Celtic Sea FLOW – potential range of regional manufacturing opportunities.


Photo courtesy of Principle Power. Artist: DOCK90

Morning Session - 10:30-12:00PM

Monday 12 June 2023

Cornwall FLOW Accelerator

CELTICSEAPOWER NERTHMORKELTEK

CATAPULT Offshore Renewable Energy

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CELTIC SEA CLUSTER

OUR 10 YEAR IMPACT

10 YEARS OF CATAPULT
Offshore Renewable Energy

£677M

At the heart of over £677m of innovation projects by total value

148

Instrumental in bringing 148 innovative new products and services to market

1350

Over 1350 UK SMEs supported

650

Partnered in over 650 research & development projects

250

Over 250 research a analysis papers published

OUR CONTACT DETAILS

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GLASGOW

BLYTH

LEVENMOUTH

GRIMSBY

ABERDEEN

CHINA

LOWESTOFT

PEMBROKESHIRE

CORNWALL

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Welcome

Julie Taylor – ORE Catapult South West Innovation Manager

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Welcome

- Housekeeping
- Both a.m. and p.m. webinar sessions will be recorded
- Questions – Please use Zoom Q&A function, not the Chat (although this will be monitored)
- Slides – These will be uploaded to Celtic Sea Cluster website: https://celticseacluster.com/
- Timetable

Timetable

PARTICIPANTS/PRESENTERS	ORGANISATION	TITLE	MINS	START	END
		MORNING SESSION			
Julie Taylor	**ORE Catapult**	Welcome. Housekeeping. Outline of morning.	5	10:30	10:35
Simon Cheeseman	**ORE Catapult**	ORE Catapult. Celtic Sea Cluster Global Offshore Wind Market Cornwall FLOW Accelerator.	10	10:35	10:45
Tom Quinn	**ORE Catapult**	FLOW in the Celtic Sea – Size & Scope. Leasing round and CfD updates.	15	10:45	11:00
All		Q&A	5	11:00	11:05
Konstantinos Bacharoudis	**ORE Catapult**	Blades	15	11:05	11:20
All		Q&A	5	11:20	11:25
Dylan Duncan	**ORE Catapult**	Towers & Foundations	20	11:25	11:45
All		Q&A	5	11:45	11:50
Julie Taylor	**ORE Catapult**	Wrap Up.	10	11:50	12:00
Total			90		

Timetable

PARTICIPANTS/PRESENTERS	ORGANISATION	TITLE	MINS	START	END
		AFTERNOON SESSION			
Julie Taylor	**ORE Catapult**	Welcome. Housekeeping, Outline of afternoon.	5	14:00	14:05
Simon Cheeseman	**ORE Catapult**	ORE Catapult. Celtic Sea Cluster Global Offshore Wind Market Cornwall FLOW Accelerator	10	14:05	14:15
Tom Quinn	**ORE Catapult**	FLOW in the Celtic Sea. Size & Scope. Update on leasing and CfD rounds.	15	14:15	14:30
All		Q&A	5	14:30	14:35
Scott Davie	**ORE Catapult**	Anchoring & Mooring Systems	15	14:35	14:50
All		Q&A	5	14:50	14:55
Bradley McKay	**ORE Catapult**	Electrical Infrastructure	15	14:55	15:10
All		Q&A	5	15:10	15:15
Julie Taylor	**ORE Catapult**	Wrap Up.	10	15:15	15:25
Total			85		

Offshore Wind and FLOW Context

Simon Cheeseman – ORE Catapult South West Programme Manager

Catapult Offshore Renewable Energy

Simon Cheeseman

- Work for Offshore Renewable Energy Catapult, as South West Programme Manager running offices in Cornwall and Devon. Delivering strategy to accelerate floating wind in the Celtic Sea.
- Background is managing complex, multi partner, multimillion pound projects in renewables both in the public and private sectors.
- Sit on the Board of the Celtic Sea Cluster and represent ORE Catapult on the Celtic Sea Developers Alliance.

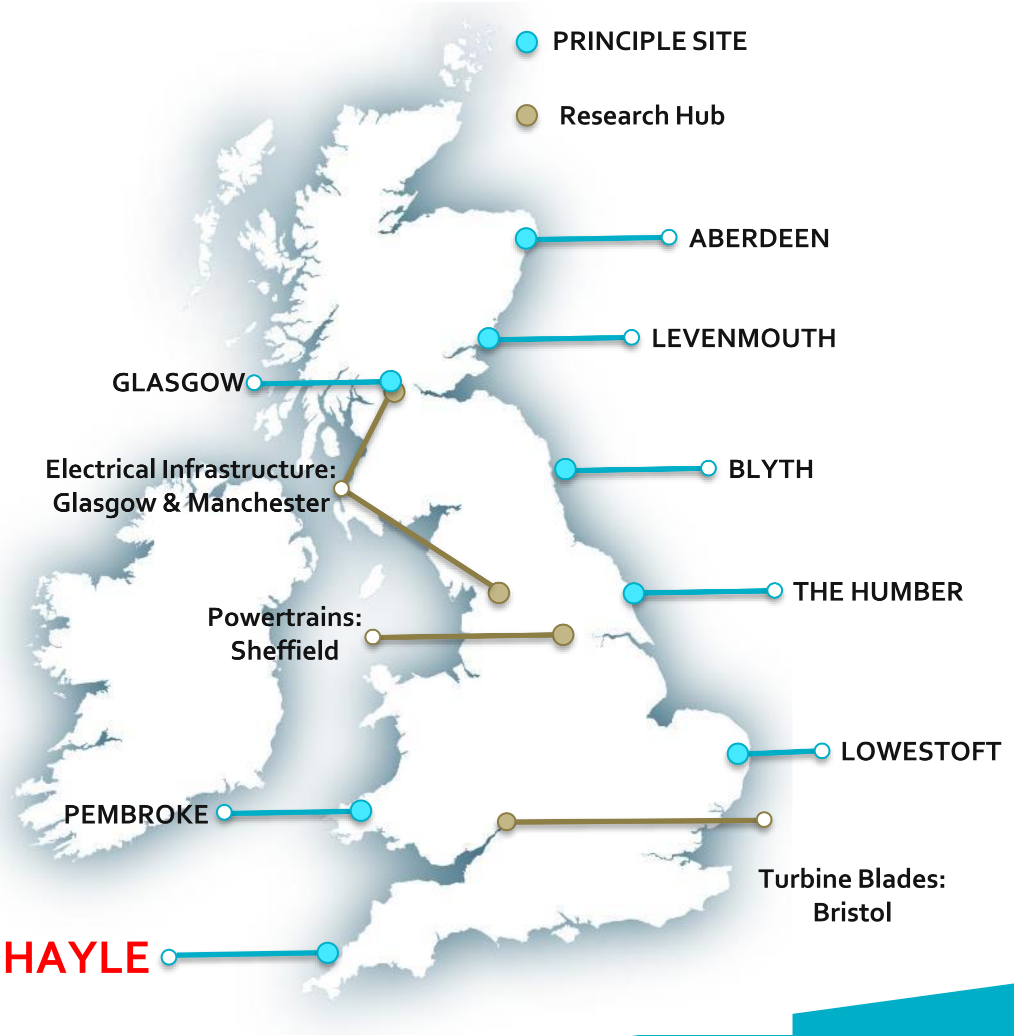
CATAPULT Offshore Renewable Energy

About ORE Catapult

Our Mission:

Deliver the UK's largest clean growth opportunity by accelerating the creation and growth of UK companies in offshore renewable energy.

1. 300+ staff including engineering and research experts with deep sector knowledge
2. Independent and trusted partner
3. Work with industry and academia to commercialise new technologies
4. Reduce the cost of offshore renewable energy
5. Deliver UK economic benefit



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Celtic Sea Cluster Publications and Case studies [Resources]

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Resources

Search this section to find publications and case study resources produced for and by the Celtic Sea Cluster and other relevant organisations.

Filter by type: **Select resource type**

Filter topic: **Select topic**

01 June 2023

New Report: E^C Simulator Impact Case Study

21 April 2023

New Report: Manufacturing Variants and Future Steps.

17 March 2023

New Report: Innovation in Low Carbon Design and Manufacturability The South-West Transmission Network and Floating Offshore Wind Optimization in the Celtic Sea

