Supergen
Offshore Renewable Energy
Autumn Assembly
University of Oxford
Thursday 29 September 2022
www.supergen-ore.net | #SupergenORE22

Multi Energy Vector Demonstration Project Feasibility Study:

Decarbonising Shipping Utilising Renewable Hydrogen

Dr Matt Allmark*, Dr Stephanie Ordonez-Sanchez, Dr Matt Lewis and Dr Alberto Roldan Martinez, Bertie Webster, Chris Shaw, Julia Komar, Molly Isaacs

*allmarkmj1@Cardiff.ac.uk

Cardiff University
Prifysgol Caerdydd
University of Strathclyde Engineering
Prifysgol Bangor University

Supergen Energy Networks
Supergen Offshore Renewable Energy
Supergen Energy Storage

Project Background

- Supergen Cross-Hub 'Seedcorn' funding.
- Project Aims:
  - 'to assess the feasibility constructing a UK based demo of utilizing green hydrogen-based fuels to power industrial shipping activities.'
  - Can this be done using curtailed OSW power.
- Funding of 20K: limited RA time, student placements.

Sector Reviews

Green Hydrogen Production:

Fuel	Hydrogen			Ammonia	Methanol	Synthetic methane
Synthesis method	**Alkaline electrolyser**	**PEM electrolyser**	**Solid oxide electrolyser**	**Low-carbon Haber-Bosch**	**Hydrogenation**	**Methanation**
Feedstock	H_2O, KOH, Ni cat.[4]	H_2O, polymer membrane, Pt/ Ir cat.[4, 18]	H_2O, ceramic cell membrane[4]	Green H_2, N_2, metal cat.[8, 23]	Green H_2, CO_2, metal cat.[4]	Green H_2, CO/CO_2[4]
Energy demand	50-73 MWh/t[4]	47-73 MWh/t[4]	37 MWh/t[4]	12.5 MWh/t[4]	11.02 MWh/t[4]	26.9 MWh/t[4]
Efficiency	60-70%[3]	65-80%[3]	60-65%[3]	55-60%[23]	-	-
TRL	7-9[4]	7-8[4]	6-7[4]	7[4]	7[4]	6-7[4]
Storage	Liquified below -250∘C[7] / compressed up to 800 bar[29]			Liquified at 80 bar or -33∘C[8]	Liquid at ambient T and p[7]	Liquified at -162∘C (prior purification)[4]
Carbon footprint	0.56 tCO_2eq/tH_2[4]			0.12 tCO_2eq/tNH_3[4]	-0.67 tCO_2/tCH_3OH[4]	-1.31 tCO_2/tCH_4[4]
Good interaction with renewable energy	No[17]	Yes[12]	No[12]	Yes[23]	Yes, with a H_2 storage unit[4]	Yes[4]
Cost	650-1200 €/kW[4]	1,000 €/kW[4]	1,000 – 2,000 €/kW[4]	735-800 €/t[4]	400-600 €/t[4]	2000-3500 €/t[4]

Green Hydrogen Utility:

