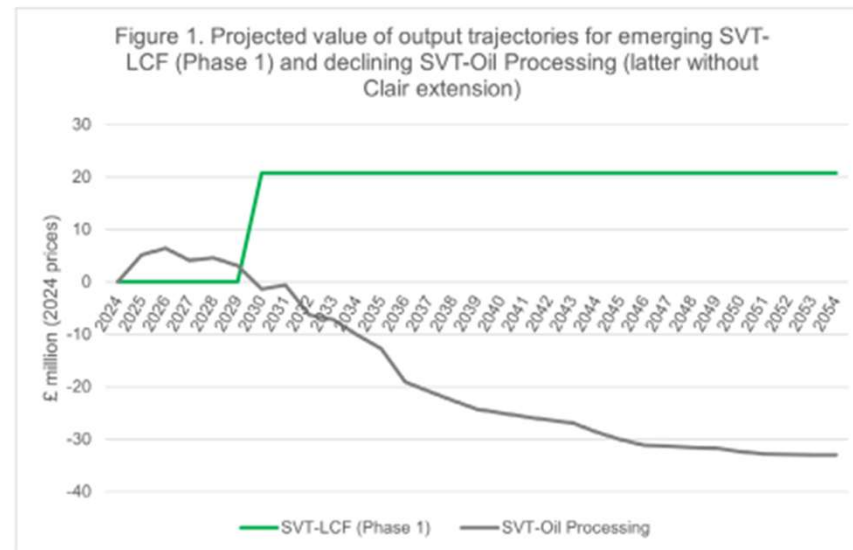
However, whether such gains are possible depends crucially on whether wage costs are driven up in Shetland's very constrained local labour market as the economy expands. On the other hand, by the mid-2030s and beyond, competition in the local labour market will help limit net job losses, which we estimate would be capped at 55 over the long term, and could even be entirely mitigated.

Phase 1 of LCF production at SVT could provide a strong backbone for Shetland's transition, with net local GRDP gains of between £2.8 million and £6 million. Crucially, the shift to LCF production at SVT makes better use of Shetland's limited labour resources (In addition to reusing existing infrastructure and land, while avoiding redevelopment costs). This is reflected in our finding that the net impact on Shetland's GRDP is positive in all timeframes, i.e., the positive impacts of Phase 1 of LCF production at SVT more than offset the negative impacts of the decline in oil processing activity. A peak in annual GRDP growth of £8-23 million (depending on labour market and other cost/price conditions) would occur in the early 2030s. From 2040, Phase 1 LCF production at SVT could deliver a sustained boost in income generation of between £2.8 million and £6 million per annum.

Early action supporting LCF production at Shetland's Sullom Voe Terminal is an essential step in laying the foundation for the UK's net zero ambitions.

Baseline of worse-case scenario with Wood Mackenzie data

- Could planned Phase 1 LCF production offset the decline?
- Information on (more capital intensive) activity from Veri Energy
- Varying assumptions about Shetland labour market responses



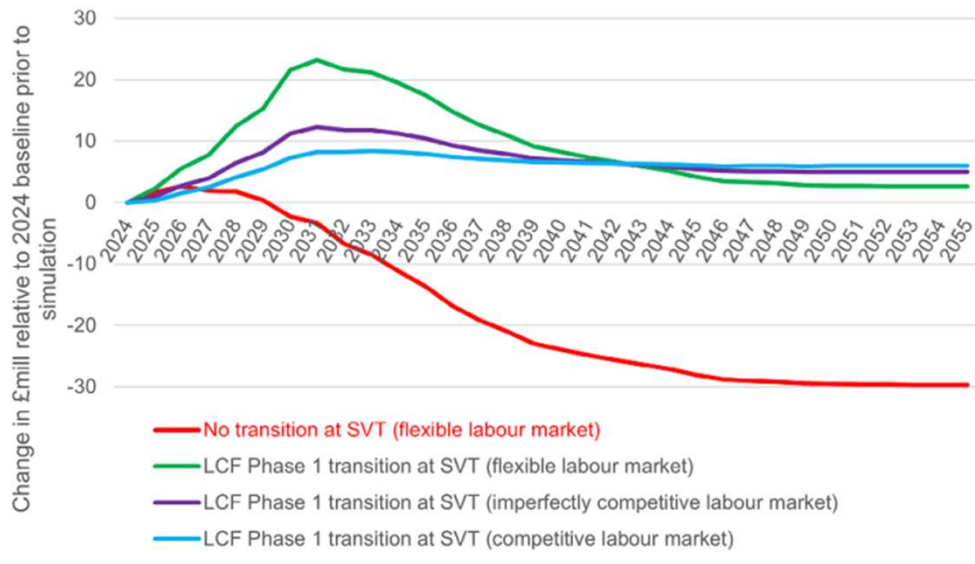
Source: Produced using Wood Mackenzie projections and LCF Phase 1 scenario data provided to the CEP team.



“Phase 1 of planned low-carbon fuel (‘LCF’) production at SVT could alone mitigate the risk to jobs across the Shetland economy from the projected decline in oil processing activity and boost the islands’ GDP by at least £2.8 million per annum”

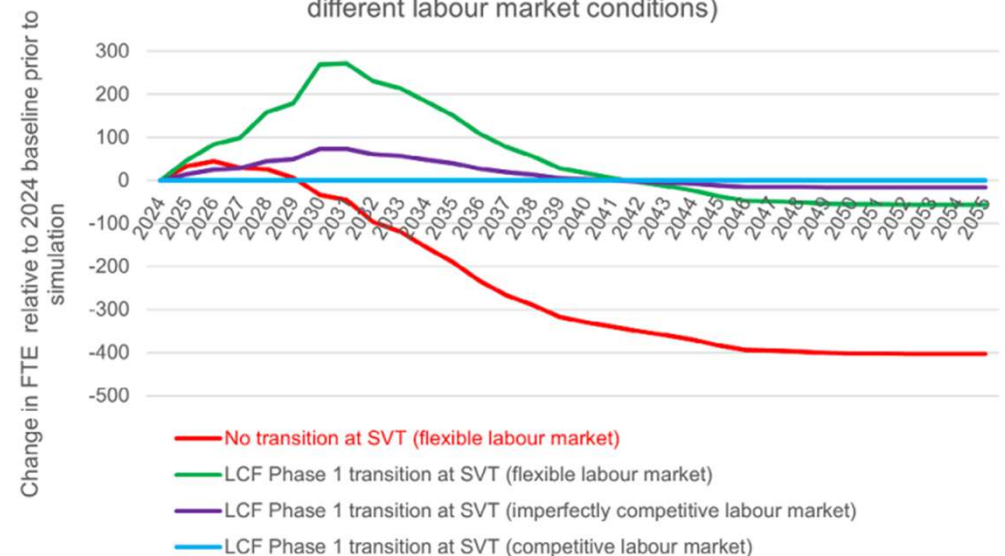
Key driver of GRDP/GVA boost: more productive use of Shetland’s limited labour resources

Figure 5: Change in Shetland GRDP across Shetland associated the combined shock of SVT-Oil Processing decline and SVT-LCF Phase 1 deployment (under different labour market conditions)



Source: CEP’s simulation using SEM.

Figure 2: Change in total full-time equivalent (FTE) employment across Shetland associated the combined shock of SVT-Oil Processing decline and SVT-LCF Phase 1 deployment (under different labour market conditions)



Source: CEP’s simulation using SEM.



Net GRDP/GVA growth with very limited displacement of jobs, especially in the long term.

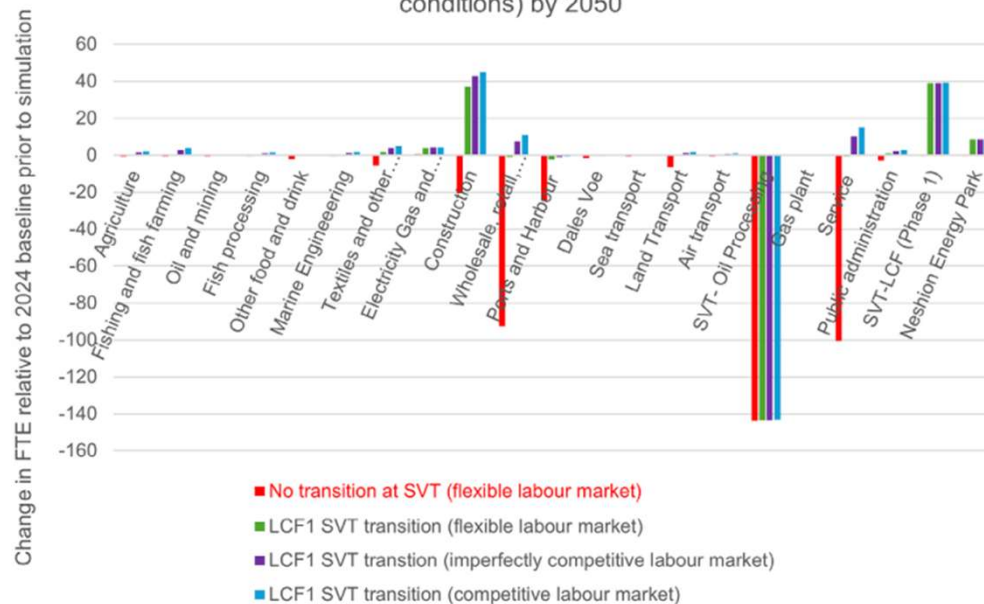
But Shetland resource constraints could bring some mid-term pressures on the cost of living and doing business pressure: LCF stimulus maximised before full extent of oil decline.

Figure 3: Sectoral employment change in total full-time equivalent (FTE) associated the combined shock of SVT-Oil Processing decline and SVT-LCF Phase 1 deployment (under different labour market conditions) by 2036



Source: CEP's simulation using SEM.

Figure 4: Sectoral employment change in total full-time equivalent (FTE) associated the combined shock of SVT-Oil Processing decline and SVT-LCF Phase 1 deployment (under different labour market conditions) by 2050



Source: CEP's simulation using SEM.



Next steps for CEP's research in Shetland

Insight Brief

Attracting up to 28 more workers to Shetland could increase economic benefit of Dales Voe ultra-deep-water quay by 50%

By Karen Turner, Antonios Katris, Abdoul Karim Zanhoo and Paulina Gonzalez Martinez

CEP research asked

How will the creation of the new Dales Voe ultra-deep-water quay impact the Shetland economy? The facility is being planned to support the deployment of low-carbon energy and the decommissioning of oil and gas facilities.

Key Finding 1

Despite the worker and skills challenges in Shetland's labour market, the Dales Voe facility will boost income generation in Shetland (measured as regional GDP). Without any additional workers attracted to Shetland, income generation is projected to:

- Peak at an additional £2.4 million in 2034, when offshore wind and decommissioning activity at the site is expected to be at its highest.
- Stabilise at around £0.8 million per year thereafter.

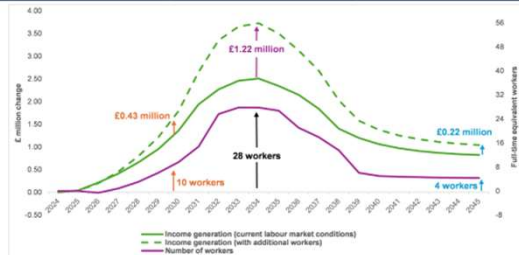
Key Finding 2

Operating the new facility will require only a couple of additional workers. However, any increased activity within the Shetland supply chain to service Dales Voe will depend on workers shifting from other sectors. This is likely to create competition for labour between sectors, driving up wages, which will inevitably have some impact on the (already high) cost of living and doing business in Shetland.

Key Finding 3

Compared to Key Finding 1, if sufficient additional workers can be attracted to fill these vacant supply chain jobs at different points in time, the income generation boost in Shetland will increase. With additional workers, income generation will:

- Increase, on average, by 27% in each year.
- Peak at £3.7 million in 2034.
- Stabilise at £1 million per year thereafter, with almost no upward pressure on local costs and prices.



Issues and questions arising

- The problem is that the number of additional workers required varies year-by-year. However, when the Shetland economy stabilises on that £1 million per annum trajectory from Key Finding 3, the number of workers will also settle - only requiring 4 additional workers each year thereafter.
- This suggests a balance of transitory and more settled migrants, both of which could be tricky to attract at the times they're needed (up to 28 additional workers are required to deliver that £3.7 million peak in 2034; but only 10 in 2030, and 21 in 2036).
- Can Shetland's public services and infrastructure cope with the additional workers (especially if they bring families)? Does the additional income generation boost of attracting more workers - and avoiding costly wage competition within Shetland - help make the case for any public investment required?

Focus on the proposed use of low-carbon fuels produced at SVT in decarbonising Shetland's marine sector

- Focus on the planned local use of LCF produced at SVT
- Extend focus to planned LCF Phase 2 – with proposed power link to NE1 offshore windfarms
- And proposed carbon storage activity

Continue to build out scenario simulations around Lerwick Port Authority investment at Dales Voe

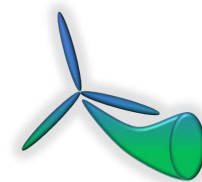
- Existing work (opposite): applied case for SEM peer review

New work focusing on Statkraft's plans for green hydrogen and ammonia export production at Tagdale

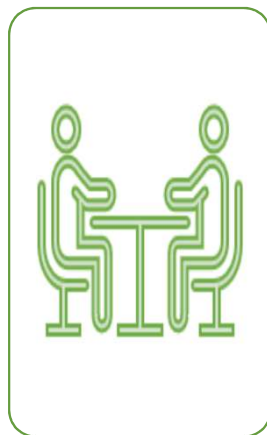
- Including potential to utilise thermal energy generated during electrolysis to supply renewable heat to homes/businesses

Last week the team visited Shetland to engage with local stakeholders around building up the scenario set during the remainder of Ocean REFuel and going forward through other projects, including CEP involvement in the UKRI Energy Demand Research Centre (Equity Theme)



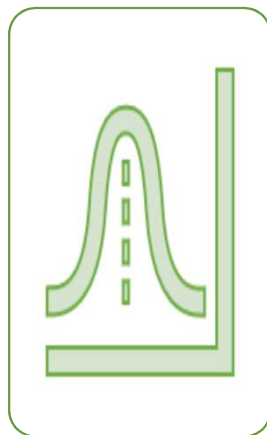


Public Perceptions



Deliberative Workshops

- Qualitative
- N ~ 60
- Shetland Islands
- April 2025 & March 2026
- Exploring Diverse perspectives



Survey

- Quantitative
- N = 1,511
- Nationwide
- October 27 through November 4, 2025
- Measuring prevalence
- Testing Associations
- Generalizable conclusions



UNIVERSITY OF
BATH

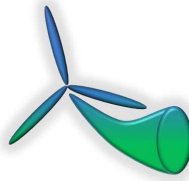


Deliberative Workshop

March 27 & 28, 2026

1:00 PM – 5:30 PM

Islesburgh Complex, Lerwick, Shetland



Session 1: Hydrogen & Ammonia: First Impressions, Feelings, Benefits, Concerns

Session 2: Hydrogen & Ammonia Applications

Session 3: Envisioning Shetland's Future: What Matters Most?