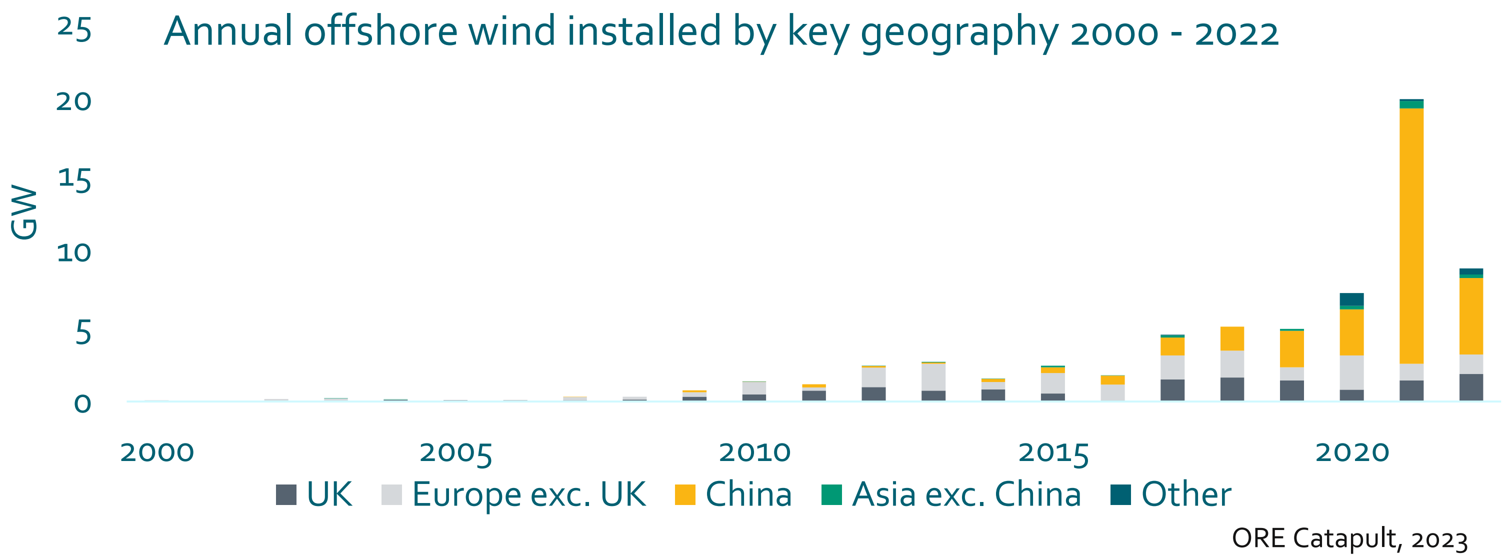
16 March 2023

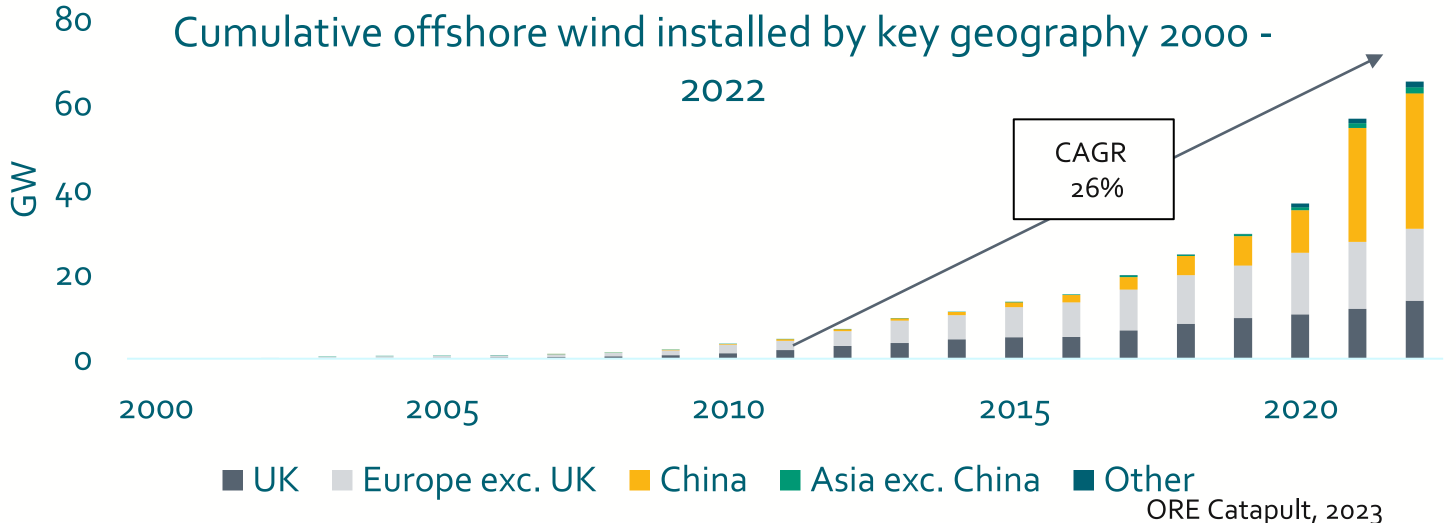
New Report: Innovation in Low Carbon Design and Manufacturability The Future Potential Role of Offshore Multipurpose Connectors

Global offshore wind growth

Offshore Renewable Energy

Offshore wind global capacity to date





- Up to 2015, offshore wind very much a European play
- Generally, countries building on existing onshore wind expertise
- China overtook the UK as the world's leader in offshore wind capacity after installing 16.9GW in 2021.

- UK share of capacity falling from peak 53% in 2012 to 21% in 2022
- Total Europe share falling from 91% in 2012 to 47% in 2022
- Compound Annual Growth Rate from 2010 to 2020 of 27%

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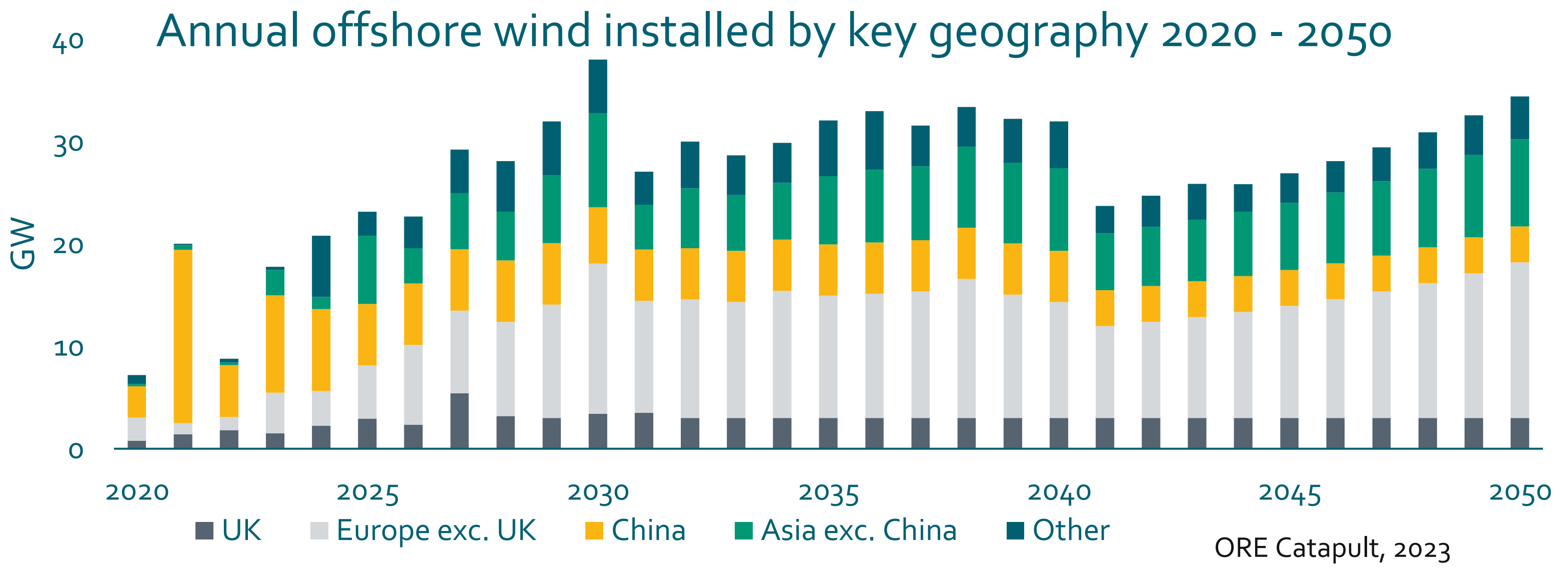
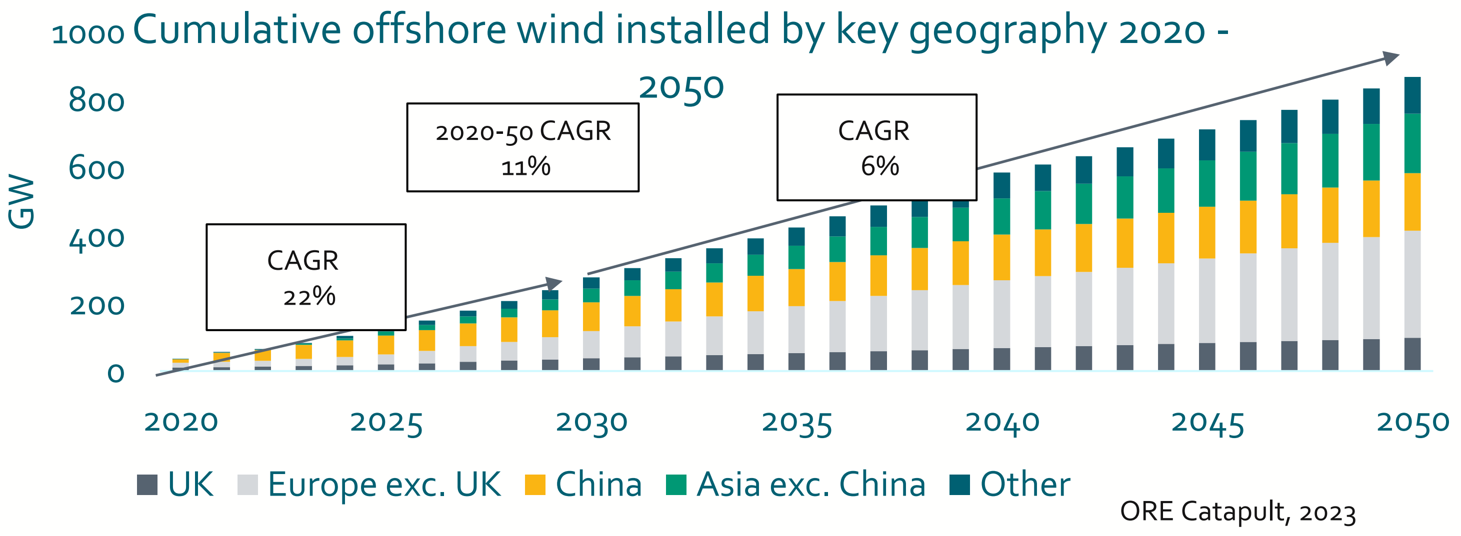
Offshore wind global capacity forecast





- Our forecast assumes a near-term push to achieve 2030 targets
- Annual installations increase from ~9GW in 2022 to 38GW in 2030 and 34GW in 2050

- Total Europe share falling from 47% in 2022 to 39% in 2050
- China share drops from peak of 49% in 2022 to 20% by 2050
- Other markets grow share from 2% in 2022 to 13% by 2050