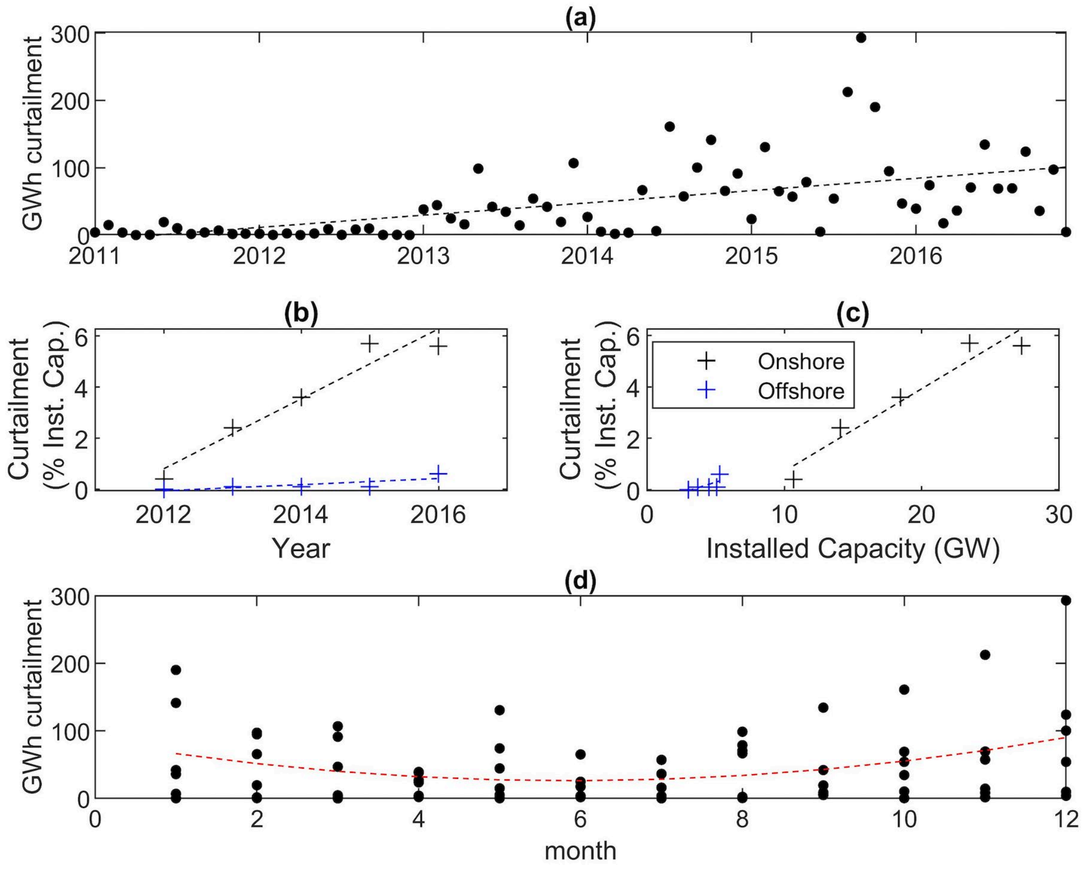
Technology	TRL	Fuel Type	Fuel Volumetric Energy Density [GJ/Nm3]	Power and Propulsion Technology	Auxiliary Technologies	Fuel to Power efficiency %	On board Volumetric requirements m3 *	CO2 Emissions kgCO2/G	NOx Emissions % of HFO	SOx Emissions %of HFO
Current technology	9	Heavy fuel oil	35[2]	Combustion	Scrubbers		1,000[2]		100%	100%
Hydrogen AFC		Hydrogen liquefied - 253°C	8.5[2]		Insulation, cryogenic storage	50-60[5]	4,117[2]		Not avoided	0%
Hydrogen PEMFC		Hydrogen liquefied - 253°C	8.5[2]		Insulation, cryogenic storage	50-60[5]				0%
Two stroke Hydrogen combustion engine	6	Hydrogen compressed 700 bar	7.5[2]	Internal Combustion engine			4,667[2]		0%	0%
Hydrogen Gas Turbine	6[4]	Hydrogen compressed 700 bar	7.5[2]	Gas Turbine					0%	0%
Two stroke Ammonia combustion engine	5	Ammonia at 10 bar	12.7[2]	Internal Combustion engine		85[5]	2,755[2]	5%		5-10%
Ammonia SOFC	6/7?	Ammonia at -34°C	12.7[2]	SOFC						0%
four stroke Otto-cycle engine	9[3]	Methanol	15.8[1]	four stroke Otto-cycle engine				90% of HFO?	~40%[6]	10%[6]
Two stroke dual fuel engine	8/9 - Commercially ready	Methanol	15.8[1]	Two stroke diesel engine	EGR or SCR systems to reduce NOx		2,215[2]	90% of HFO?	~70%	0%
Two stroke LNG combustion engine	8	Hydrocarbon mainly methane	118% MJ/kg 43%kg/m3 Of HFO	Combustion			~2 times HFO	26% of HFO?	70-80%	1-10%