Session 4: Energy Projects in Shetland

Session 5: Economic Impacts of Energy Development

Session 6: Community Benefits – Priorities & Concerns

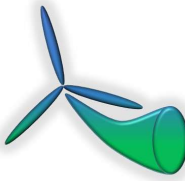


UNIVERSITY OF BATH

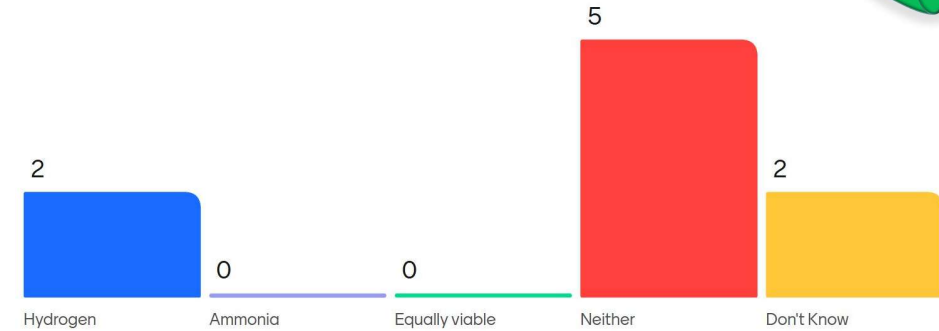
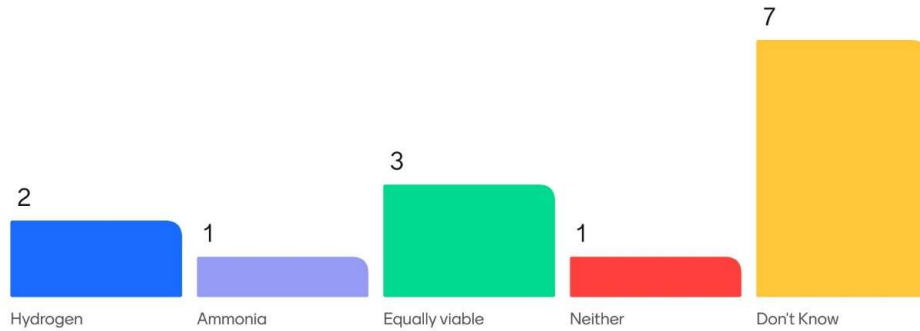
CARDIFF UNIVERSITY PRIFYSGOL CAERDYDD

Day 1

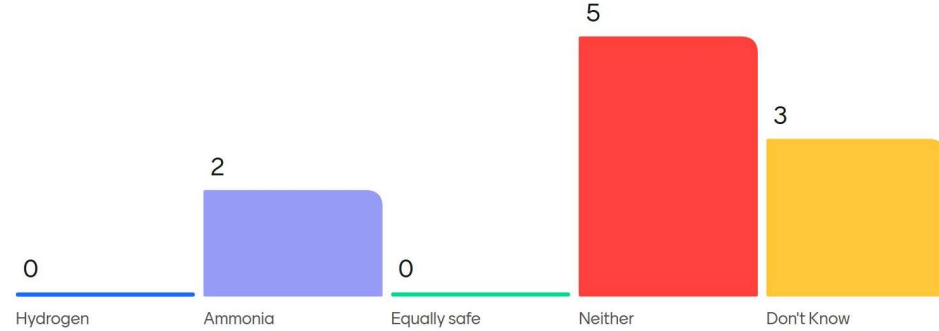
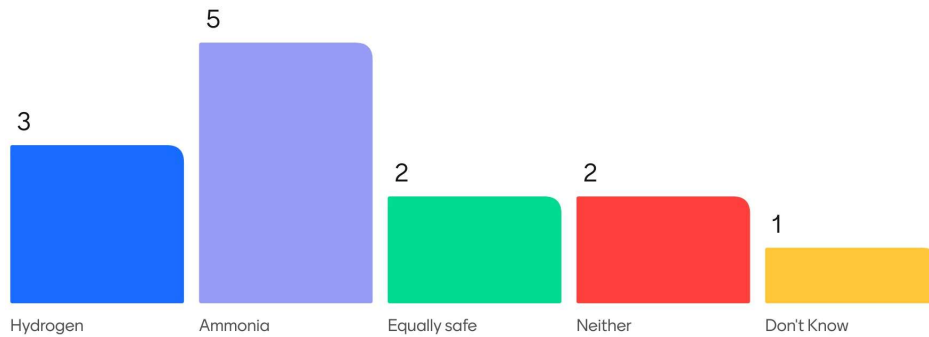
Day 2



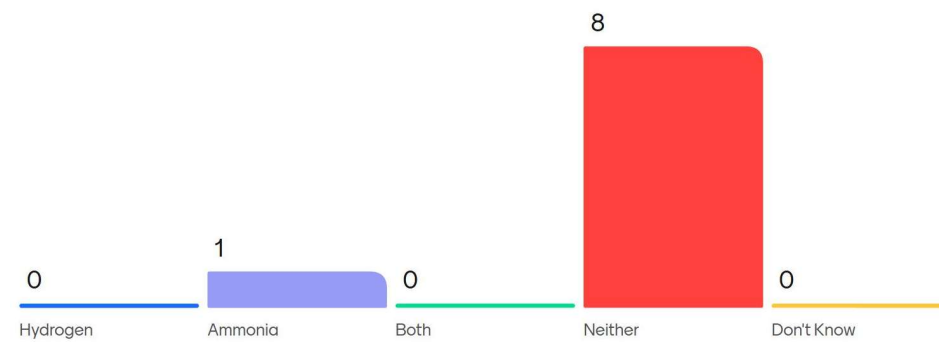
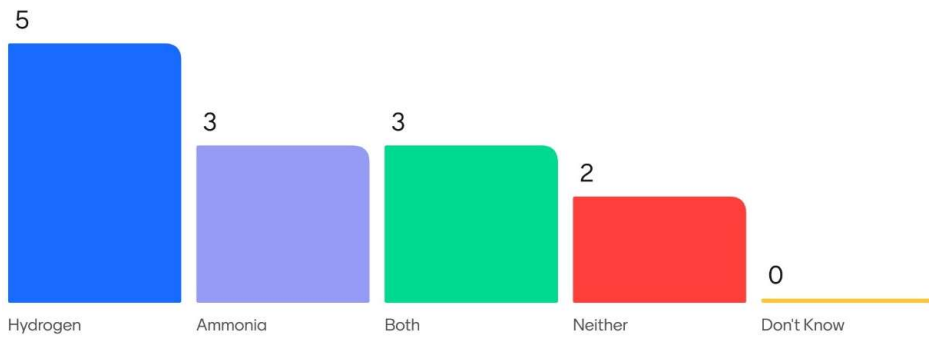
Viable



Safer

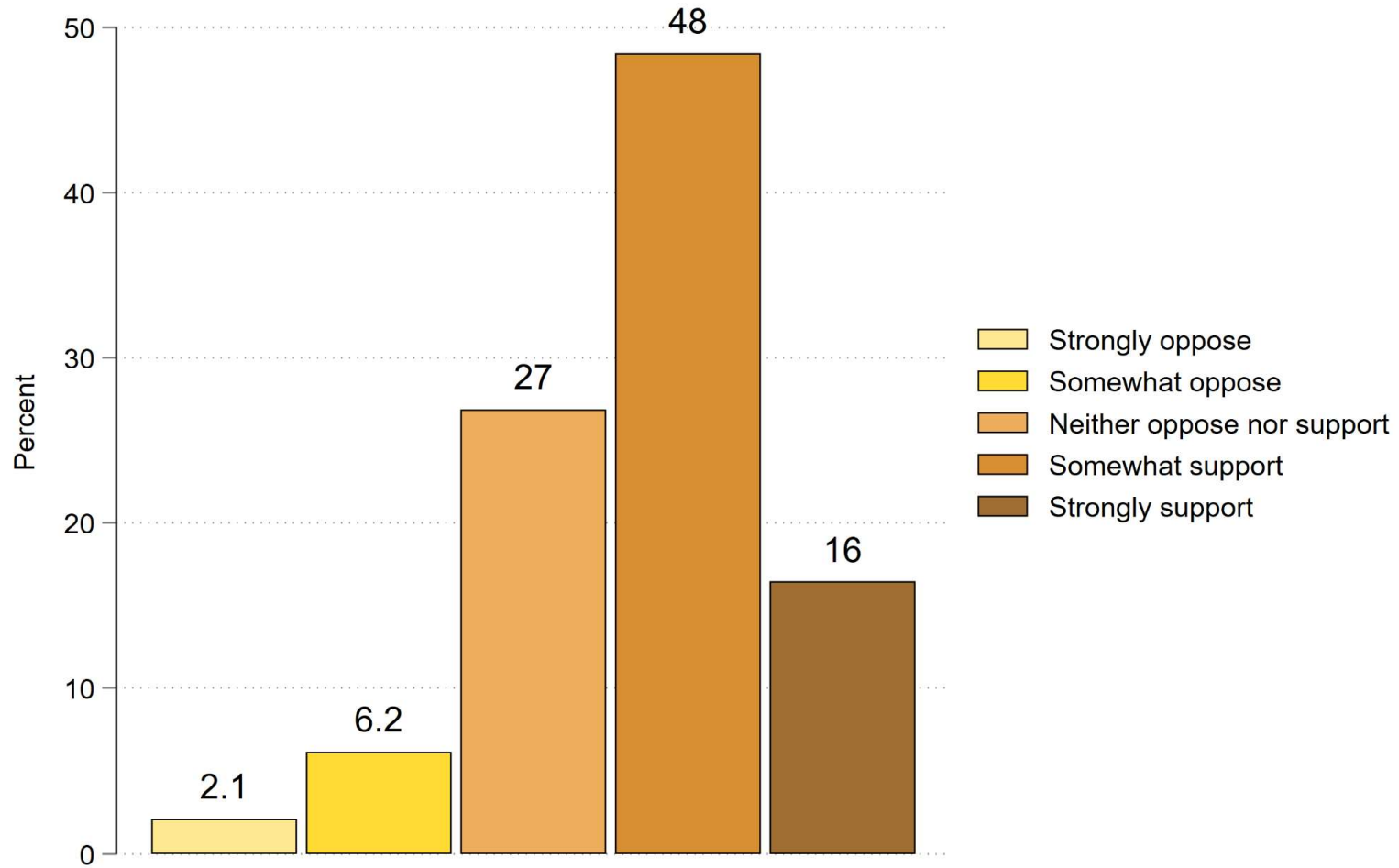


Prefer





Support for Hydrogen Policies

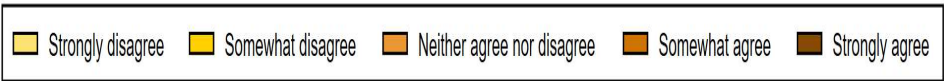
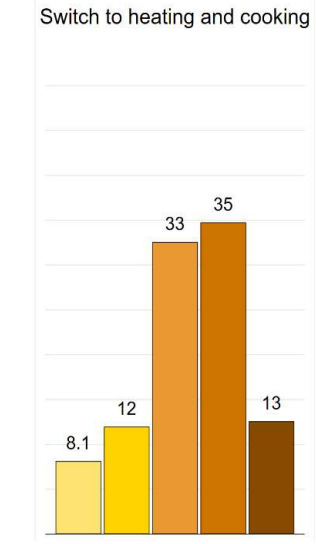
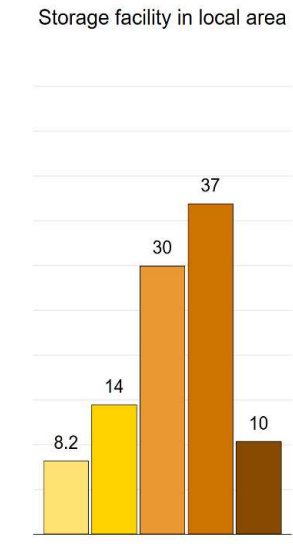
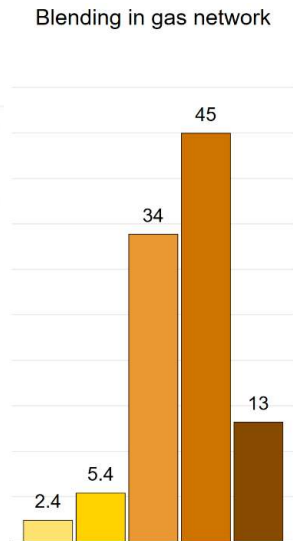
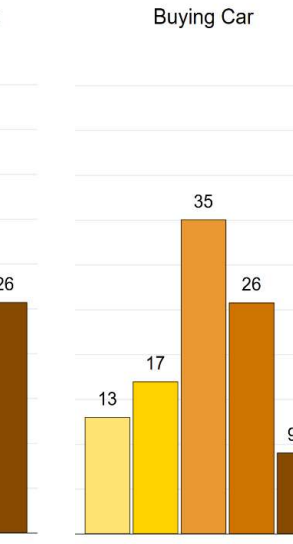
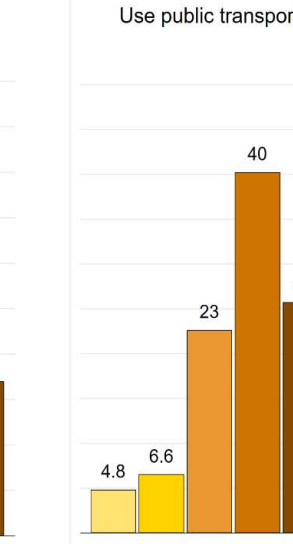
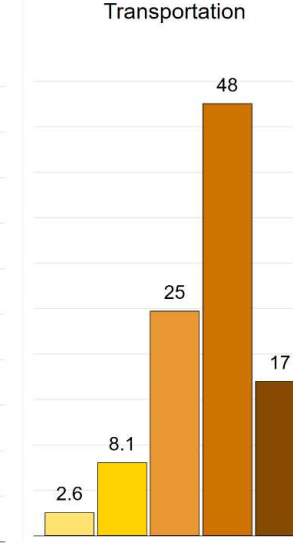
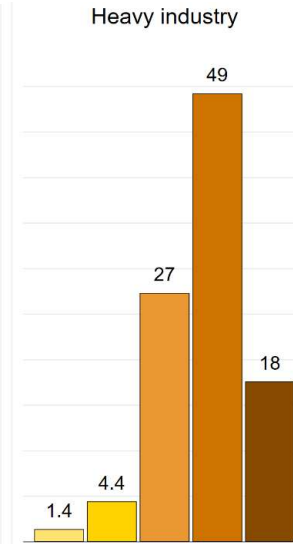
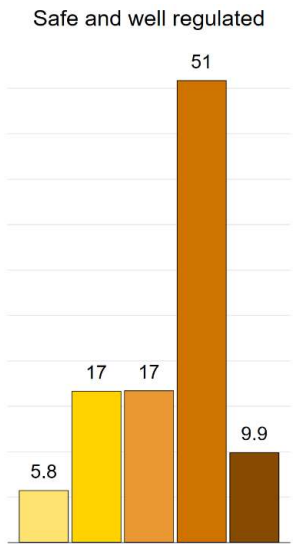