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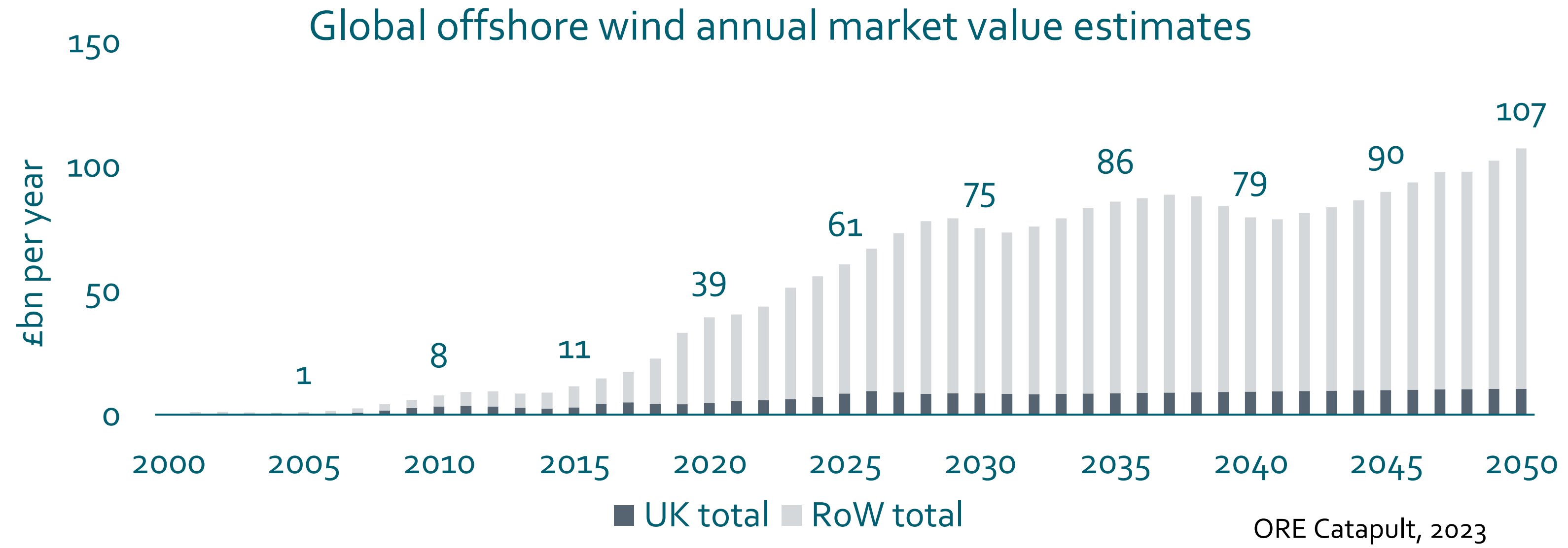
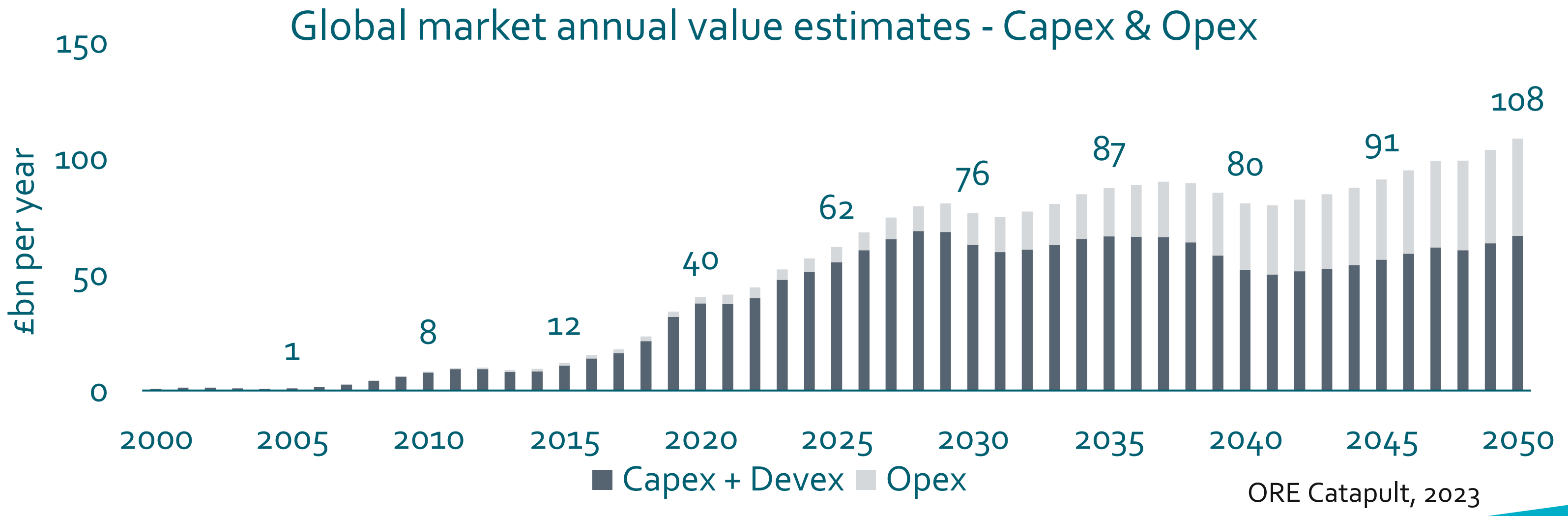
Offshore wind global market value estimates





- Near doubling of market value from 2020 to 2030 due to ramp-up to 2030 targets
- Market value reaches £107bn per year by 2050 – slower increase due to more gradual ramp-up and cost reductions

- Capex always forms largest share of value while building out
- Opex taking increasing share as installed base grows
- Continuous pipeline important for short-term construction jobs

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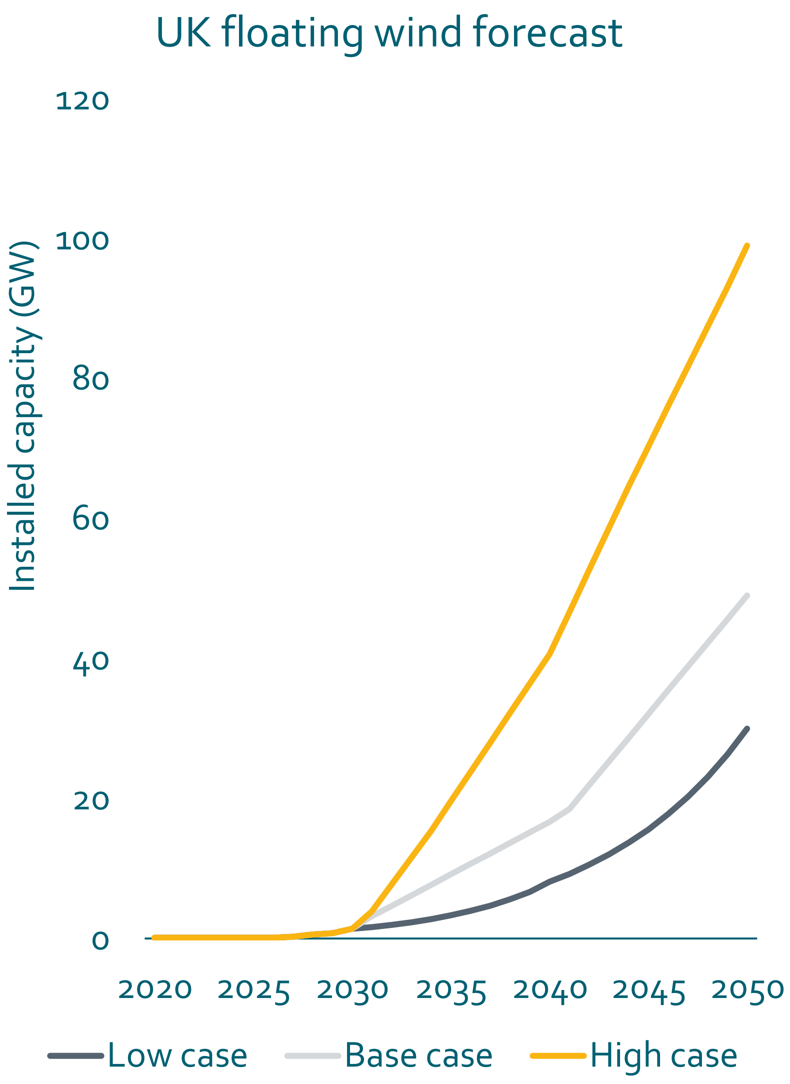
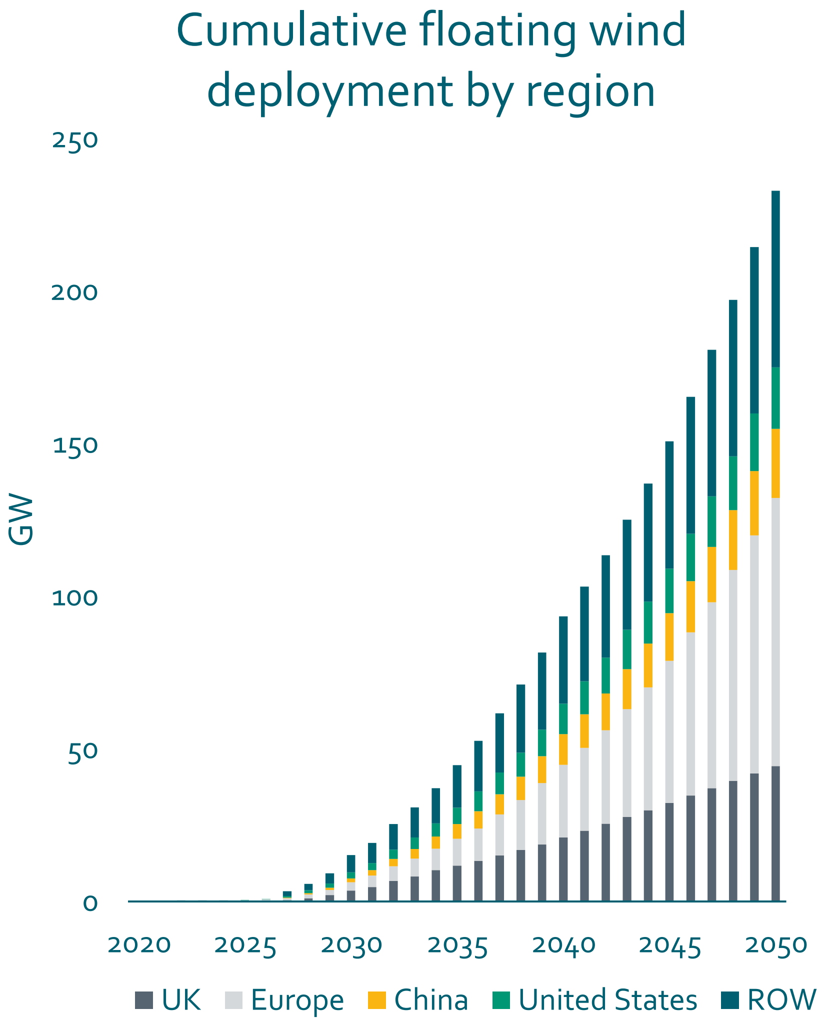
Floating wind is expected to take off from a standing start