Supergen Energy Networks
Supergen Offshore Renewable Energy
Supergen Energy Storage

Cardiff University Prifysgol Caerdydd
University of Strathclyde Engineering
Prifysgol Bangor University

Modelling Green H_2 Production for Bulk Liquid Shipping

- Using curtailed OSW wind power to produce green hydrogen – how far can a LNG tanker travel?
- Test case: LNG Tanker energy consumption: 1.89 km/MWh [1].
- We consider, hydrogen combustion at 40% and Fuel Cells at 55 %, efficiency.



Modelling Green H_2 Production for Bulk Liquid Shipping

Model Overview

Model Length: 1 year; Model Resolution: 10 min

Wind Data: Weibull Sampling

Turbine Rating – 3.6 MW (SWT 3.6) Cp – 0.35;

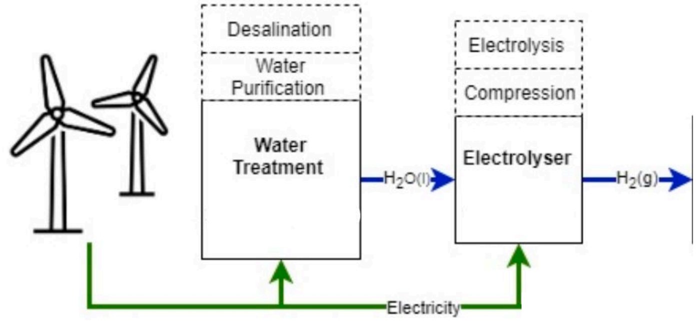
No Columns 5; No. Rows 5

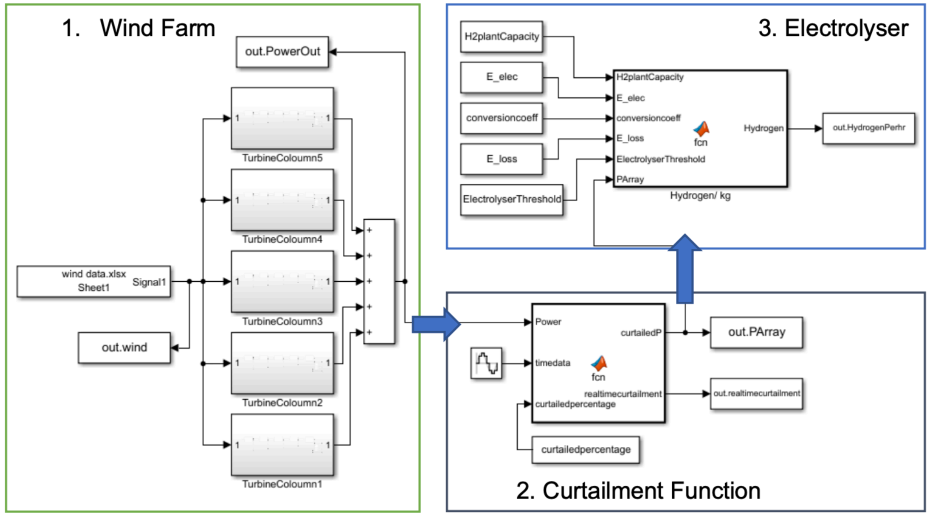
Turbine Modelling – Power Curve
Downtime Modelling – Average down time [2]
Wake Modelling - Park Wake model [3]

Hydrogen Modelling – PEM Electrolyser adapted from [4]

$$m_{H_2} = \frac{E_{curt}}{\frac{E_{elec}}{\eta} + E_{Osm} + E_{Comp}}$$

Curtailment Modelling – Based on Balancing Mechanism data (Elexon) [4]