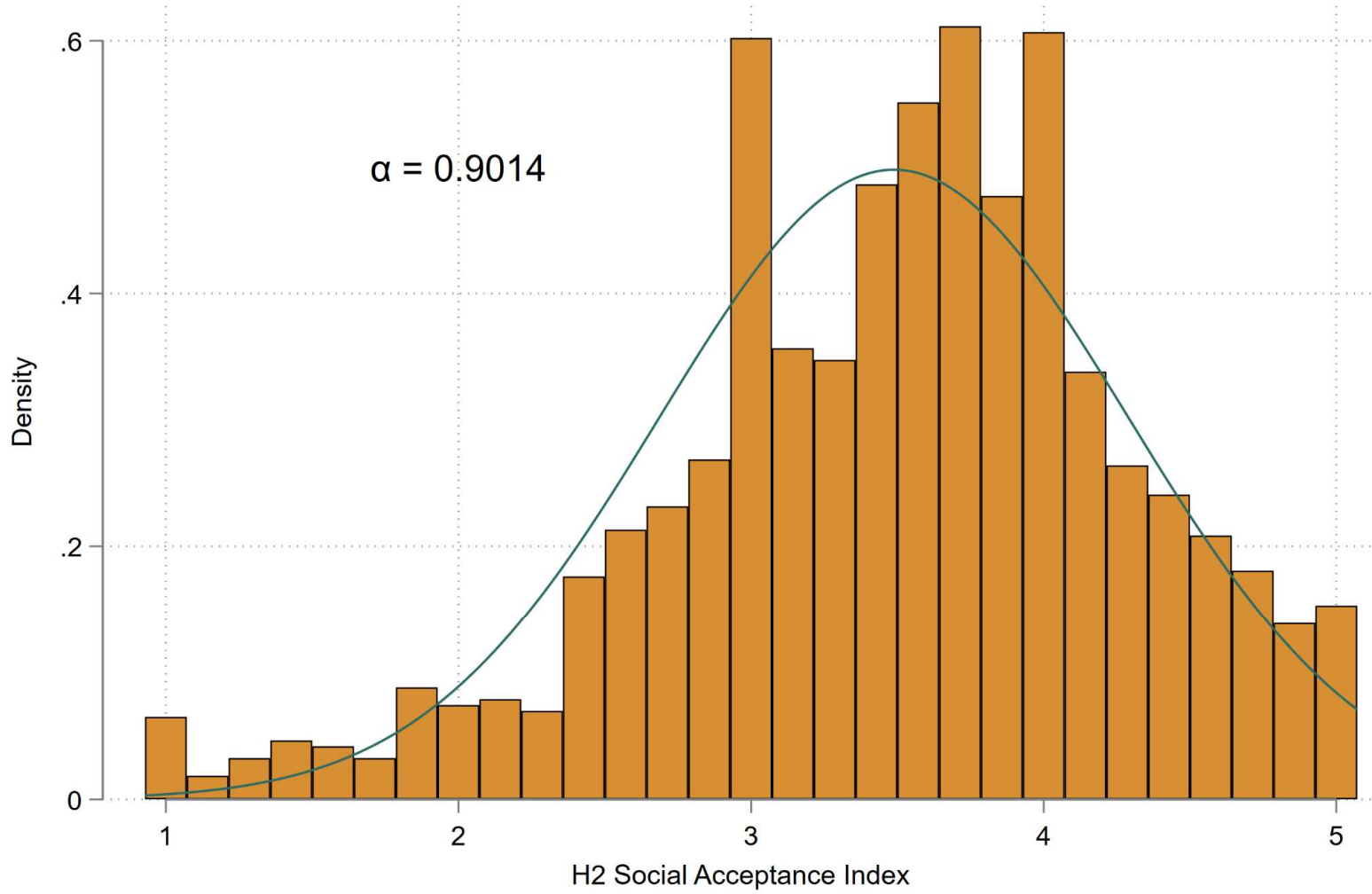
UNIVERSITY OF
BATH

CARDIFF
UNIVERSITY
PRIFYSGOL
CAERDYDD

Social Acceptance

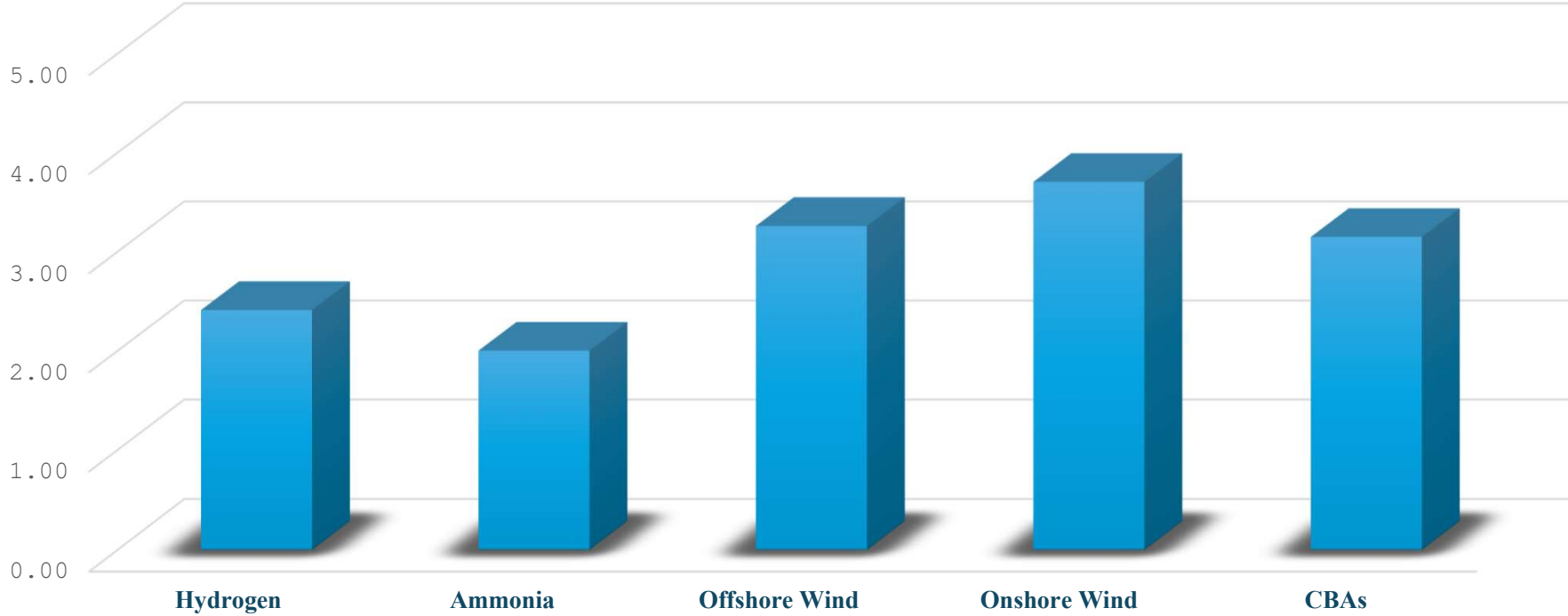


Social Acceptance





Familiarity

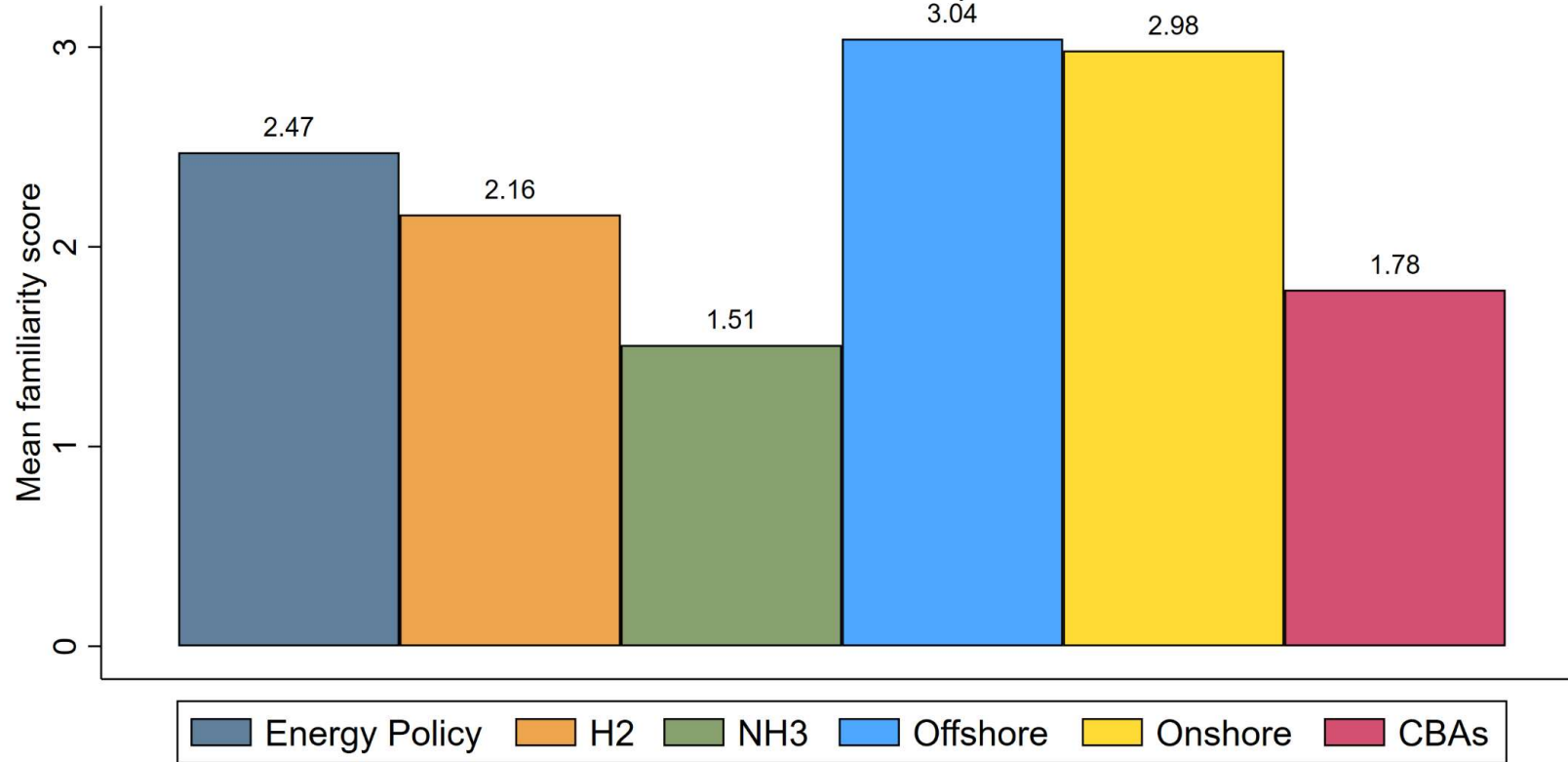


- 1. Not at all familiar (I've never heard of it before)
- 2. Slightly familiar (I've heard of it but don't know much)
- 3. Somewhat familiar (I know the basics)
- 4. Fairly familiar (I have a good understanding)
- 5. Very familiar (I am very well-informed)