- ScotWind leasing round allocated nearly 17GW to floating offshore projects.
- March 2023 saw the announcement of 5.4GW of floating wind lease capacity from the INTOG round.
- Scotland is expected to be one of the largest markets in the world for floating offshore wind with planned projects currently making up 31% of the global floating pipeline.
- The UK has a target of 5GW of installed floating wind capacity by 2030.
- Forecasts for the UK market depend on total OSW deployment – geographical constraints are not an issue.

- Europe is expected to be a first-mover in floating wind as it was with bottom-fixed
- Elsewhere, the west coast of US, Japan, S. Korea and Taiwan are likely to be core floating wind markets

ORE Catapult, 2023

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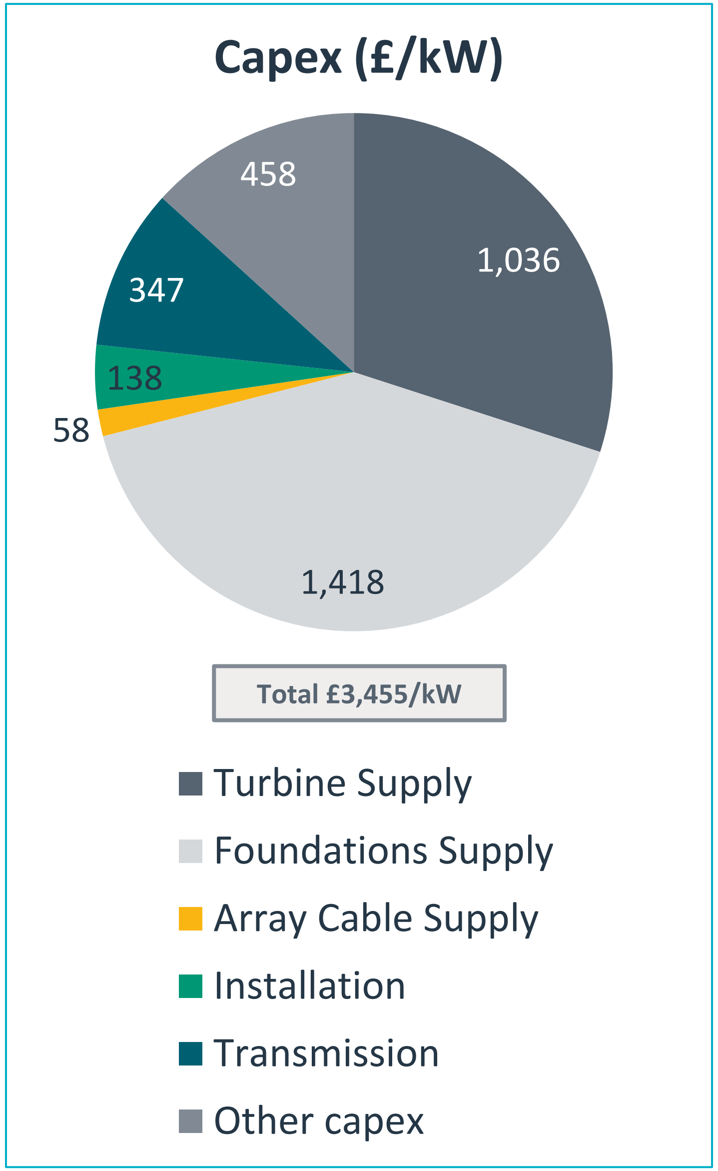
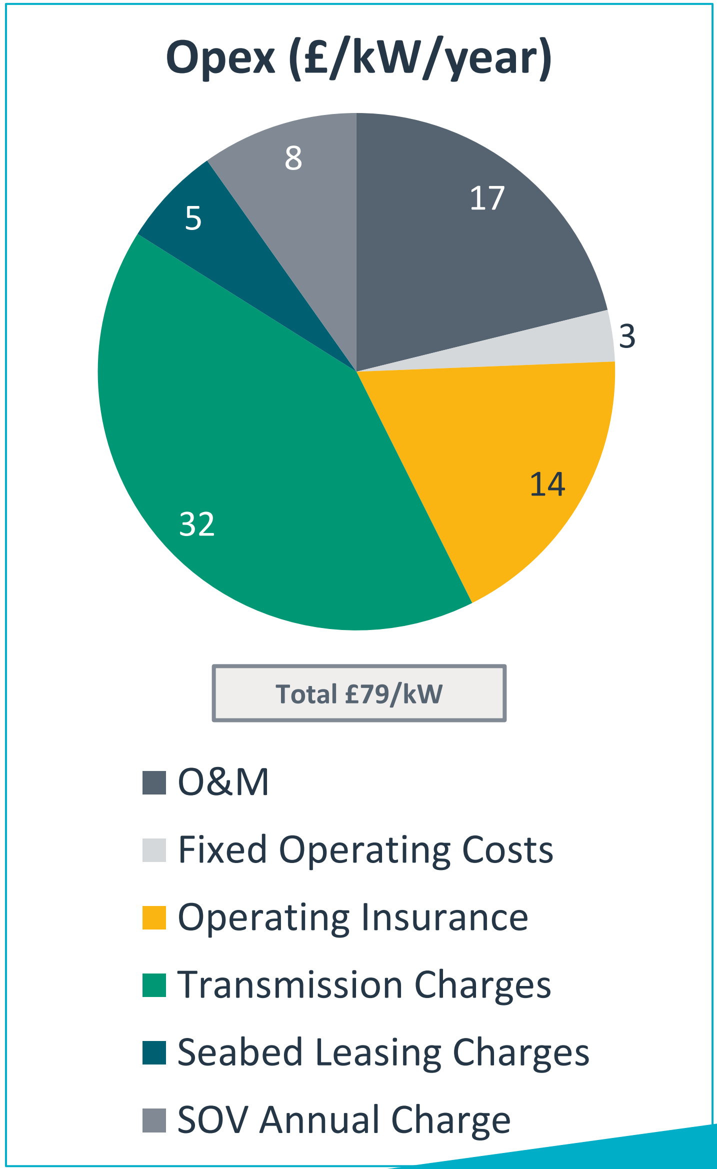
2030 Reference Site (Floating)

Scenario Definition	Unit	2030 Ref Site
Turbine numbers	#	67
Turbine rating	MW	15MW
Windfarm capacity	MW	1,005MW
Mean wind speed at hub height	m/s	10.52
Turbine foundation type	text	Semi-sub
Array cable type	kV	66kV
Transmission System Type	#	HVAC
Water depth	metres	98
Distance to O&M port	km	100
Distance to cable landfall	km	85
O&M Vessel Strategy	text	SOV





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Marine Operations Laboratory to understand DP & Marine Simulations constraints & future ports, vessel and marine operations needs

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Ec simulator to output: Levelized Cost of Energy (LCOE) Levelized Cost of Carbon Abatement (LCCA) and Energy returned for Energy Invested. Will model virtual sites and help define key assumptions for FLOW in the 2030's.