Modelling Green H_2 Production for Bulk Liquid Shipping

Conclusions

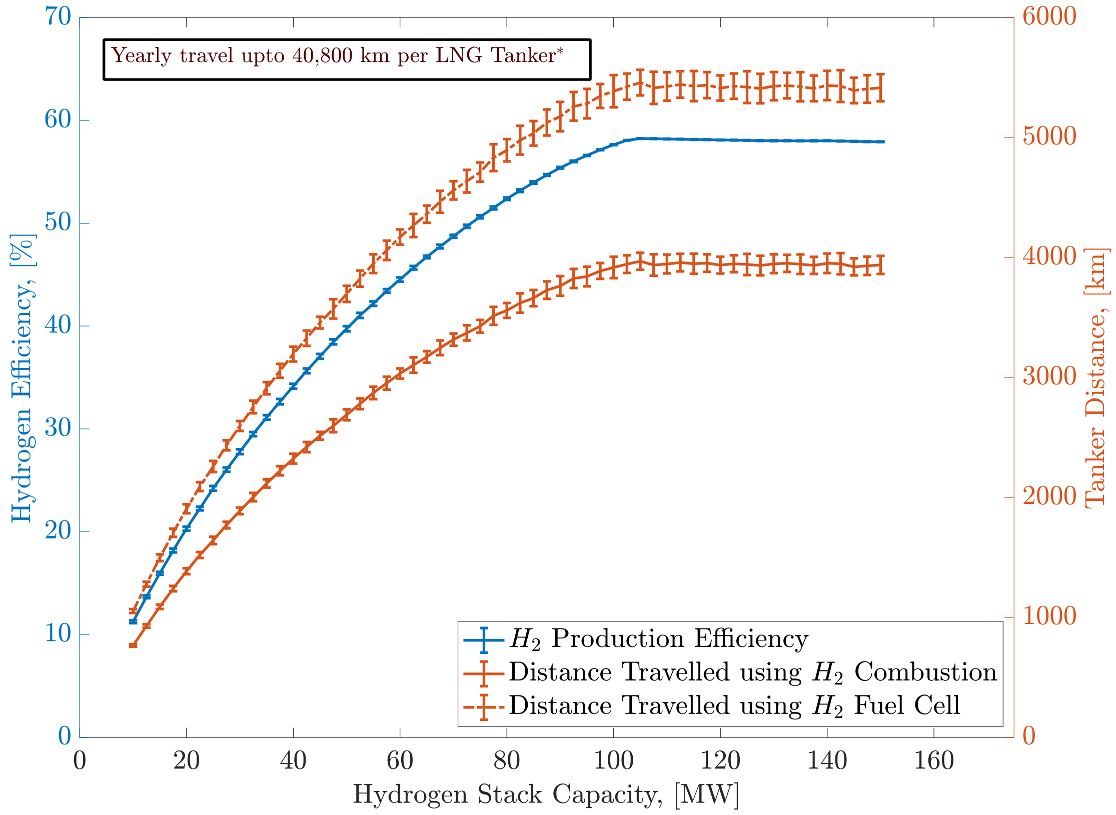
- Curtailment based demo is seems unfeasible

- Curtailment rates growing in both offshore and onshore contexts.

- For the ~100 MW array, max distance travelled by LNG tanker is ~4,000km at 8% curtailment rate.

Analysis shows high sensitivity to installed electrolyser capacity, curtailment rate and kWh/kg of hydrogen.