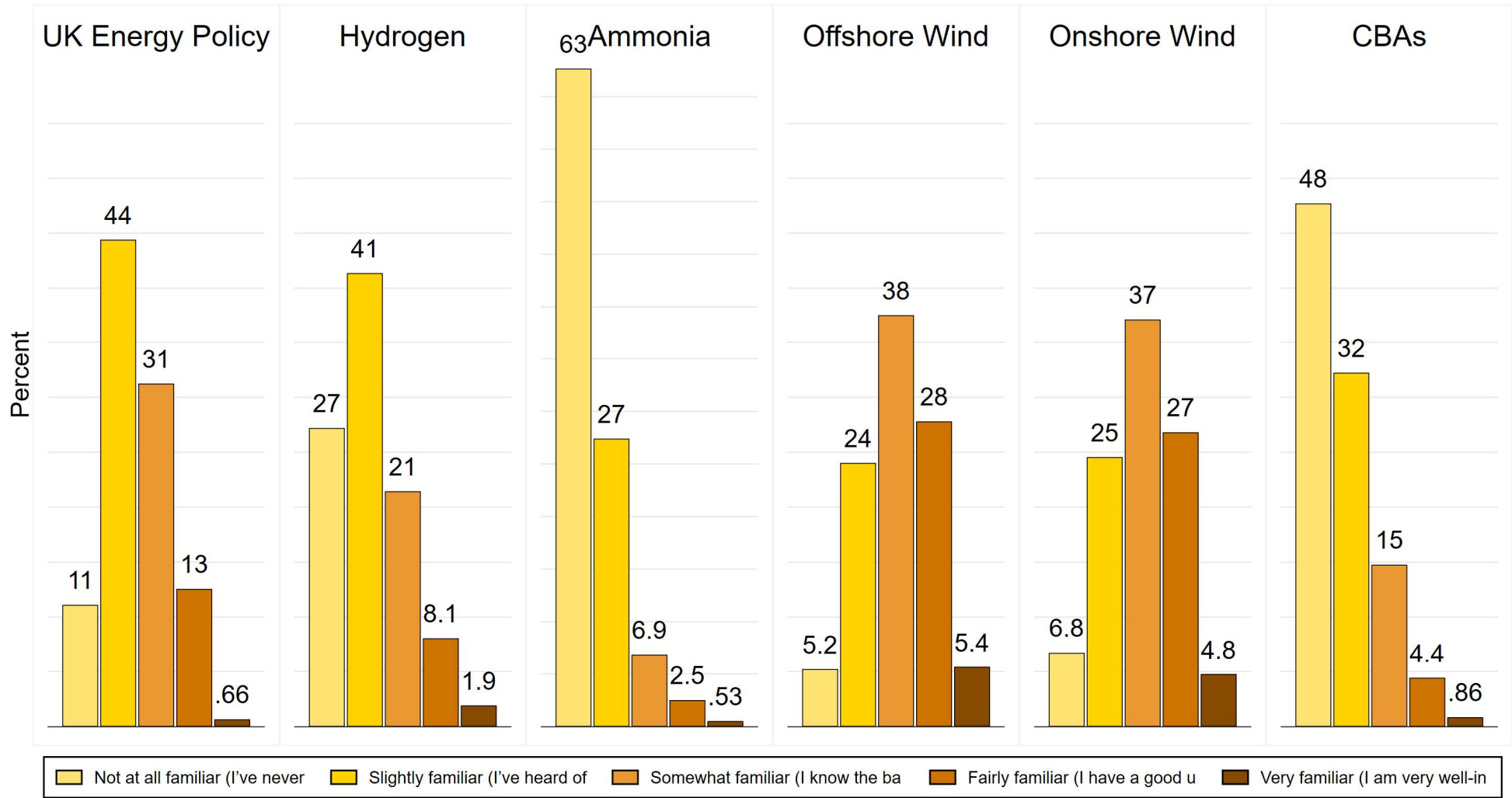
Familiarity with UK Energy Policy Areas

Mean scores across respondents

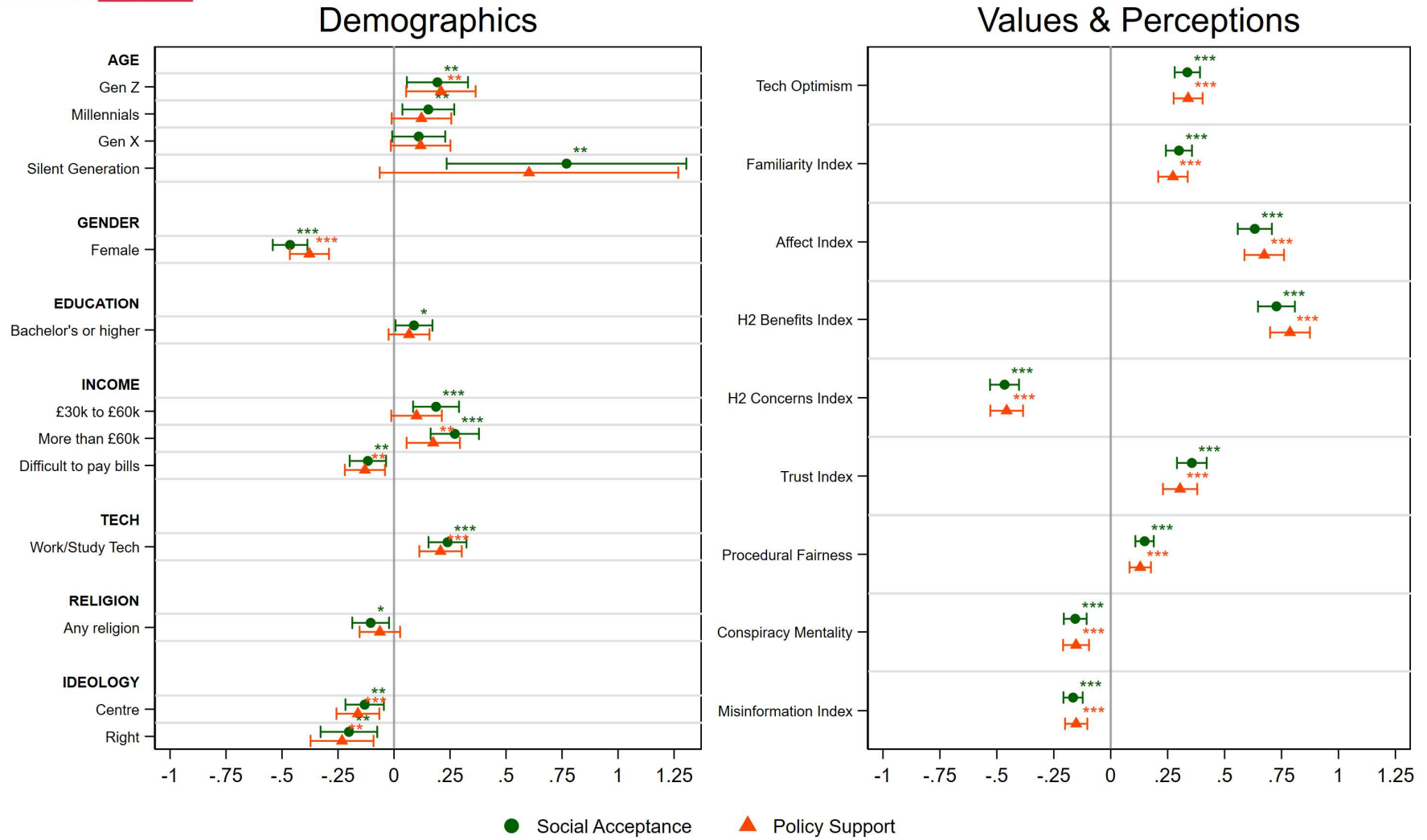


1. Not at all familiar (I've never heard of it before)
2. Slightly familiar (I've heard of it but don't know much)
3. Somewhat familiar (I know the basics)
4. Fairly familiar (I have a good understanding)
5. Very familiar (I am very well-informed)

Familiarity

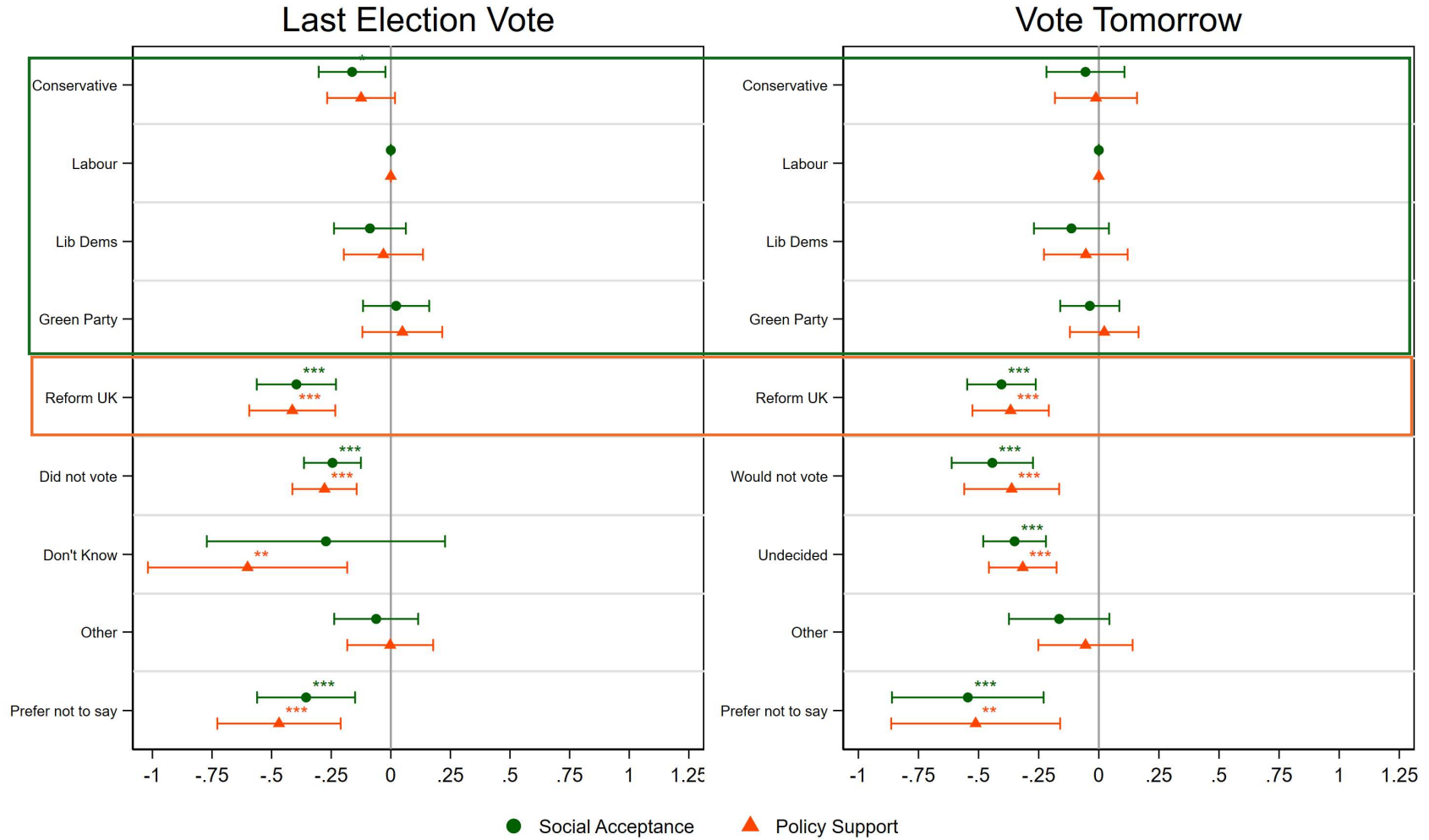


Hydrogen Acceptance and Policy Support: Bivariate Associations



Each coefficient comes from a separate regression with robust SEs. Capped lines represent 95% CIs. Stars: * p < .05, ** p < .01, *** p < .001

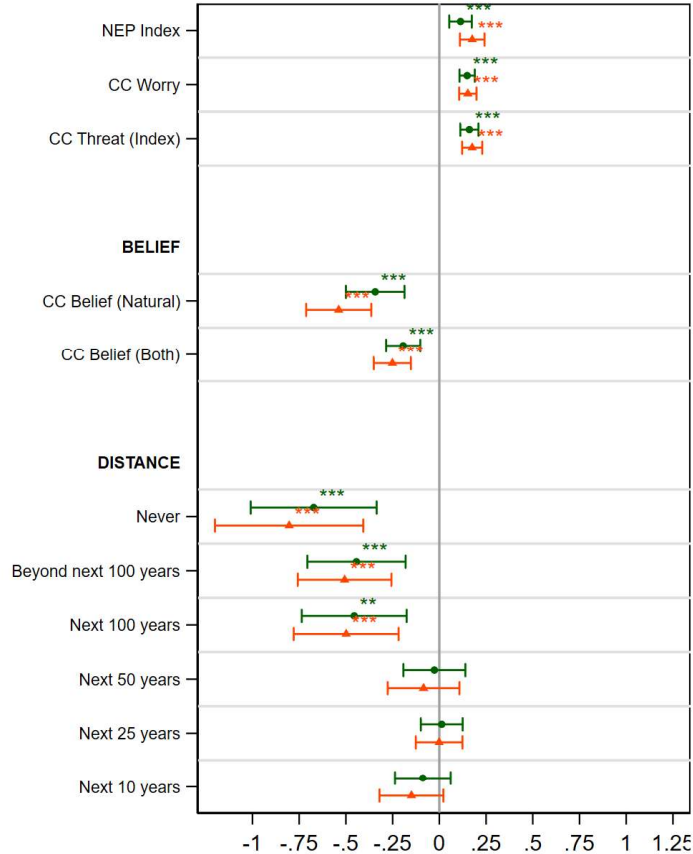
Hydrogen Acceptance and Policy Support: Bivariate Associations



Each coefficient comes from a separate regression with robust SEs. Capped lines represent 95% CIs. Stars: * p < .05, ** p < .01, *** p < .001



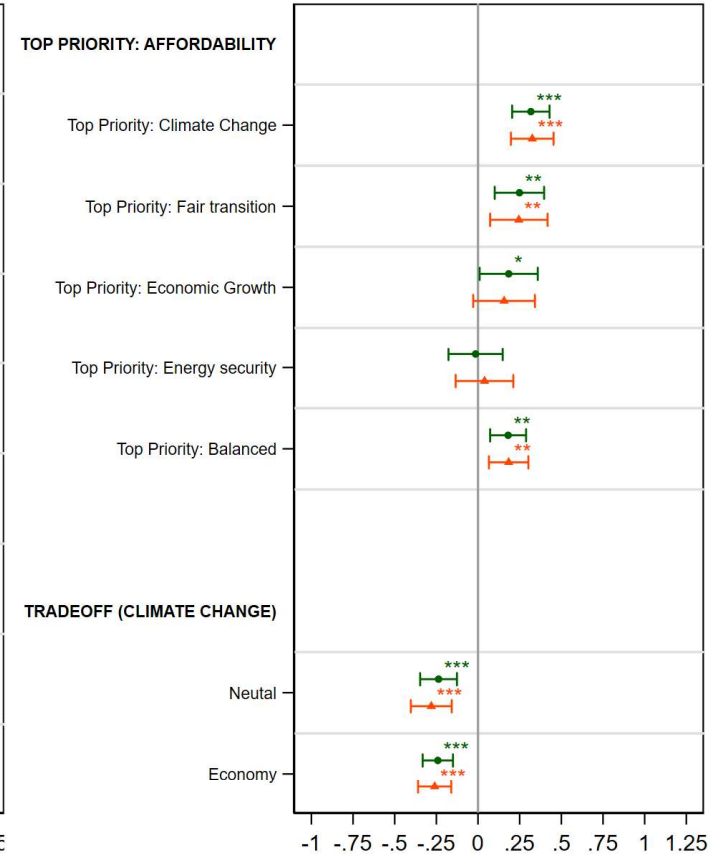
Climate Change Concerns



Energy Concerns



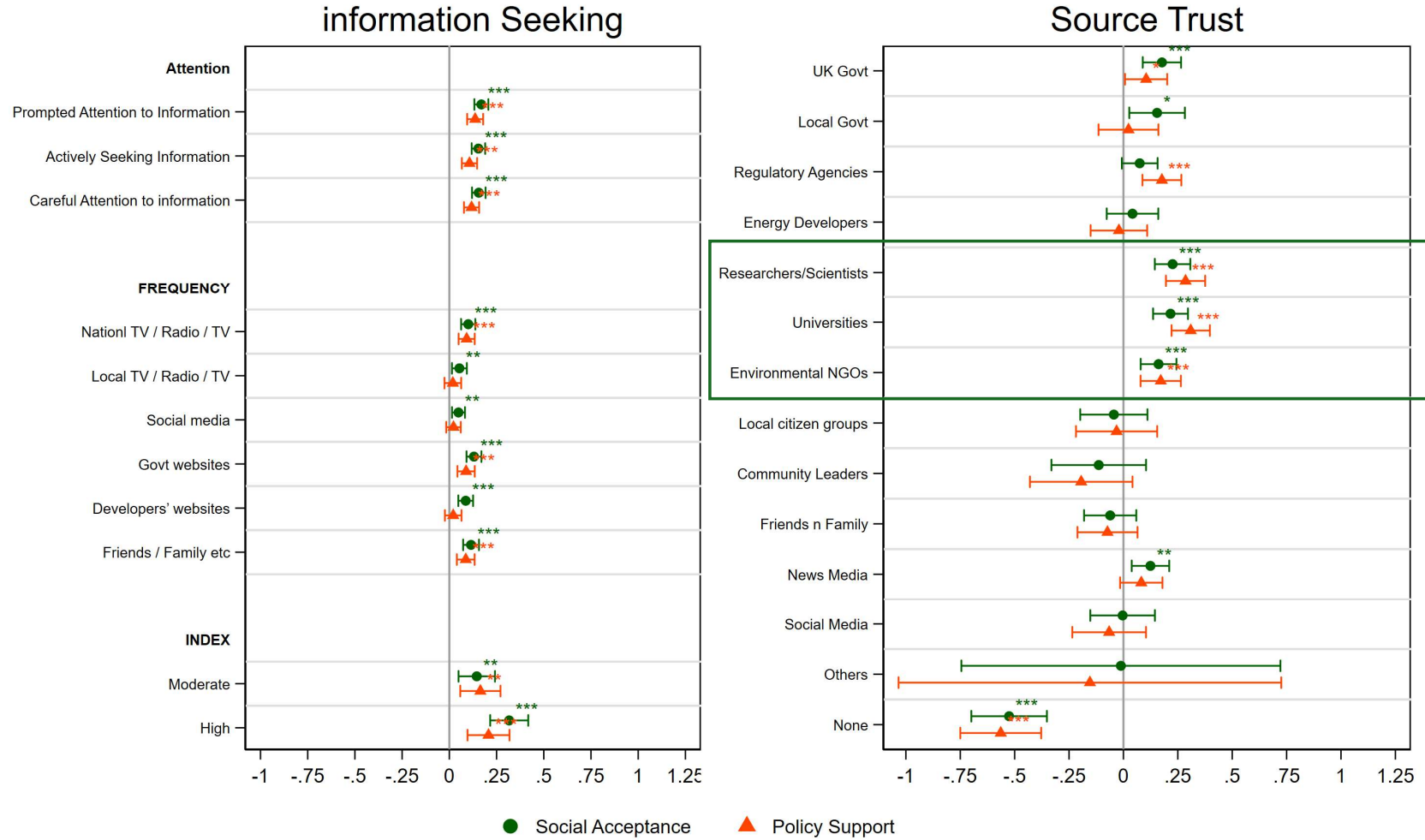
Energy Policy Priorities



● Social Acceptance ▲ Policy Support

Each coefficient comes from a separate regression with robust SEs. Capped lines represent 95% CIs. Stars: * $p < .05$, ** $p < .01$, *** $p < .001$