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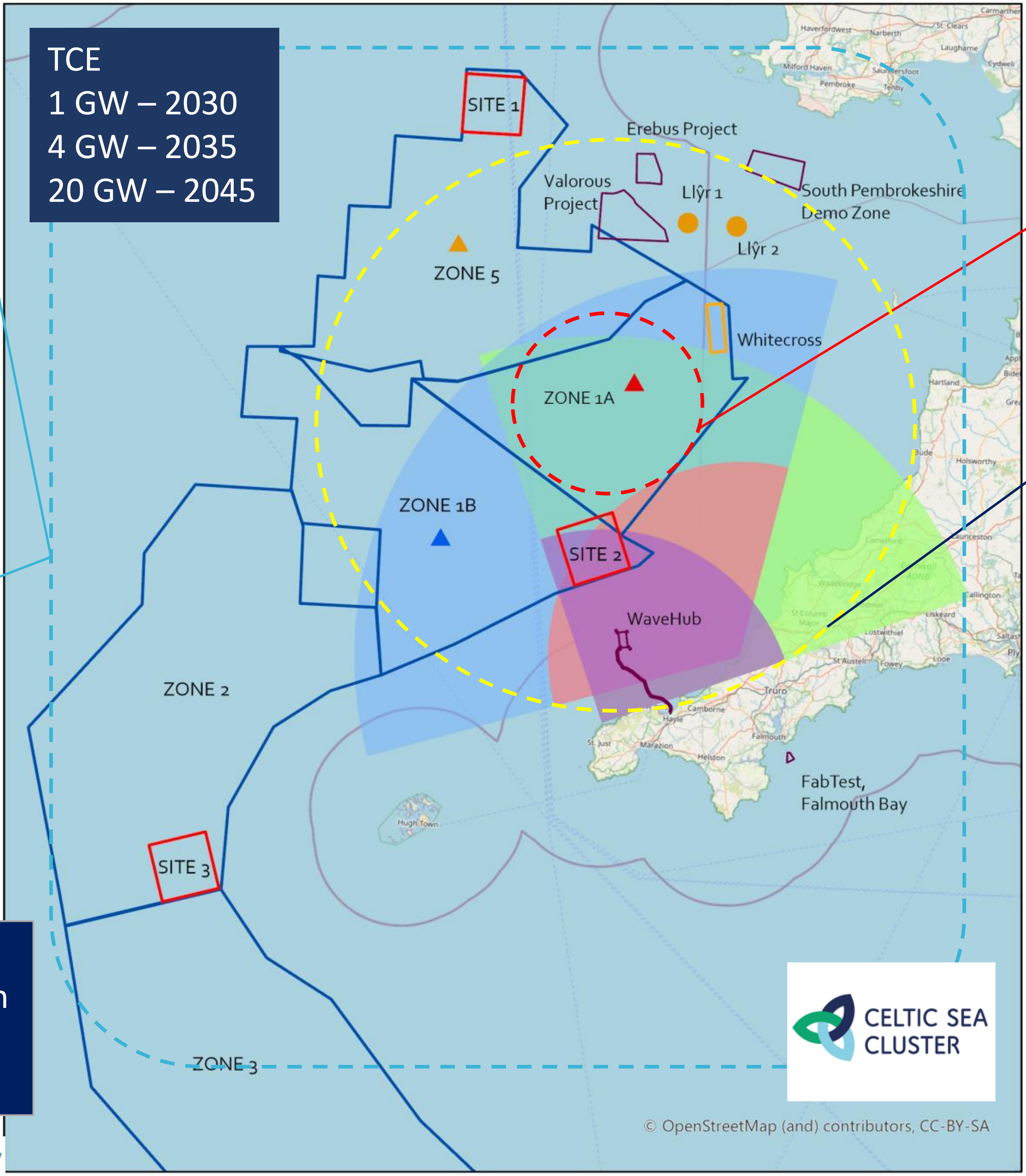
Low Carbon materials & fabrication. Looking at blades, towers, foundation and electrical infrastructure and understanding the local opportunity

Cornwall FLOW Accelerator



12 months wind resource acquisition by Flidar commencing March 2022

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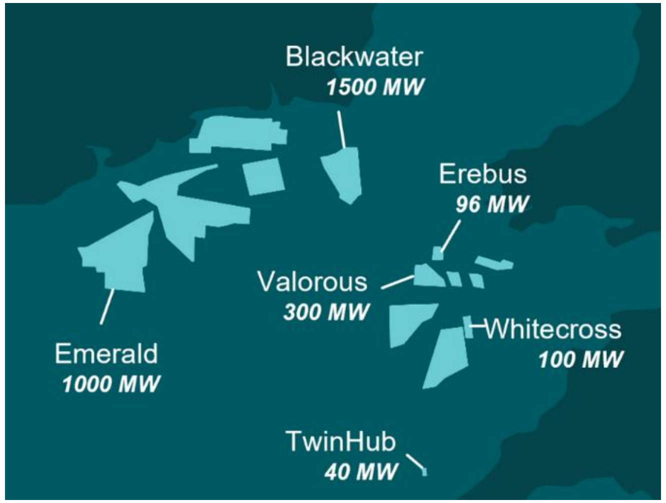
Understand how we can reduce carbon associated with EIA's, drive local solutions, accelerate the development phase



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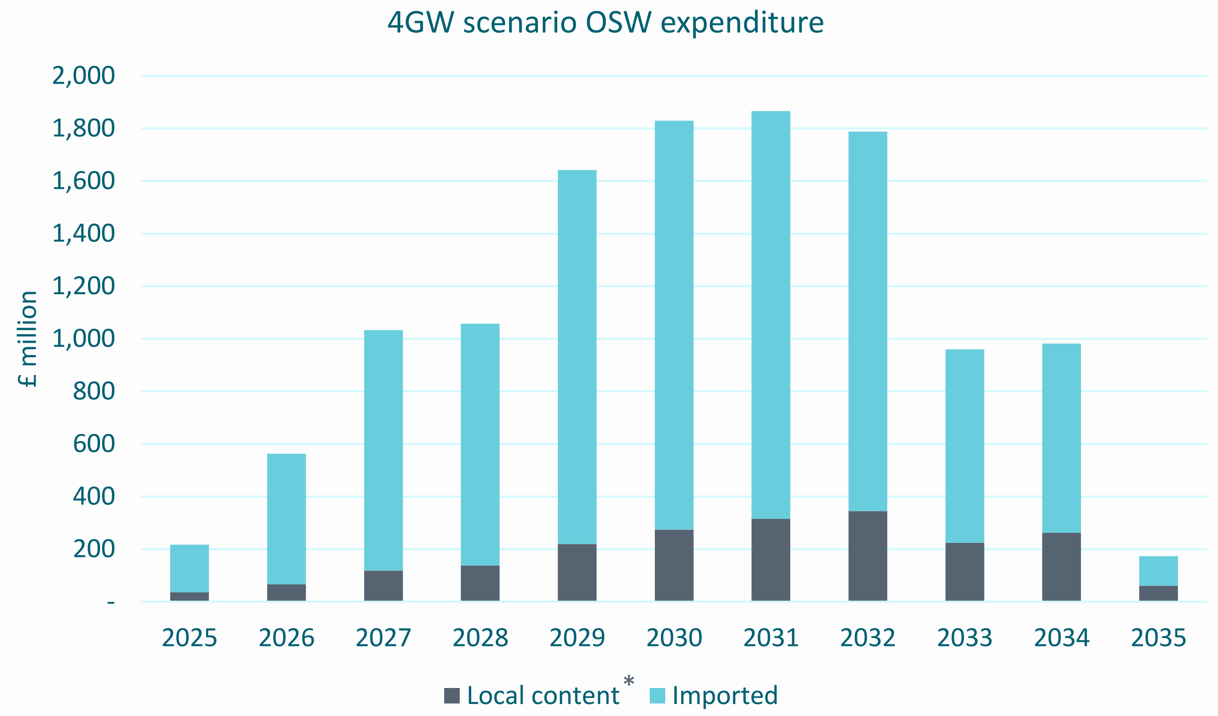
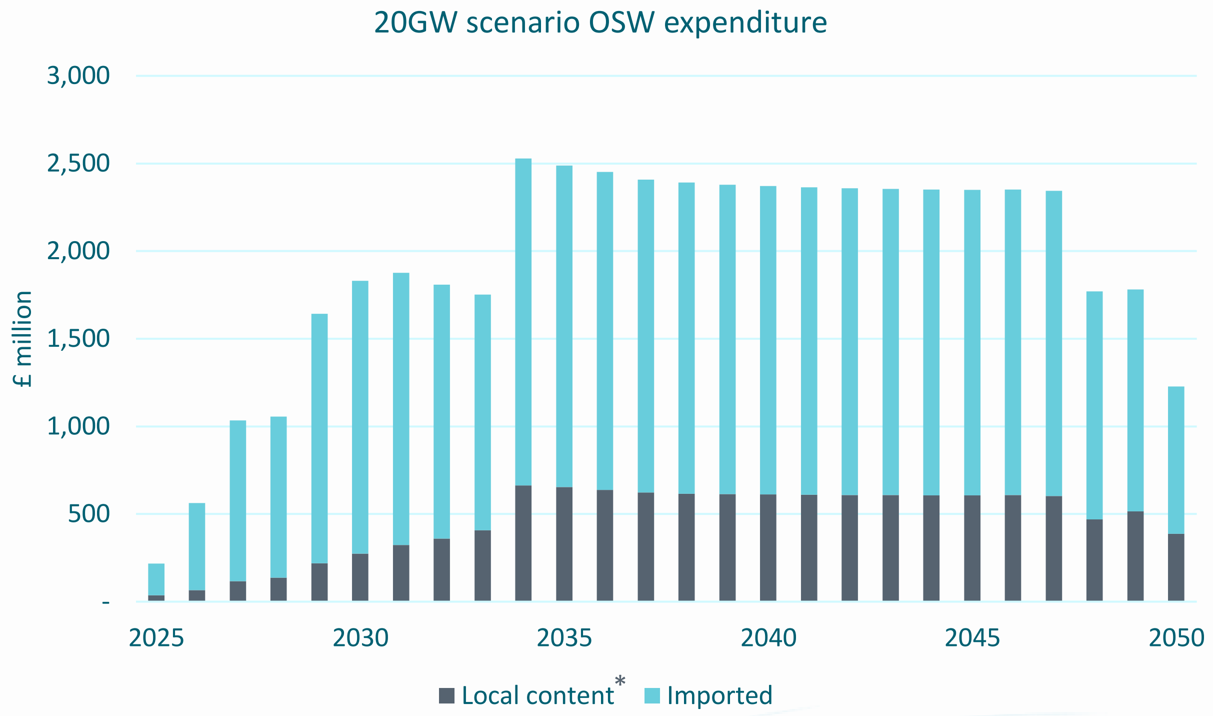
Tom Quinn

Offshore Renewable Energy

Market opportunity for the Celtic Sea region





Components	***Unit***	**4GW case**	**20GW case**
Turbines / substructures	*#*	235	1,035
Mass of substructures	*tonnes*	837,000	3,877,000
Mooring lines	*km*	600	2,600
Anchors mass	*tonnes*	24,200	120,000
Array cables	*km*	580	2,900
Export cables	*km*	1,100	5,200