Curtailment /%	Compressed H2 /tonnes per year	Hydrogen Energy /MWh	Car Range /1000km	LNG tanker range /km	Homes powered via Fuel cell
5.5	146	4870	12514	3682	812
8.5	230	7659	19714	5790	1277
14	374	12470	32057	9427	2078
22	590	19630	50571	14840	3271



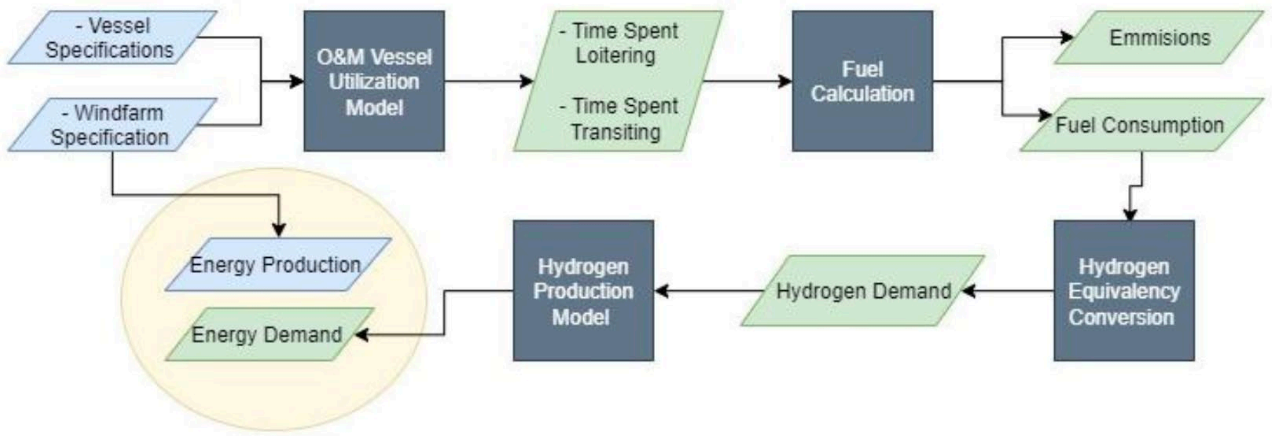
*Based on statistics presented in [1]

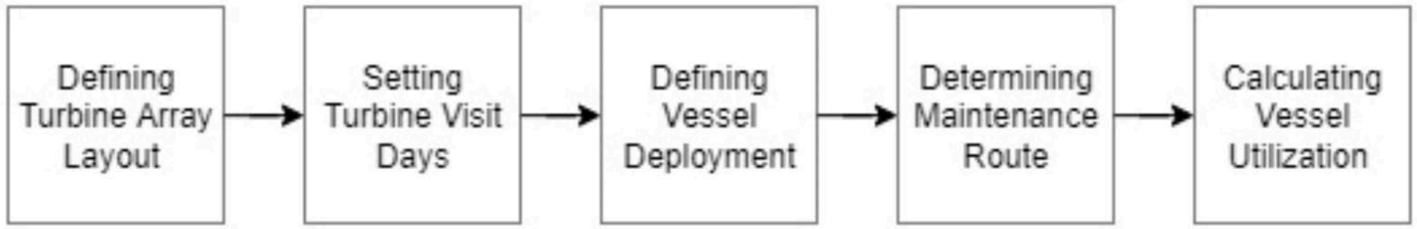
Modelling OSW Maintenance powered via H_2

Model Overview

Windfarm:
No turbine 72,
Number of Columns/rows: 9/8, Column/Row
Spacing: 3km/2.5km
Distance from Port: 8 km
Turbine Visit Rate: 0.052.

Vessel Spec:
Type: CTV
Transit Speed: 48.2 km/h
Fuel Consumption Idling: 130 L/h
Fuel Consumption Transit: 320 L/h





Modelling OSW Maintenance powered via H_2

Key Findings:

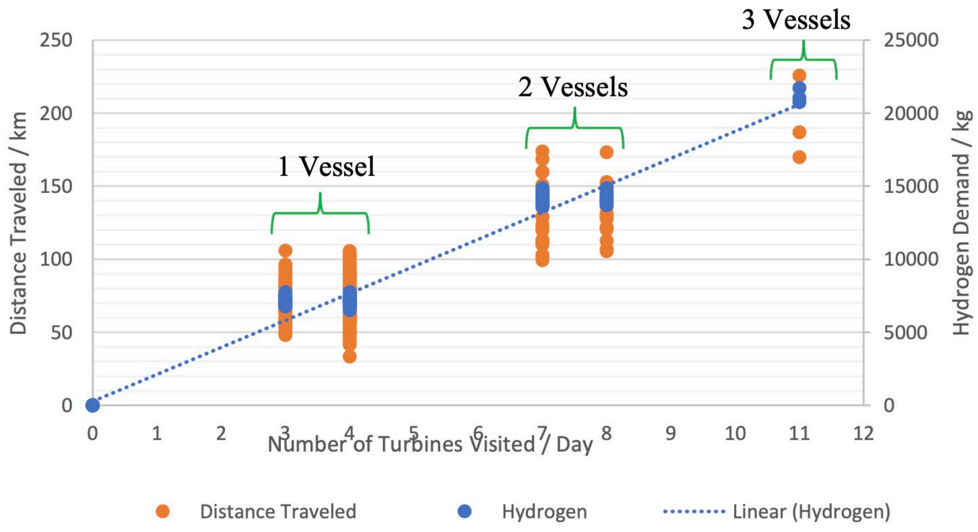
MO-VUMA Tool developed, simulating O&M vessel movements.

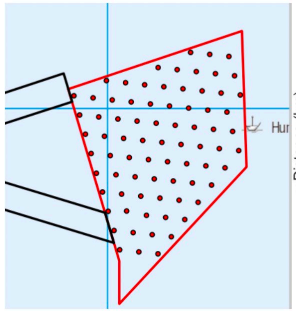
Applied to Humber Gateway Windfarm.

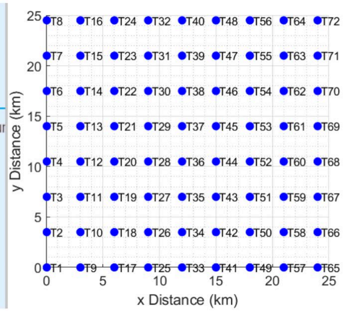
Annually 582,262 L of MGO used.

Equivalent H_2 demand: 242,151 kg/H_2

Would require 16-18% of Humber Gateways' energy output.







Conclusions

- Offshore H_2 production model produced and illustrated – inclusion of downtime, curtailment variation, wind variation, array structure.
- Development of MO-VUMA Tool developed, simulating O&M vessel movements.
- Current models suggest that curtailment based green hydrogen pilot infeasible.
- ~17% of Humber Gateway array energy would be required to power O&M activities.

Any Questions?

References:

[1] Millborrow, D. 2010. Breaking down the cost of wind turbine maintenance. *Windpower Monthly* 15 June. Available at: Breaking down the cost of wind turbine maintenance | Windpower Monthly

[2] Rabia Shakoor, Mohammad Yusri Hassan, Abdur Raheem, Yuan-Kang Wu, Wake effect modeling: A review of wind farm layout optimization using Jensen׳s model, Renewable and Sustainable Energy Reviews, Volume 58, 2016, Pages 1048-1059, https://doi.org/10.1016/j.rser.2015.12.229.

[3] Dinh, N. Leahy, P. McKeogh, E. Murphy, J. and Cummins, V. 2020. Development of a viability assessment model for hydrogen production from dedicated offshore wind farms. *International Journal of Hydrogen Energy* 46, pp. 24620-2463, https://doi.org/10.1016/j.ijhydene.2020.04.232

[4] Michael Joos, Iain Staffell, Short-term integration costs of variable renewable energy: Wind curtailment and balancing in Britain and Germany, Renewable and Sustainable Energy Reviews,
Volume 86, 2018,Pages 45-65, https://doi.org/10.1016/j.rser.2018.01.009.

[5] McKinlay, C. Turnock, S. and Hudson, D. 2021. Route to zero emission shipping: Hydrogen, ammonia or methanol. *International Journal of Hydrogen Energy*. 46 pp. 28282-28297. Doi: https://doi.org/10.1016/j.ijhydene.2021.06.066