Hydrogen Acceptance and Policy Support: Bivariate Associations

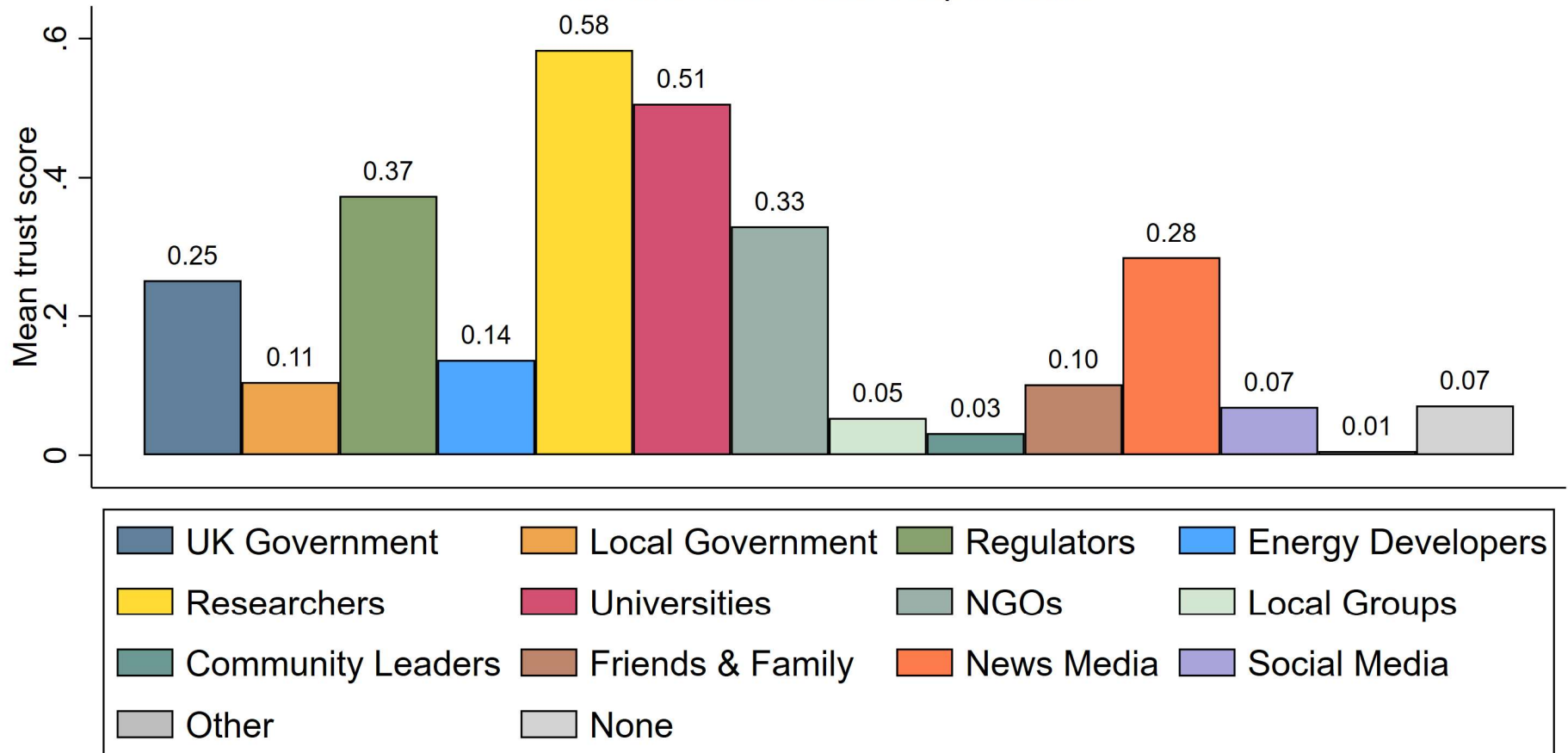


Each coefficient comes from a separate regression with robust SEs. Capped lines represent 95% CIs. Stars: * p < .05, ** p < .01, *** p < .001



Trust in Information Sources

Mean scores across respondents



Conjoint Experiment: Project Preferences



| Features | Levels | | | | | |
|--|---|---|---|--|-------------------------------|--------------------|
| Project Type | Hydrogen | Ammonia | | | | |
| Energy Source | Offshore renewable (wind / wave / hybrid) | Onshore renewable (wind / solar) | Nuclear | Natural Gas | Coal | |
| Management / ownership | UK Government | Devolved Governments (Wales, Scotland, Northern Ireland) | Local Council | Community / shared ownership | Private developers (UK based) | Foreign developers |
| Proximity / visibility | 1-5 miles (likely visible from your home/workplace) | 5-20 miles (potentially visible while commuting to and from home/workplace) | Beyond 20 miles (not likely visible from your home/workplace) | | | |
| Environmental / ecological impact | Some impact with effective mitigation measures in place | Significant impact on environment or ecosystem | | | | |
| Community Benefits | Utility bill cuts / Subsidized gas or electricity | Job share (quota) for the local population | Communities (schools, healthcare parks) | Affordable housing and local infrastructure | Environmental restoration | |
| Energy Distribution | Mostly used in your local area | Used both locally and elsewhere in UK | Mostly used in UK outside your area | Mostly exported to other countries | | |
| Community Engagement | No consultation, decisions made by experts only | Basic consultation with local leaders and council | Public <u>consulted</u> , input considered | Community had strong <u>say</u> in decisions | | |

Project Preferences: Example Task



Please select the project you would prefer the government to support.

Step 1 of 5

Project type

Ammonia

Ammonia

Energy Source

Natural Gas

Coal

Management / ownership

Community / shared ownership

Devolved Governments (Wales, Scotland, Northern Ireland)

Proximity / visibility

5-20 miles (potentially visible while commuting to and from home/workplace)

1-5 miles (likely visible from your home/workplace)

Environmental / ecological impact

Significant impact on environment or ecosystem

Some impact with effective mitigation measures in place

Community Benefits

Job share (quota) for the local population

Environmental restoration

Energy Distribution

Mostly exported to other countries

Mostly used in your local area

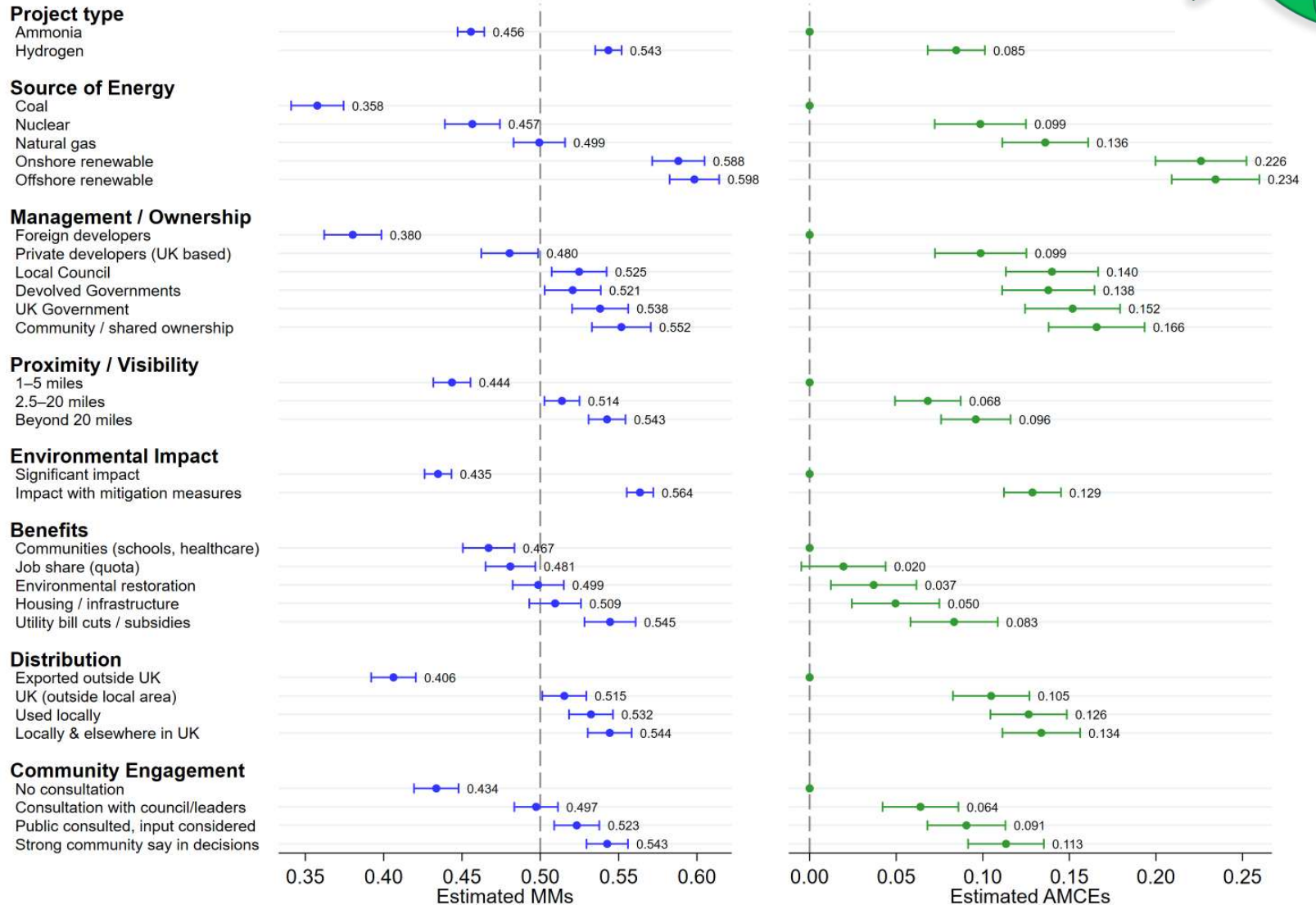
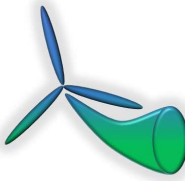
Community Engagement

Basic consultation with local leaders and council

Basic consultation with local leaders and council

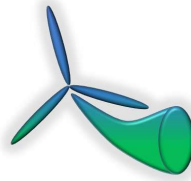


Public Preferences for H2 and NH3 Project Characteristics (Conjoint Experiment)

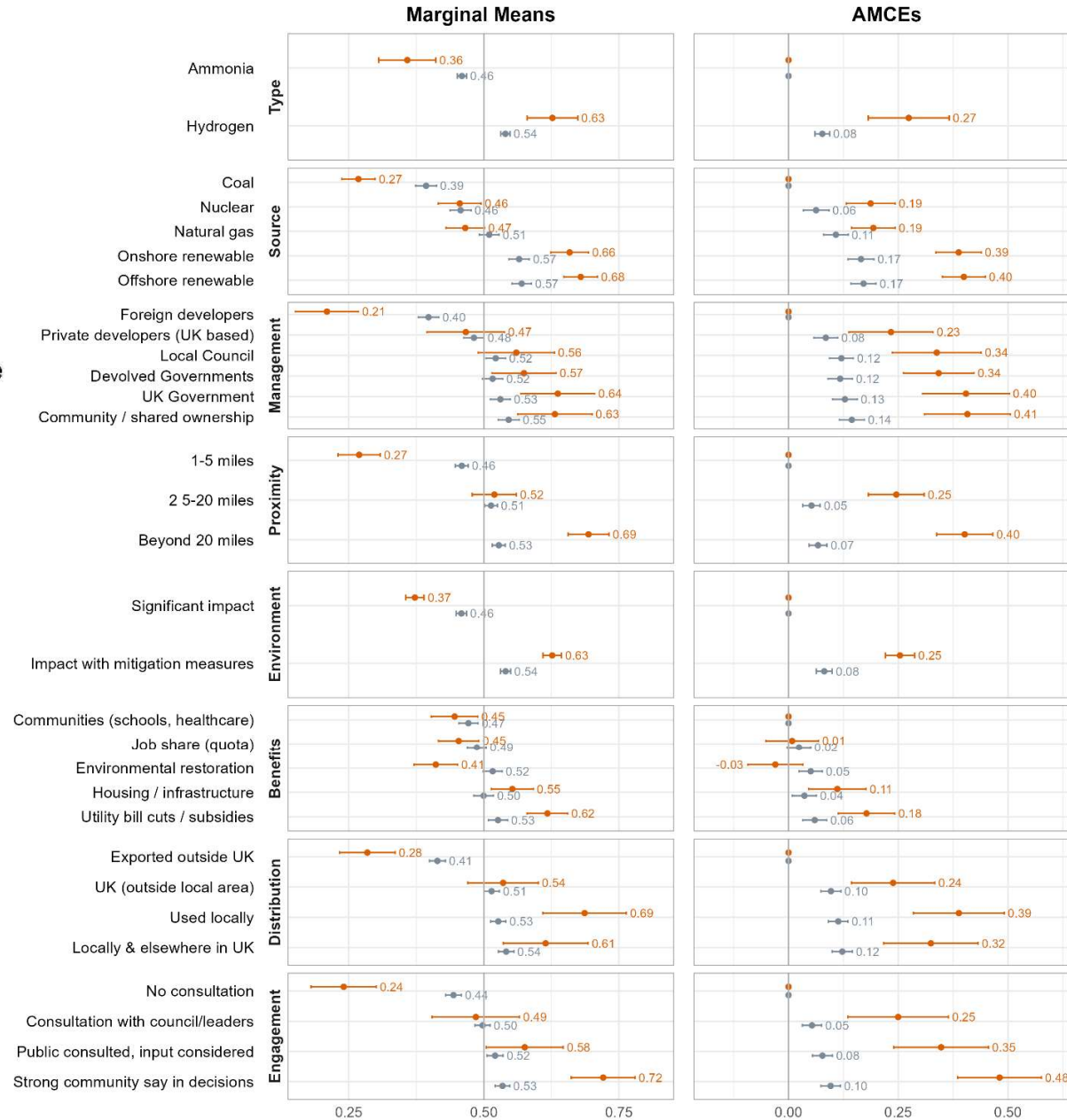


Siddiqi, M.U.A., Poortinga, W., Demski, C. Attribute priorities shape public support for hydrogen and ammonia energy projects. *Nature Communications*. (Under review).

Preferences by Self-Reported Attribute Priority (MMs and AMCEs)



— Others — Most cared for respective attribute



Siddiqi, M.U.A., Poortinga, W., Demski, C. Attribute priorities shape public support for hydrogen and ammonia energy projects. *Nature Communications*. (Under review).



UNIVERSITY OF
BATH

CARDIFF
UNIVERSITY
PRIFYSGOL
CAERDYDD

Preferences for Project Characteristics – National Survey



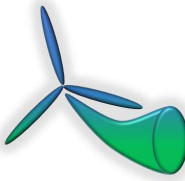
- Hydrogen projects receive higher support than ammonia (public familiarity with both technologies remains low)
- Strong preference for renewable energy sources across political groups, but support varies
- Environmental mitigation increases acceptance, even for green projects
- Community and public ownership increases support
- Fair distribution of benefits is critical (Bill reductions, subsidies)
- UK-wide distribution with local use strongly increase support
- Proximity still affects acceptance
- Engagement strongly improves support
- Public support depends on multiple project features (design choices matter)
- Priority attributes matter more for some groups
 - People who care most about a feature react strongly to changes in that feature
 - Average support scores can hide strong opposition or support in subgroups



UNIVERSITY OF
BATH



Broad Takeaways (Shetland Workshops)



- Participation marked by motivation, curiosity, caution, and occasional confusion
- Preference for ‘green’ hydrogen, with important caveats
- Stronger acceptance of applications in heavy transport and industry
- Scepticism over local benefits vs. fears of becoming an ‘energy dumping ground’
- Key concerns: environmental impacts, scale of development, community benefits
- Very peculiar socio-economic context – industry shouldn’t worry about precedents
- Mistrust linked to information gaps and limited transparency – educational materials
- Strong connections with Renewable Energy Technologies
 - Perceptions of lost control shaped by experiences with past projects (esp. Vikings)
 - Development of and transition to new energy technologies does not occur in vacuum
 - Inherit socio-technical landscape shaped by legacy infrastructure, institutions, actors, and practices
 - Carries forward long-standing public perceptions, collective experiences, and dominant narratives



- Design projects around public priorities
 - Project design should consider different publics, not only overall averages
- Ensure credible mitigation and strong engagement
- Careful management of scale
- Sensitivity to location and visibility
- Expand shared ownership and community benefit mechanisms
- Procedural fairness is as important as technical design
 - Early, meaningful community engagement (strong place attachment)
 - Once public attitudes solidify they are rarely reversed by factual corrections alone
 - Crucial to adopt a proactive approach
 - Target communication to different groups
 - Grounded in an informed understanding of the audience's psychological predispositions.
 - Honest, accessible information from trusted local sources
 - Accessible and relatable public facing educational materials
 - Local impacts must be addressed directly (proximity)
 - Provide clear local benefits



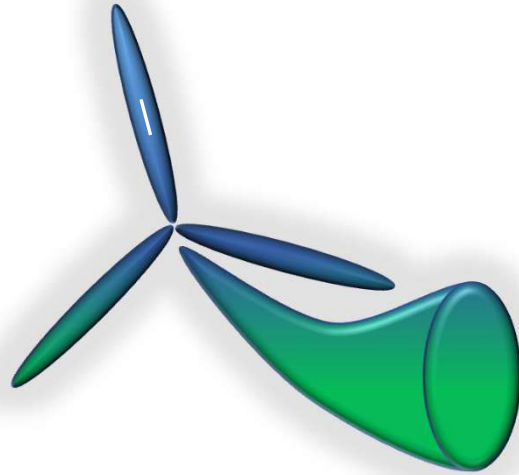
UNIVERSITY of STRATHCLYDE
CENTRE FOR
ENERGY POLICY



UNIVERSITY OF
BATH



Engineering and
Physical Sciences
Research Council



Ocean-REFuel (Ocean Renewable Energy Fuel)

"Next generation Renewable Ocean Energy"

Thank you!