*Scenarios assume £600-700m invested into ports and fabrication facilities

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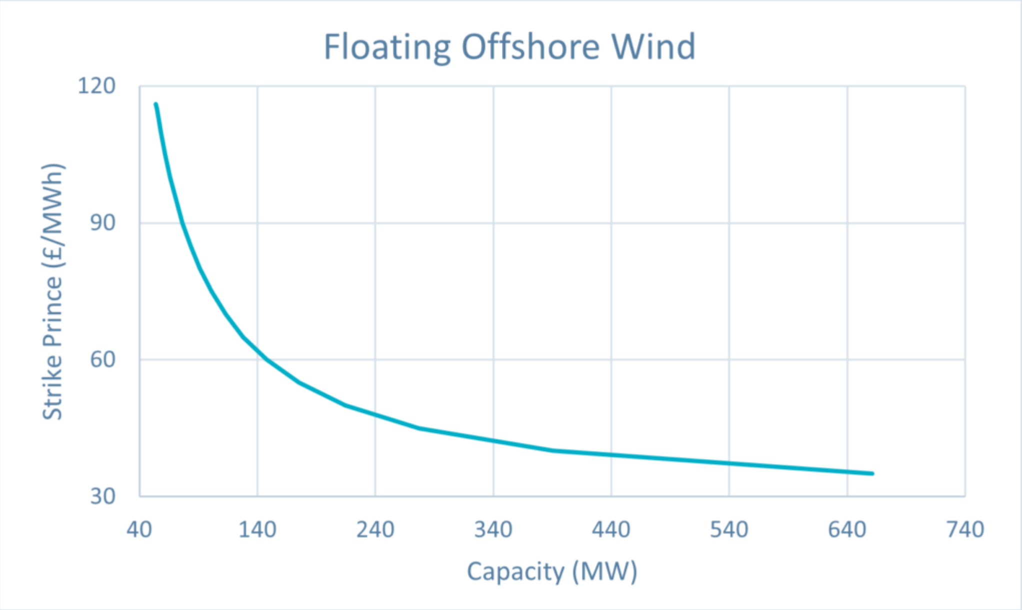
CfD auctions putting pressure on developers

- CfD auctions to be run annually
- Current auction (AR5) has FOW competing with other "emerging" tech in Pot 2 such as biomass, geothermal, wave & tidal.
- Auction Pot 2 budget of £25m (£35m minus £10m ringfenced for tidal) allows for ~40-150MW of FOW depending on strike price bid if FOW outbids other technologies
- FOW maximum strike price of £116/MWh (2012 terms, ~£155 today) will be a challenge for some developers

However…

- Budgets for future rounds will likely increase to allow for greater FOW deployment
- Non-price criteria may be included in future CfD rounds



Questions and Answers

Offshore Renewable Energy

Dr Konstantinos Bacharoudis

Dr Konstantinos Bacharoudis

Catapult Offshore Renewable Energy

Cornwall FLOW Accelerator

European Union
European Regional Development Fund

HM Government

NATIONAL COMPOSITES CENTRE

CATAPULT
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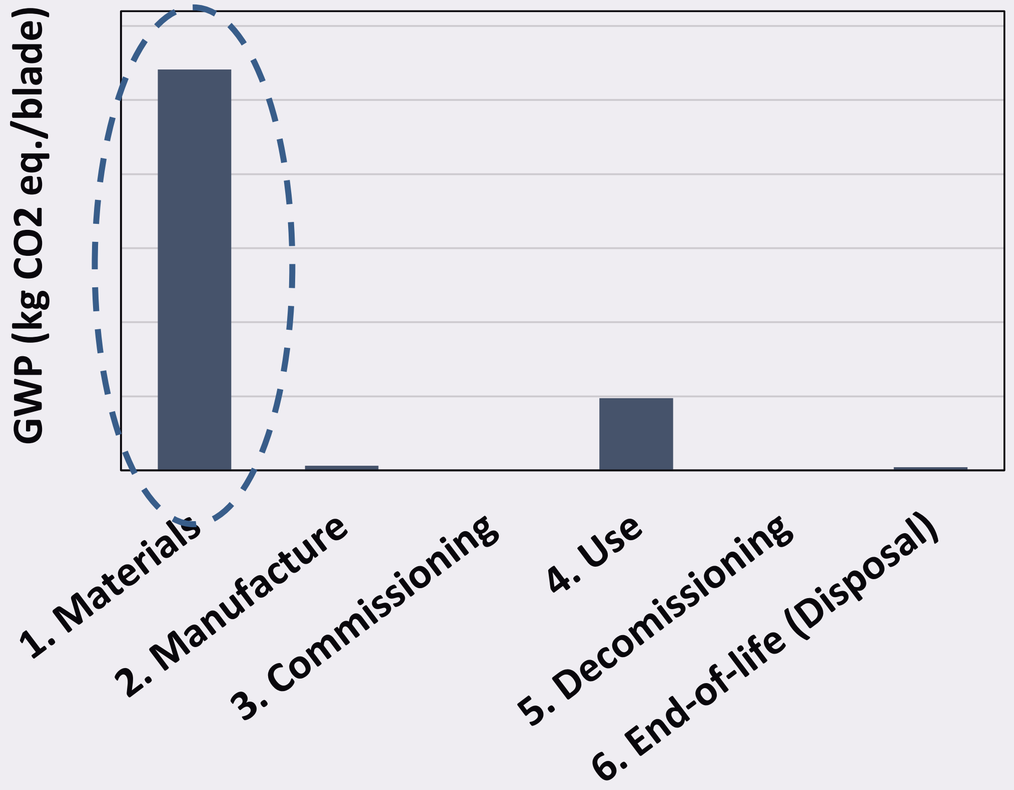
Innovative design and lifecycle assessment of wind turbine rotor blades using sustainable materials: A feasibility study

12 June 2023

Dr Konstantinos Bacharoudis

Research Motivation

Largest environmental impact of blade comes from material production



→ **Make blades more circular and lower environmental impact by constructing with alternative materials**

Material production found to account for vast majority of blade lifetime GWP (CO_2 equivalent GHG emissions)

To reduce blade impact we must:

1. Use **less impactful materials** to make blades
2. Use **recyclable materials** which enable circularity
3. Match **recycling technologies** to materials

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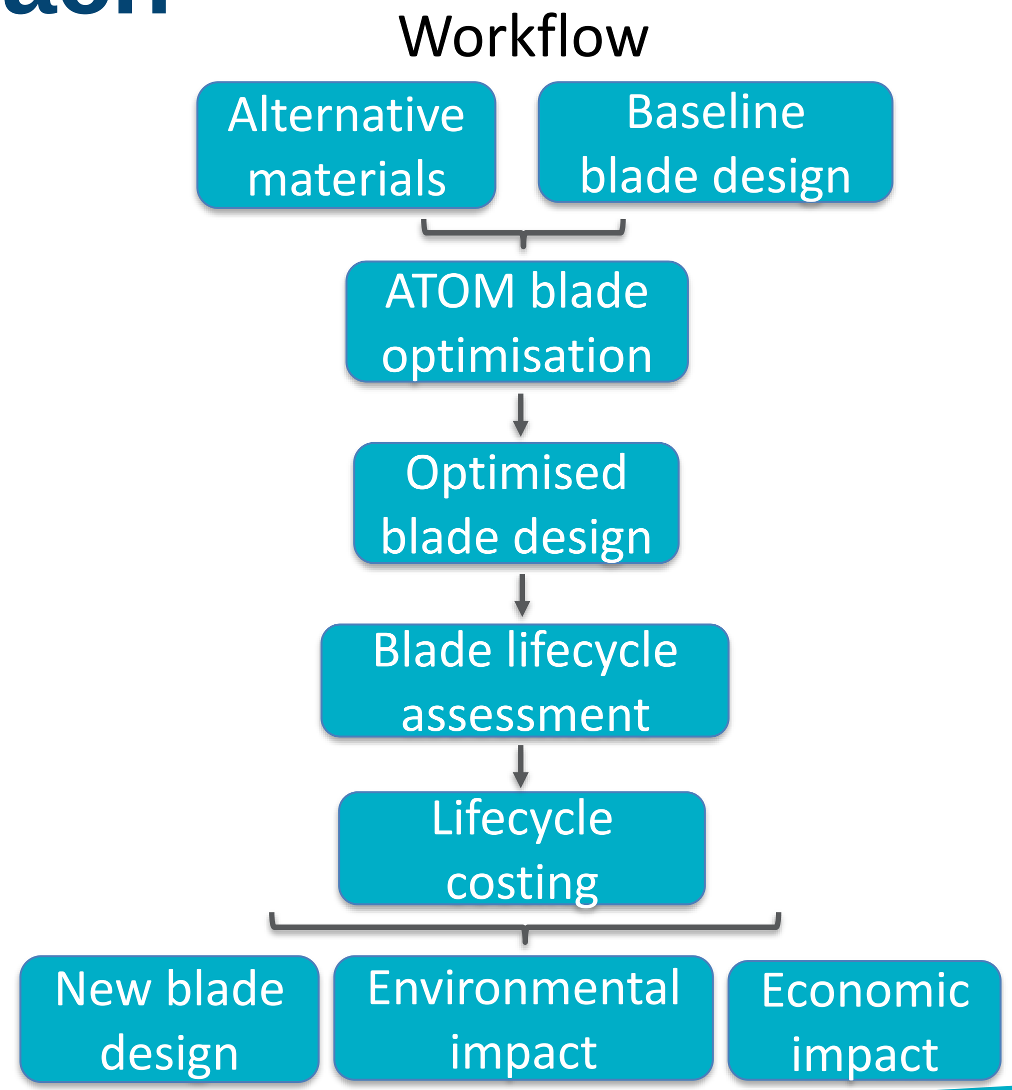
Scope and Research Approach

Explore alternative materials that meet blade performance requirements

Determine environmental impact of new materials

Specify economic impact of new materials

Produce feasible, optimized blade designs with minimum CO_2 footprint



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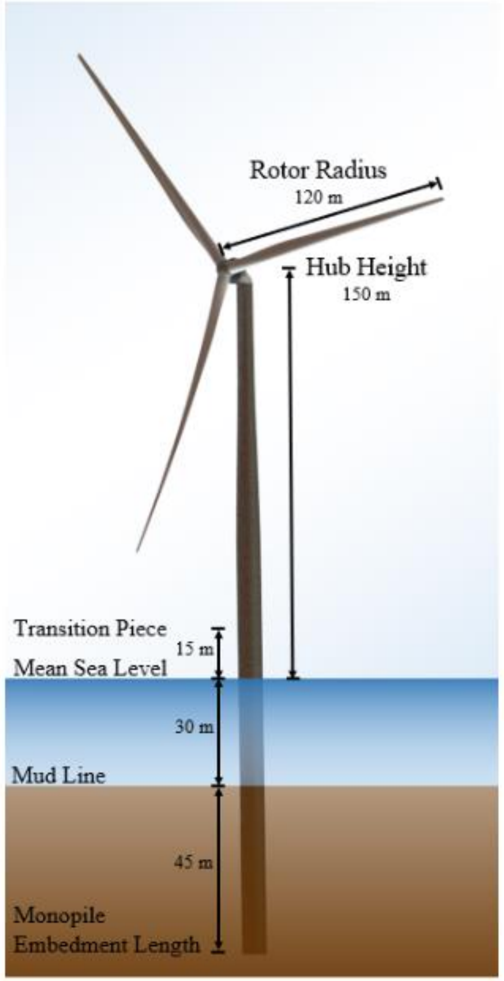
The IEA 15 MW Reference Turbine

- Developed as part of IEA Wind Task 37 by NREL and DTU[1]
- Optimised using the NREL system level design tool WISDEM[2]
- Blade length = 117m
- It is freely available[3]
- In this case study, a slight modified design was used (with an extended 122m blade). The blade has been re-designed in the frame of Cornwall FLOW Accelerator project



[1] E. Gaertner et al. Definition of the IEA 15-Megawatt Offshore Reference Wind Turbine. NREL/TP-5000-75698, 2020
[2] github.com/WISDEM
[3] github.com/IEAWindTask37/IEA-15-240-RWT

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Introduction to ATOM: Methods

Optimisation

Objective
Modified LCoE

Algorithm
Gradient based (GCMMA)

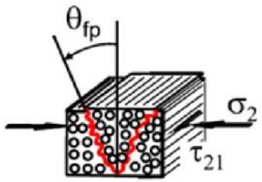
Design variables

Aero	Struct	Control
Chord Twist Thickness etc.	**Laminate thickness** **Core thickness** Region widths	Tip-speed ratio Fine pitch

Optimisation strategies

"Aero-structural" optimisation
"Frozen load" optimisation

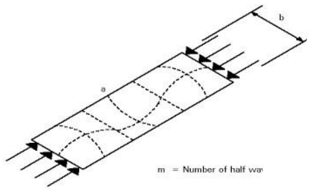
Design constraints



Strength - Puck criterion

$$D = \sum_i \frac{n_i}{N_i} \leq 1$$

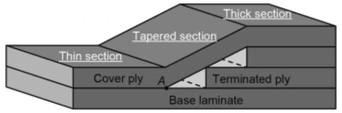
Fatigue - Linear Goodman damage



Buckling - Analytical panel

Tower clearance

Aeroelastic stability



Manufacturing - Ply taper etc.

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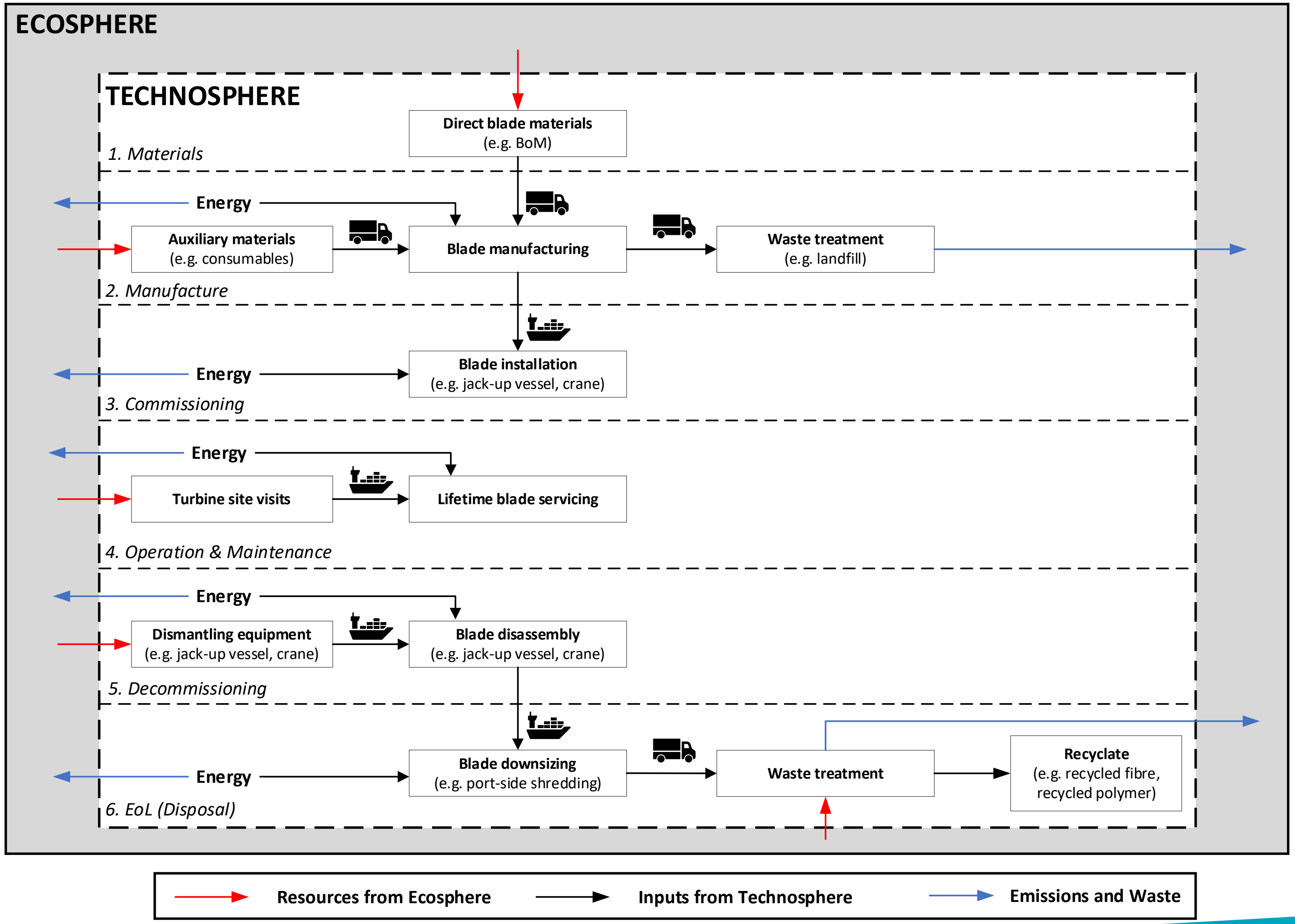
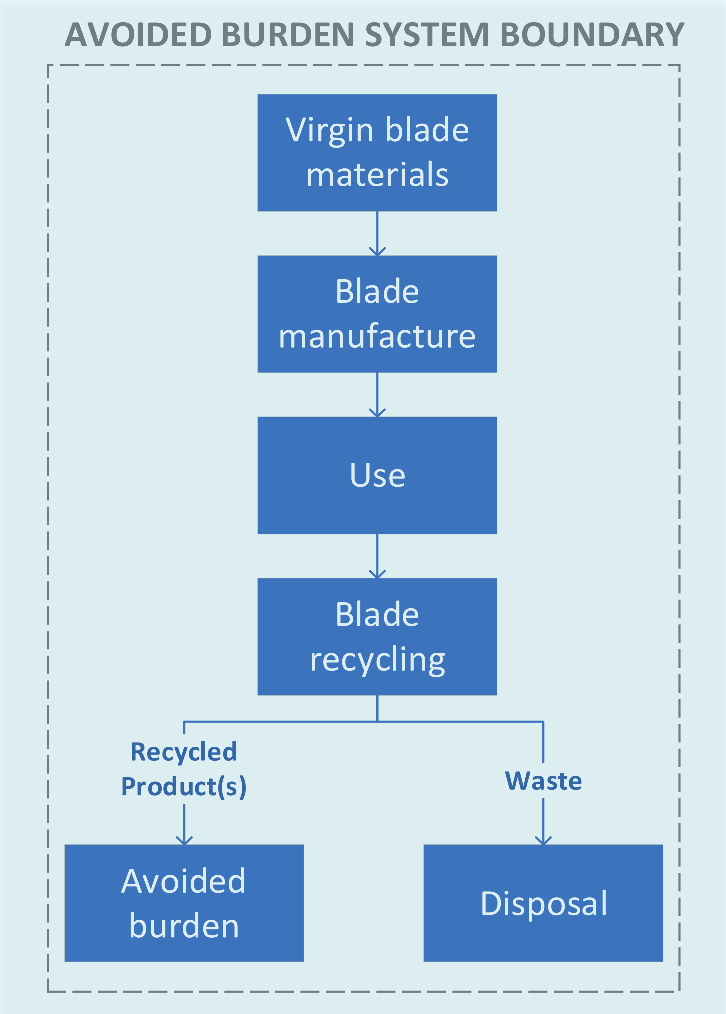
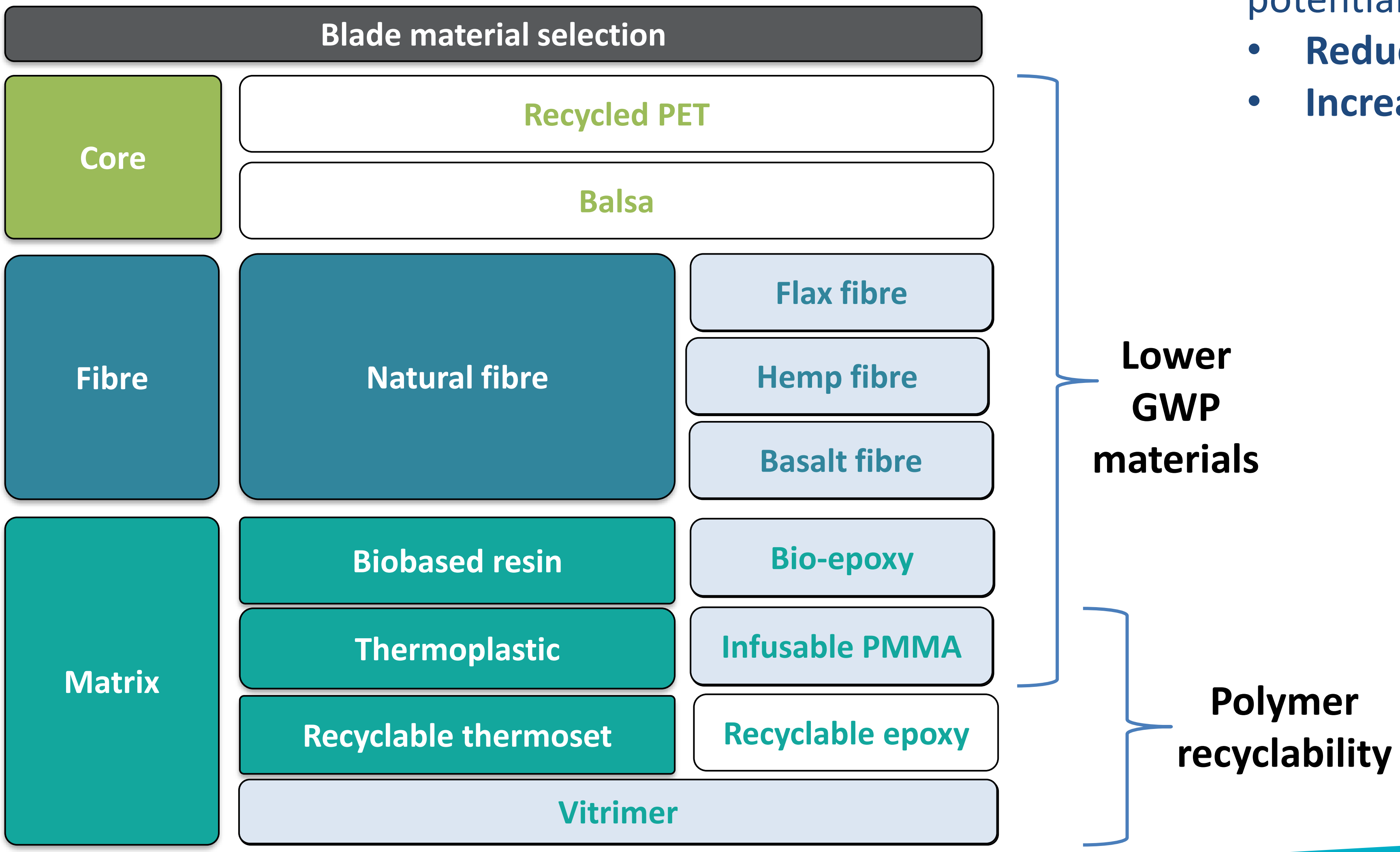
Lifecycle Assessment: Methodology