Contact us at karen.turner@strath.ac.uk and
muas21@bath.ac.uk



University of
Nottingham
UK | CHINA | MALAYSIA



UNIVERSITY OF
BATH



University of
Nottingham

UK | CHINA | MALAYSIA

Material Demand for Offshore in the UK

Jorge Llamas
Ben Davies
Akos Cseke
Jon McKechnie





Dynamic Material Flow Analysis

Material Categories

Major Materials

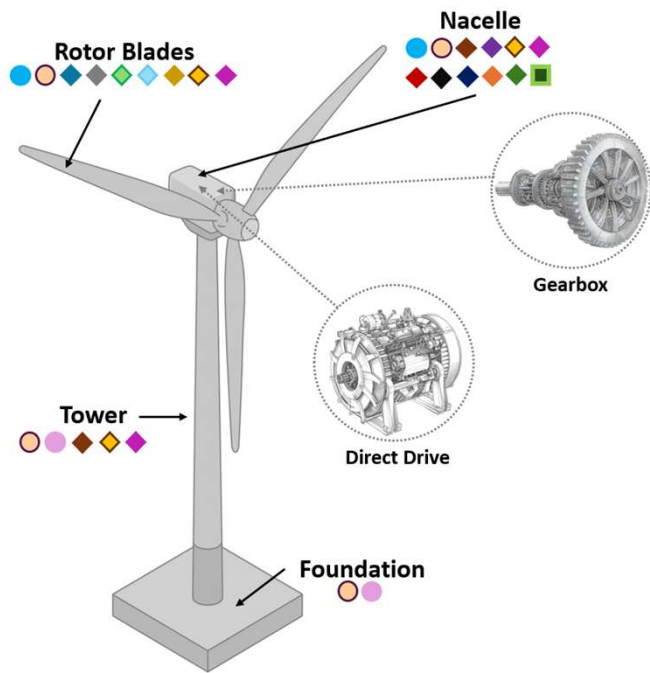
- Iron
- Steel
- Concrete

Core Materials

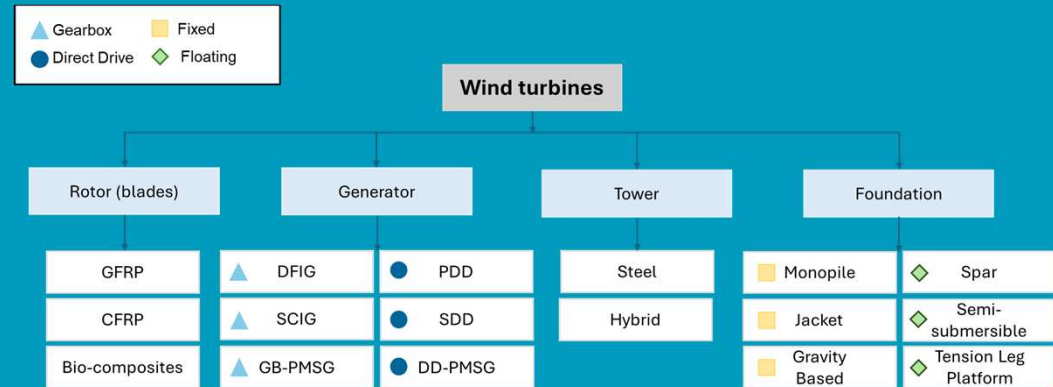
- ◆ Glass fibre
- ◆ Carbon fibre
- ◆ Bio fibre
- ◆ Polymers
- ◆ Resin
- ◆ Boron
- ◆ Copper
- ◆ Aluminium
- ◆ Molybdenum
- ◆ Chromium
- ◆ Manganese
- ◆ Nickel
- ◆ Zinc

Rare Earths

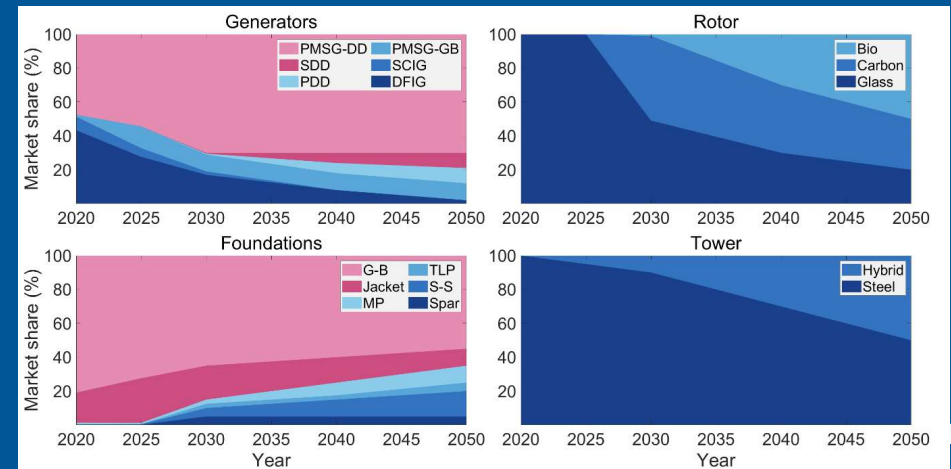
- Neodymium
- Dysprosium
- Praseodymium
- Terbium
- Yttrium



Components / Technology



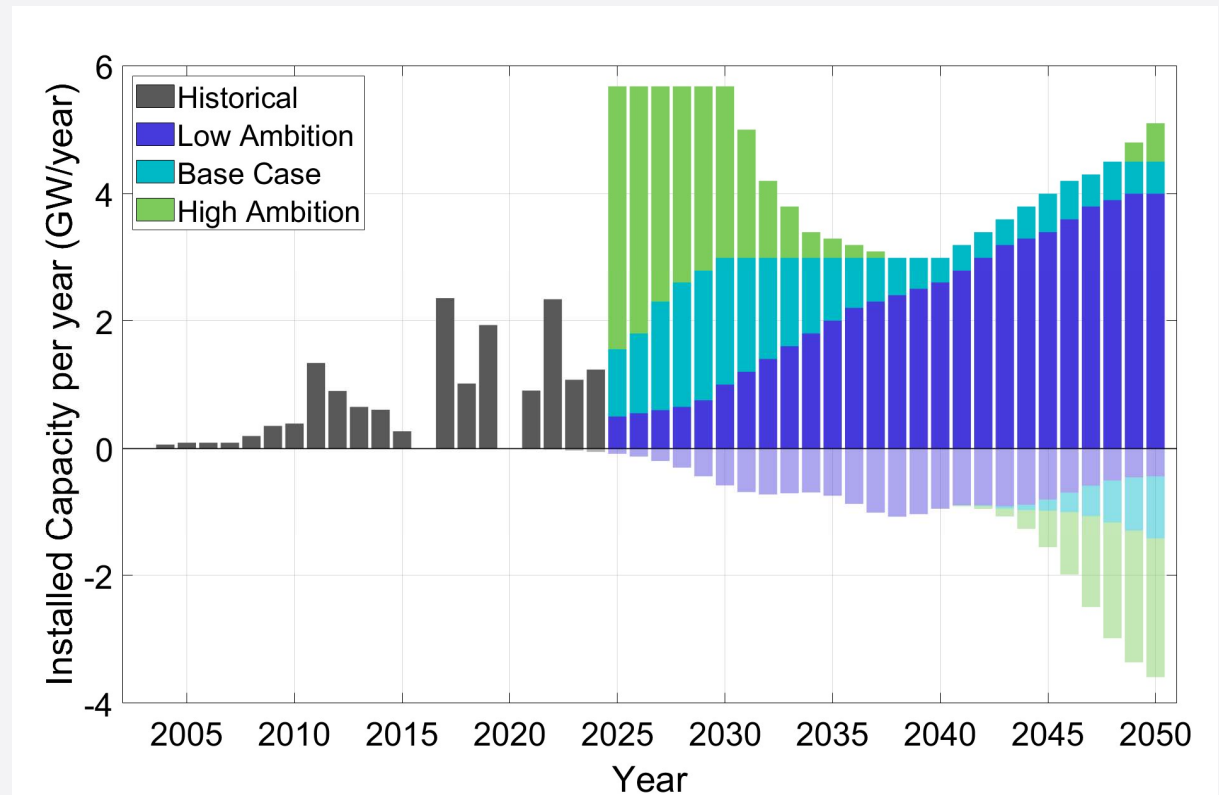
Technology Evolution





Wind installed capacity

| Year | Low Ambition | Base Case | High Ambition |
|------|--------------|-----------|---------------|
| 2025 | 16,621 | 18,288 | 21,621 |
| 2030 | 20,000 | 30,000 | 50,000 |
| 2035 | 30,000 | 45,000 | 67,500 |
| 2040 | 40,000 | 60,000 | 85,000 |
| 2045 | 57,500 | 80,000 | 105,000 |
| 2050 | 75,000 | 100,000 | 125,000 |

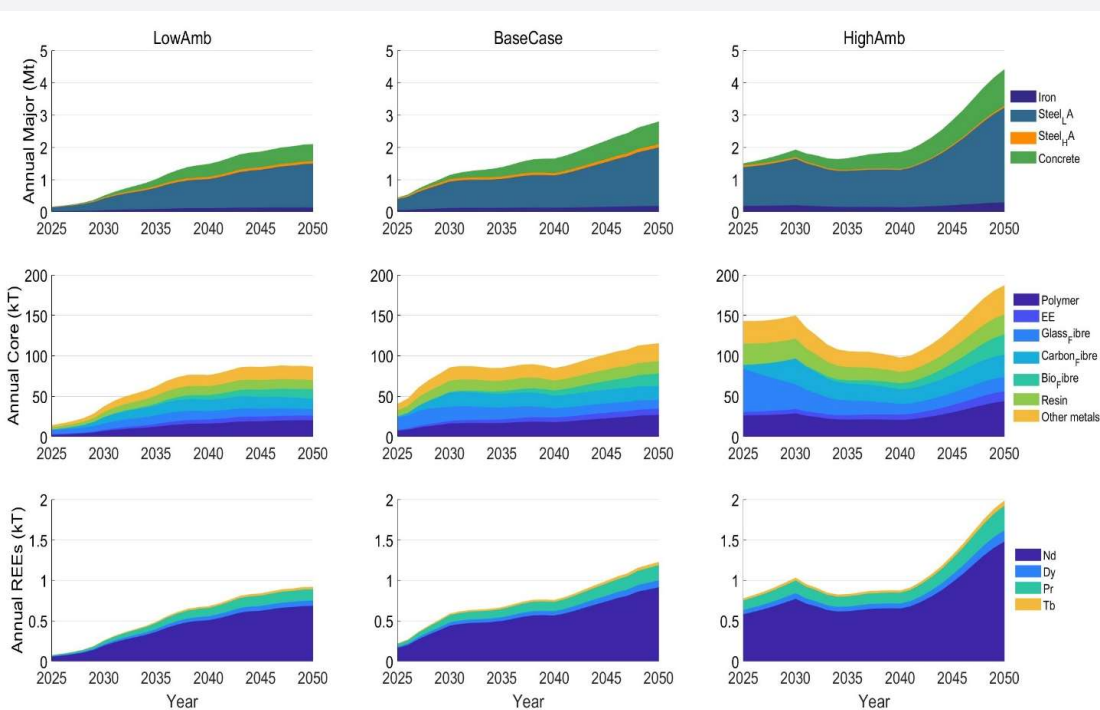




Results



1. Total Wind Material Demand



- **Major materials (steel, concrete, iron)** dominate (>90% by mass), reaching ~4.5 Mt/year by 2050 under High Ambition (vs ~2.1 Mt in Low Ambition).

- **Steel** remains the largest contributor, driven by monopiles and towers.

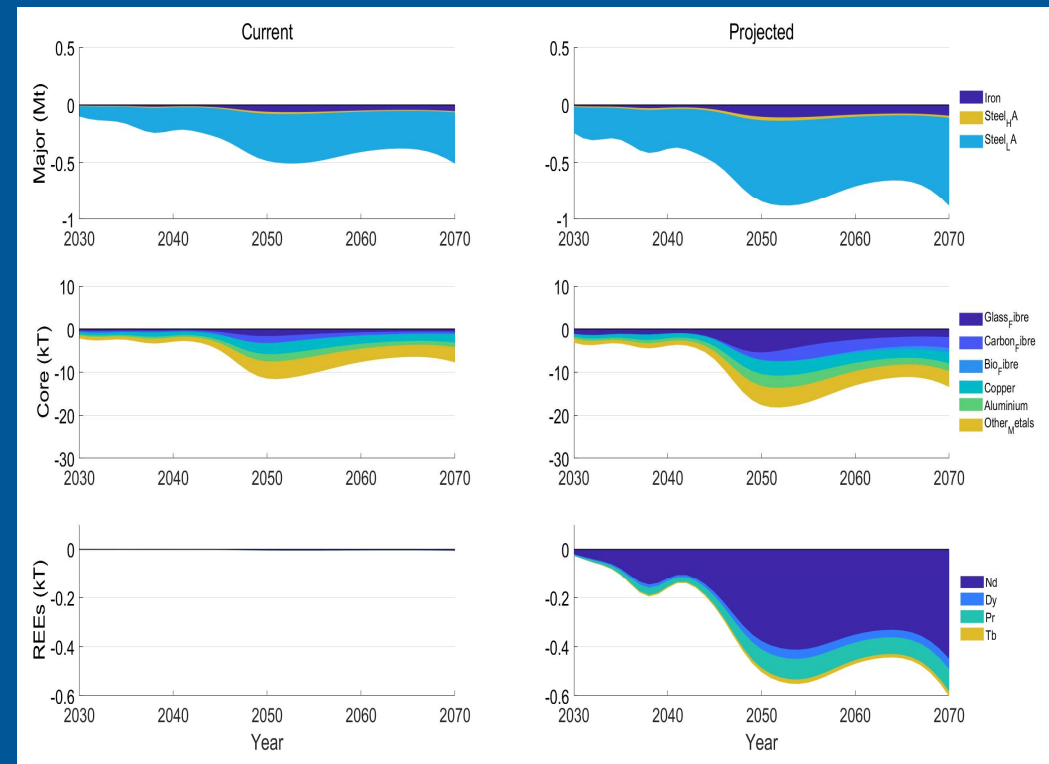
- **Composites (GFRP, CFRP)** grow with larger blades; by 2050 (High Ambition): ~0.29 Mt GFRP and ~0.03 Mt CFRP (~7% of major materials).

- **REE demand (Nd, Dy, Pr)** increases with PMSG deployment (~70% share by 2050); small by mass (<0.1%) but strategically critical.



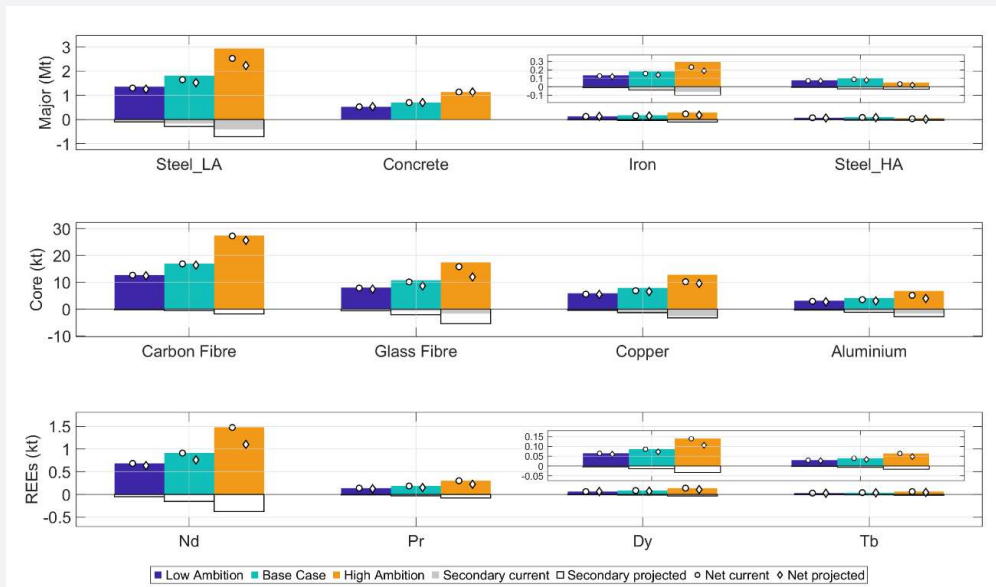
2. Secondary Material Availability

- Under current recycling rates, **secondary supply remains limited**, especially for composites and REEs (>90% virgin dependence).
- Improved recycling could raise fibre recovery to **25–30% (GFRP)** and **10% (CFRP)** by 2050, but volumes remain modest.
- Secondary flows peak after 2045; in a **closed-loop scenario**, they could supply ~25% of major materials, ~47% of core metals, and ~27% of REEs by 2050.
- Even under full circularity, **recycling alone cannot meet future demand**, reinforcing dependence on primary extraction.





3. Total Cumulative Material



- **Major materials dominate cumulative demand**, reaching **34–64 Mt by 2050**, with low-alloy steel as the single largest contributor, driven by foundations and tower structures.
- **Deployment scale directly drives material requirements**: cumulative demand nearly doubles from Low to High Ambition scenarios (**+88%**), highlighting strong sensitivity to capacity expansion.
- **Core materials grow proportionally but remain <1% of total mass**, led by copper and aluminium, reflecting increasing electrical and system complexity of larger turbines.
- **REE demand remains <0.05% of total mass but is strategically critical**, with neodymium dominating (**11–21 kt**), reinforcing supply risk concerns despite low absolute quantities.



Next steps?

- Journal paper about to be submitted.
- Look into LCA downstream processes
 - H2 storage
 - H2 distribution
 - CO2 supply chain in the UK for renewable fuels



University of
Nottingham

UK | CHINA | MALAYSIA

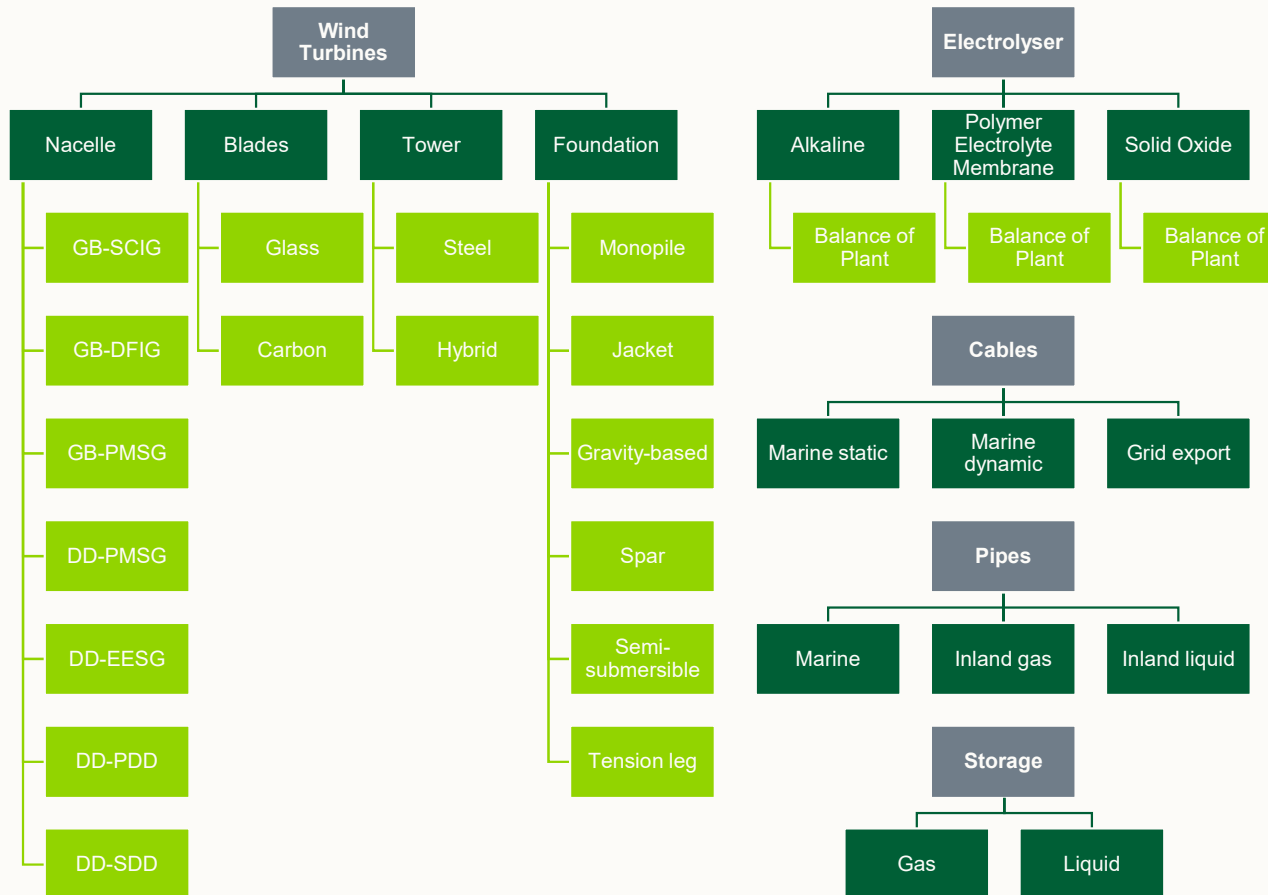
System Integration

Ben Davies





Technology options



- Many options have been defined for the specific technologies of different components.
- Some are defined by the GAMS simulation, i.e. energy transport and storage mode.
- Some are restricted by the offshore sites, i.e. fixed vs floating foundations.
- The remaining technologies can be directed for scenarios or sensitivity.
- Each technology bears an inventory of materials based on the functional unit of the component.



Base Case

- All sites:
 - Direct-drive permanent magnet generation
 - Glass fibre blades
 - Steel tower
 - Alkaline electrolysis
 - Shallow water wind farms:
 - Monopile foundations
 - Deep water wind farms:
 - Semi-submersible floating foundation
- The *Base Case* is defined for the technology that is expected to be used throughout the wind-hydrogen system.
 - Direct-drive permanent magnet synchronous generators are currently the technology of choice for off-shore wind turbines, primarily for maintenance and reliability implications.
 - Glass fibre rotor blades and steel towers are the most common technologies for these components.
 - Shallow water sites tend to monopile foundations:
 - Teesside
 - Dogger Bank
 - Sofia
 - Deeper water sites are predicted to use semi-submersible platforms:
 - NE6 Broadshore
 - NE7 Marram
 - NE8 Buchan
 - Alkaline electrolysis is the most mature electrolysis technology.

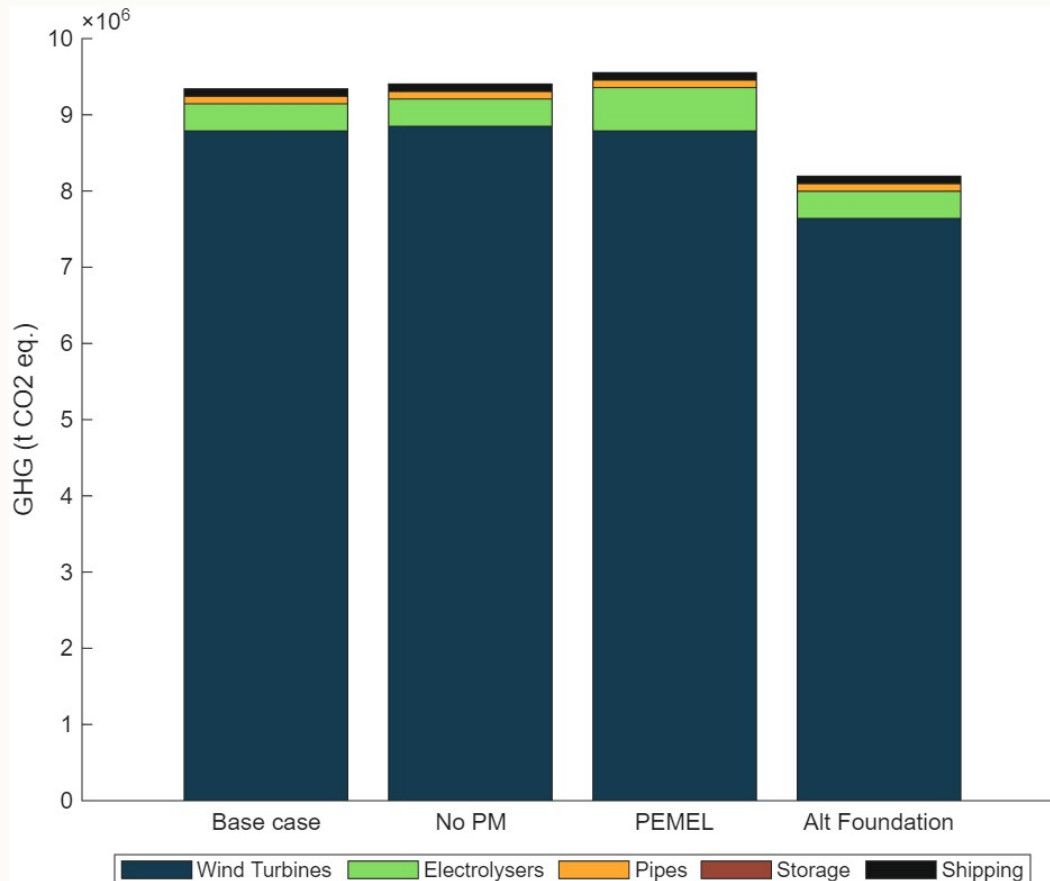


Sensitivity

- No permanent magnets
 - Gearbox induction generator
 - Next-generation electrolysis
 - Polymer electrolyte membrane electrolyser
 - Alternative foundations
 - Gravity-based in shallow water
 - Tension-leg in deep water
- With a wide selection of technologies there is a scope for a lot of scenarios based on different combinations. However, with industrial preferences a few key technologies are selected.
 - Gearbox drive induction generators could mitigate the demand for permanent magnet materials but are expected to be less reliable machines.
 - PEM is enjoying significant focus for low-temperature electrolysis in the future but introduces significant demand for platinum-based catalysts.
 - The alternative foundations technologies test sensitivity to different materials, i.e. steel vs concrete. There may be further ecological impacts (future work).



GHG impacts



- This result shows the LCA greenhouse gas emissions arising from the materials and manufacturing of the offshore wind-hydrogen network, along with the contribution of shipping for hydrogen transportation.
- The majority of GHG emissions are centred in the wind turbines; this is expected as these are comparatively massive components.
- The *Base Case* predicts 9.34×10^6 t CO₂ for the manufacture of all major components, with wind turbines making up 94% of that result, with electrolysers being a further 4%.
- Substituting for *No PMs* increases total GHG emissions by less than a percentage point to 9.40×10^6 t CO₂.
- Utilising *PEM Electrolysis* increases manufacturing emissions by greater than 2% to 9.55×10^6 t CO₂.
- The *Alternative Foundations* decrease manufacturing emissions by 12% to 8.19×10^6 t CO₂. This is due to the much lower emission factor for concrete, compared to steel foundations.
- Emissions credits for end-of-life recycling have been cut-off.



Normalised GHG impacts

Base Case

- 6.904 kg CO₂ eq. / kg H₂
- 57.53 g CO₂ eq. / MJ H₂

No PM

- 6.950 kg CO₂ eq. / kg H₂
- 57.91g CO₂ eq. / MJ H₂

PEMEL

- 7.061 kg CO₂ eq. / kg H₂
- 58.84g CO₂ eq. / MJ H₂

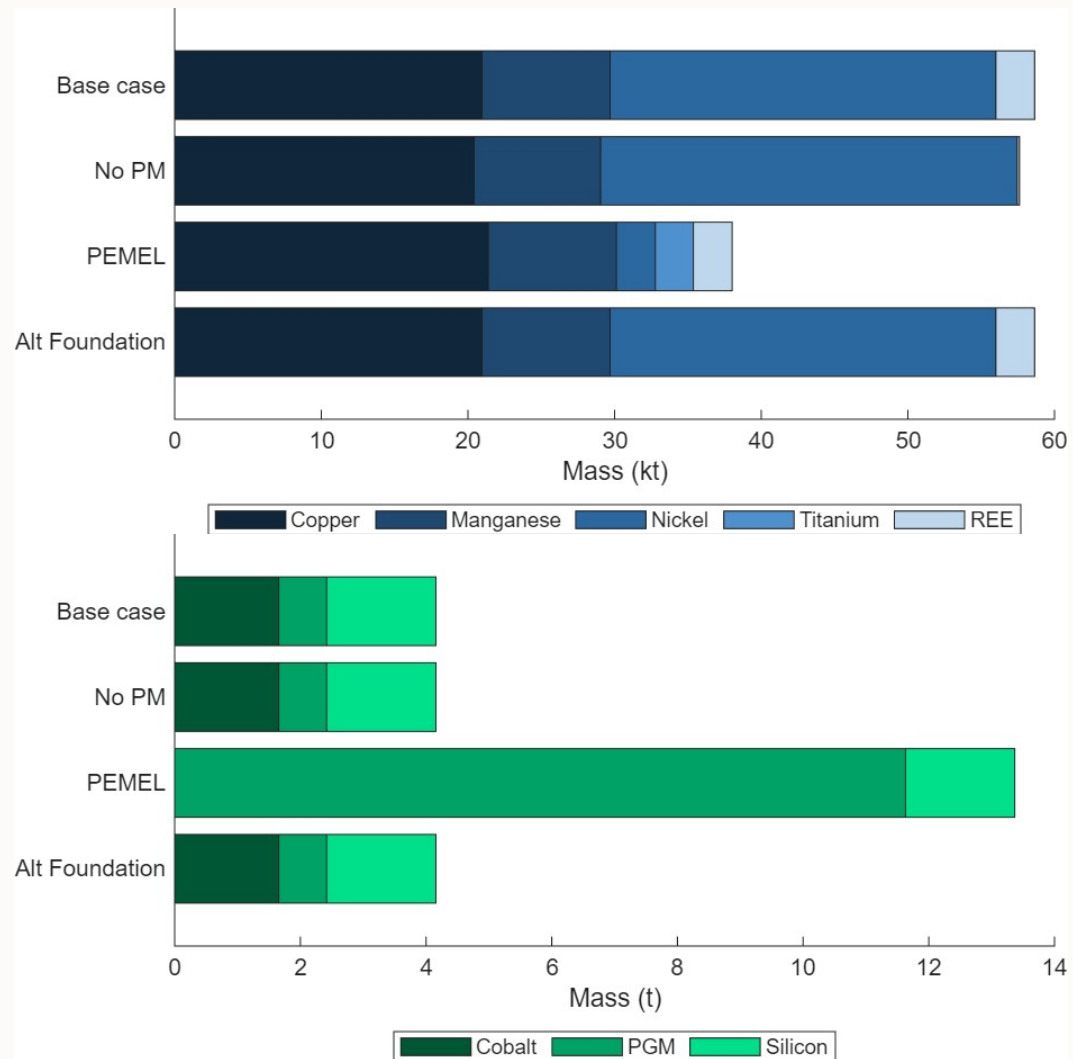
Alt Foundation

- 6.056 kg CO₂ eq. / kg H₂
- 50.46g CO₂ eq. / MJ H₂

- These results frame the GHG impacts against the system performance prediction; a 15 year lifespan, producing 90,000 t of hydrogen per year.
- At approximately 7 kg CO₂ / kg H₂ this production is lower than the expected result for grey hydrogen (10-13) though not as low as the UK's target green-hydrogen standard (~3).



Material demands



- These results show key material demands for the presented scenarios; note that the first figure (blue) is scaled three orders of magnitude greater than the second (green).
- Common features include the demand for copper and manganese in cables and electronic machines, and silicon for pipes.
- The scenarios using alkaline electrolysis see a large demand for nickel for electrodes and cobalt for catalysis. This is substituted for titanium and PGMs in the PEM electrolysis scenario.
- Critical materials such as platinum group metals and rare earth elements make up a small percentage of the overall mass of the system, though can have out-sized influence on the GHG result (previously) due to the emissions intensity of extraction. It is not necessarily appropriate to try to directly compare these material demands, though it is an important factor in the decision making for different technologies.



University of
Nottingham

UK | CHINA | MALAYSIA

Hydrogen Storage Impact Assessment

Raw materials, metal hydrides
and hydrogen tanks

Akos Cseke

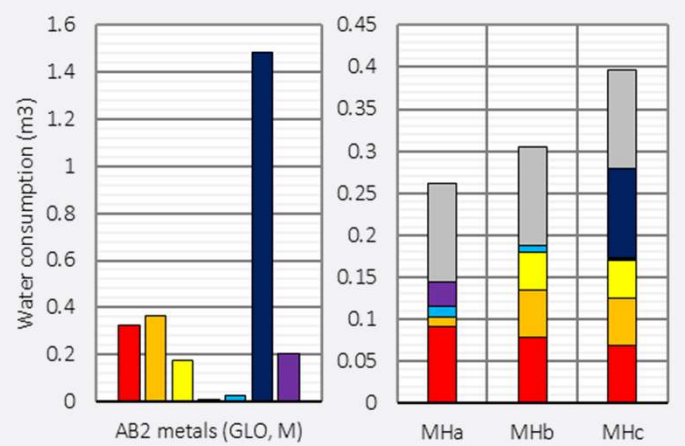
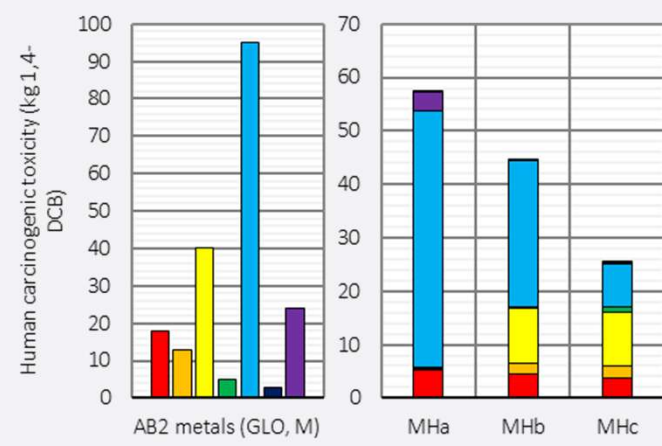
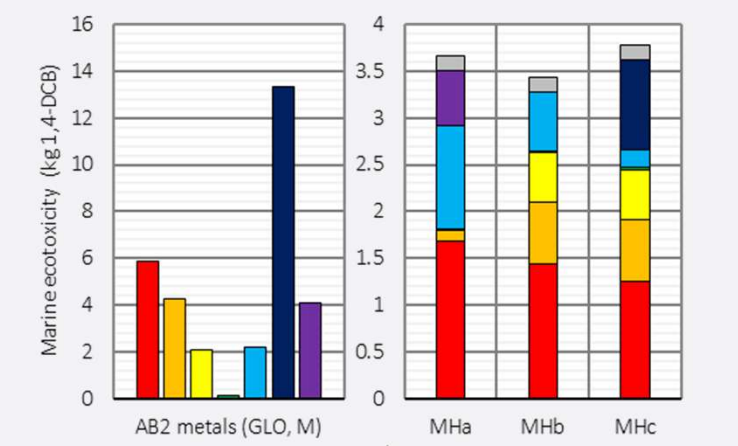
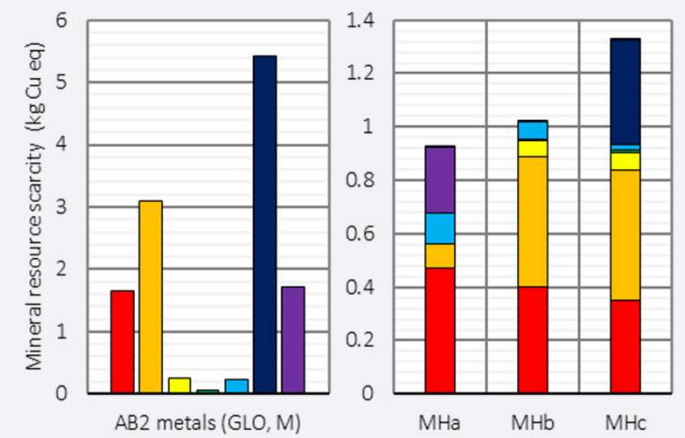
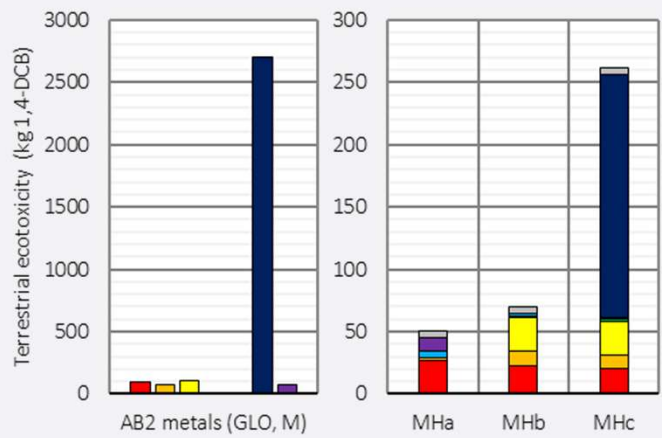
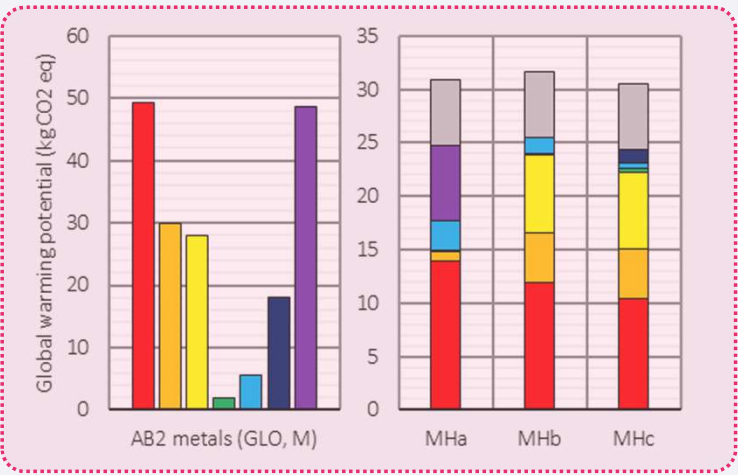




AB2 metal hydride - raw material screening (emission/1 kg)

MHa: $Ti_{0.95}Zr_{0.05}Mn_{1.46}V_{0.45}Fe_{0.09}$ | MHb: $Ti_{0.825}Zr_{0.275}MnCr_{0.8}Fe_{0.2}$ | MHc: $Ti_{0.77}Zr_{0.3}Cr_{0.85}Fe_{0.7}Mn_{0.25}Ni_{0.2}$

■ Ti ■ Zr ■ Cr ■ Fe ■ Mn ■ Ni ■ V ■ Manif.

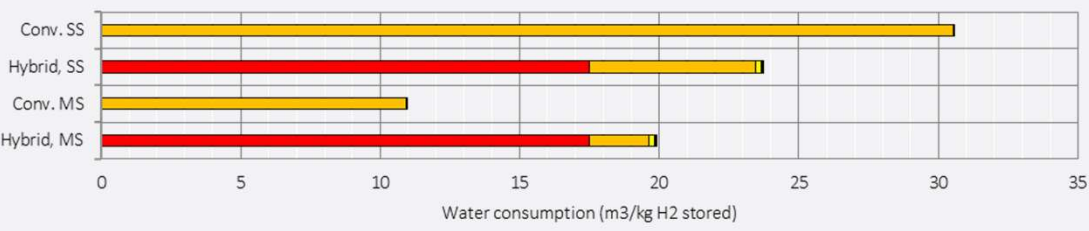
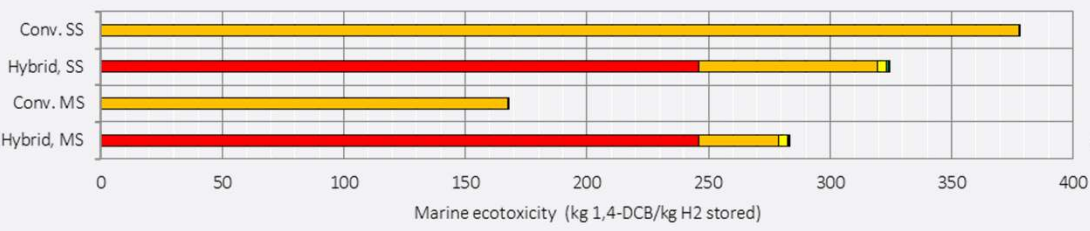
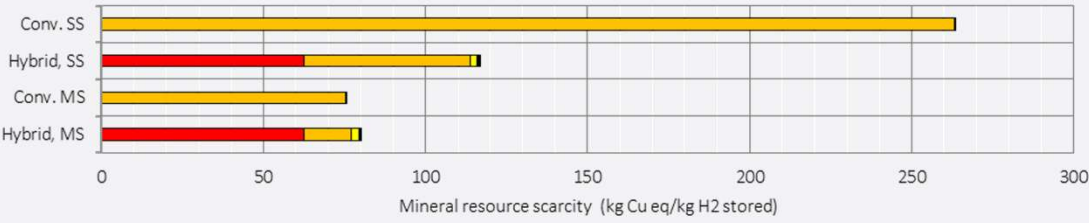
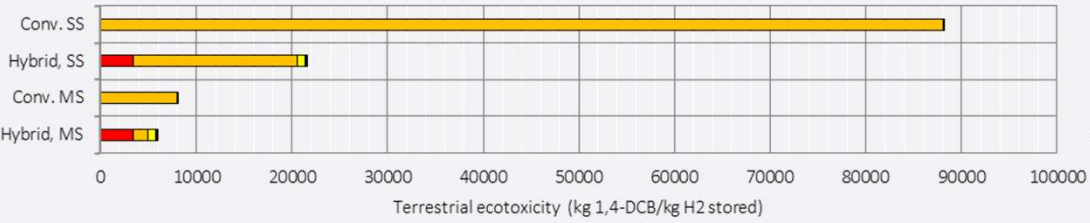
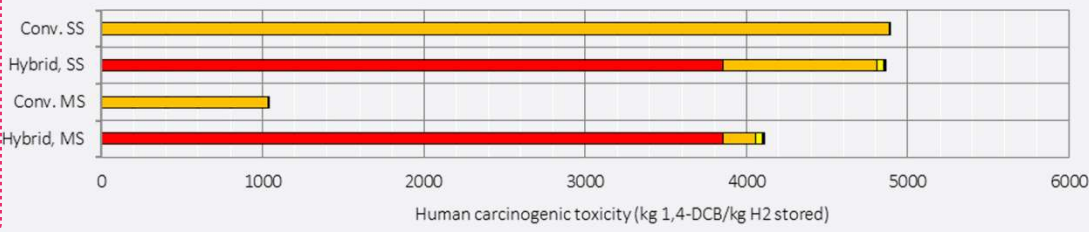
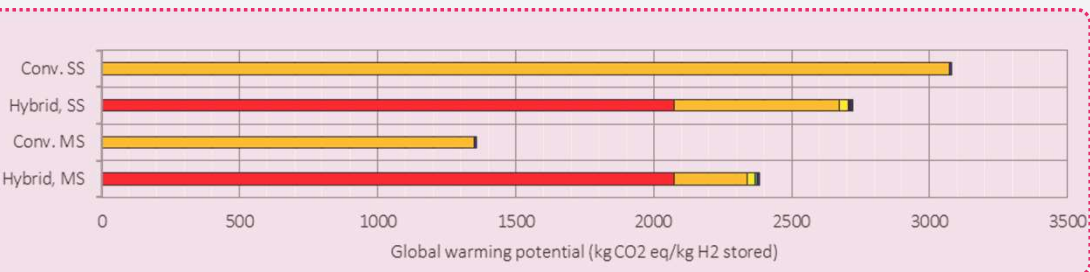




Buffer tank using Hydroalloy C5 (emission/kgH2 stored)

SS: Stainless steel tank | MS: mild steel tank | Conv.: conventional tank | Hybrid: Hybrid MH tank

■ Metal hydride ■ Tank ■ Heat exchanger ■ Blower ■ Pipes ■ Transport





Highlights, limitations, further research and next steps

Highlights

- Importance of MH recycling and reuse.
- Tank size, number of cycles over lifetime (charges - discharges), MH utilisation, MH cycling characteristics (speed) and reusability - all closely interrelated.

Limitations and further research

- Uncertainties in raw materials extraction and processing (incl. geopolitics).
- Number of cycles and required tank size.
- MH recycling/reuse options and end of life (disposal).

Next steps

- Concluded / finish publication.

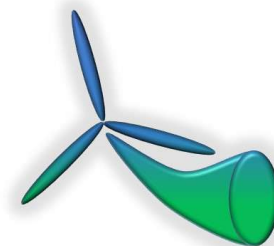


University of
Nottingham

UK | CHINA | MALAYSIA

Thank you





Questions and discussion

**Ocean Refuel funded by
EP/W005204/1**



**UK Research
and Innovation**