Alternative Material Selection



Alternative materials selected for two potential benefits:

- **Reduced cradle-to-gate GWP**
- **Increased blade recyclability**

Significant difference in material properties
↓
Conducted blade design optimisation

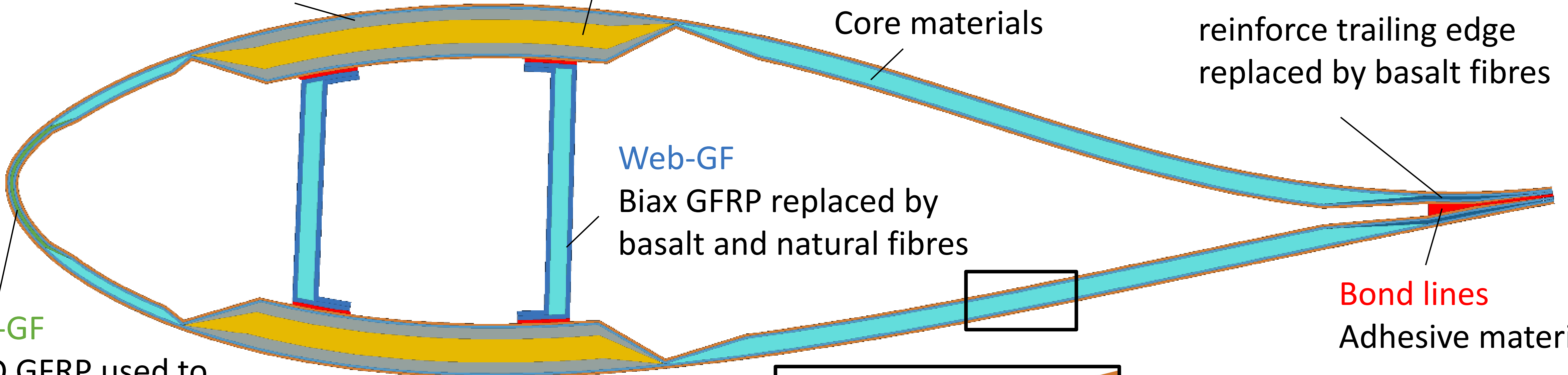
Material Deployment

Spar-GF
UD GFRP replaced by basalt but not other natural fibres

Spar-CF
UD CFRP

Cores
Core materials

TE-GF
UD GFRP used to reinforce trailing edge replaced by basalt fibres

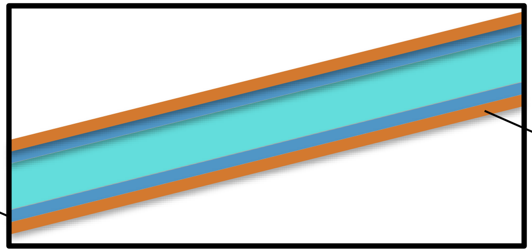


Web-GF
Biax GFRP replaced by basalt and natural fibres

Bond lines
Adhesive materials

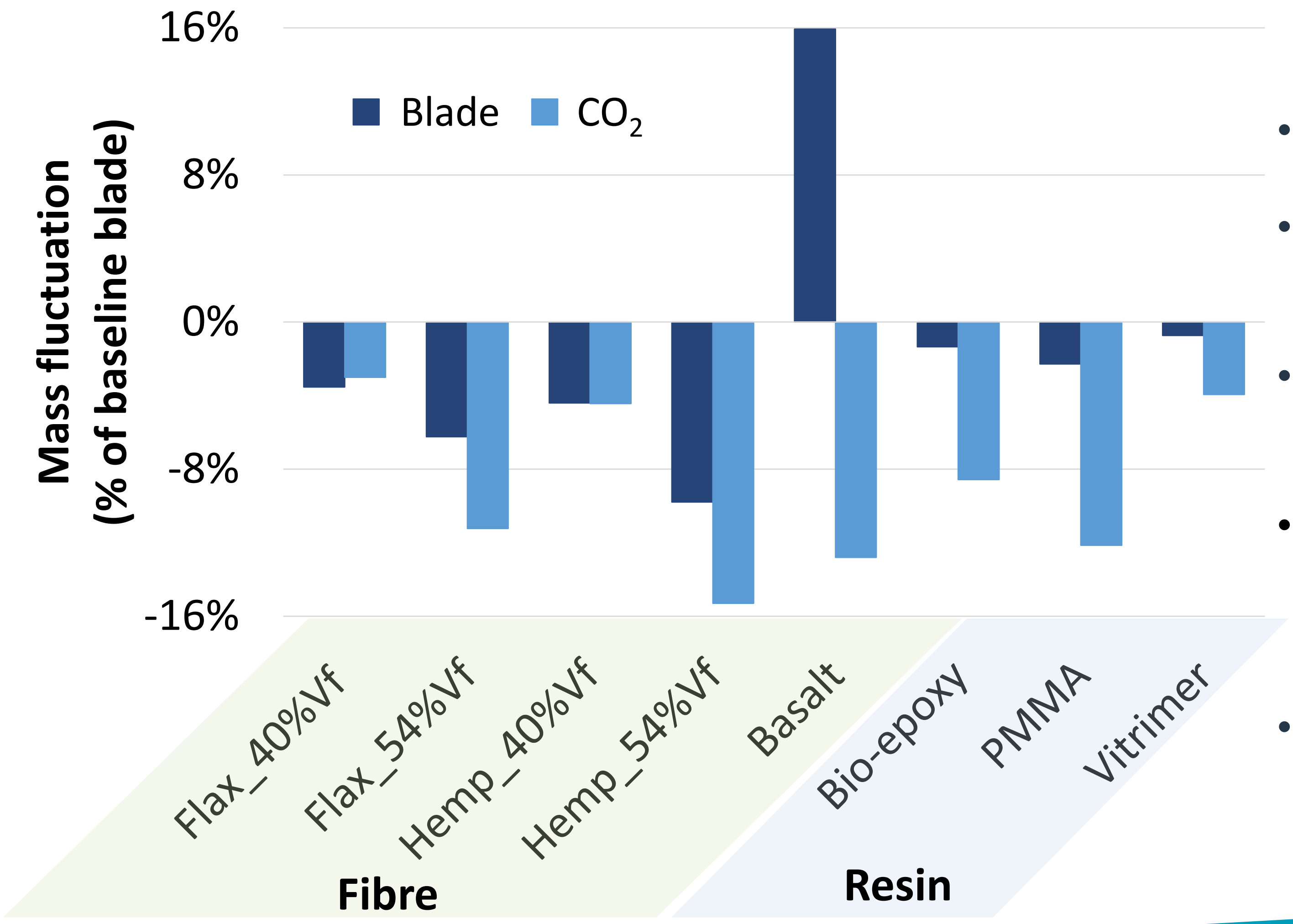
LE-GF
UD GFRP used to reinforce leading edge replaced by basalt fibres

Shell_UD-GF
UD GFRP wrapping all around shells replaced by basalt fibres



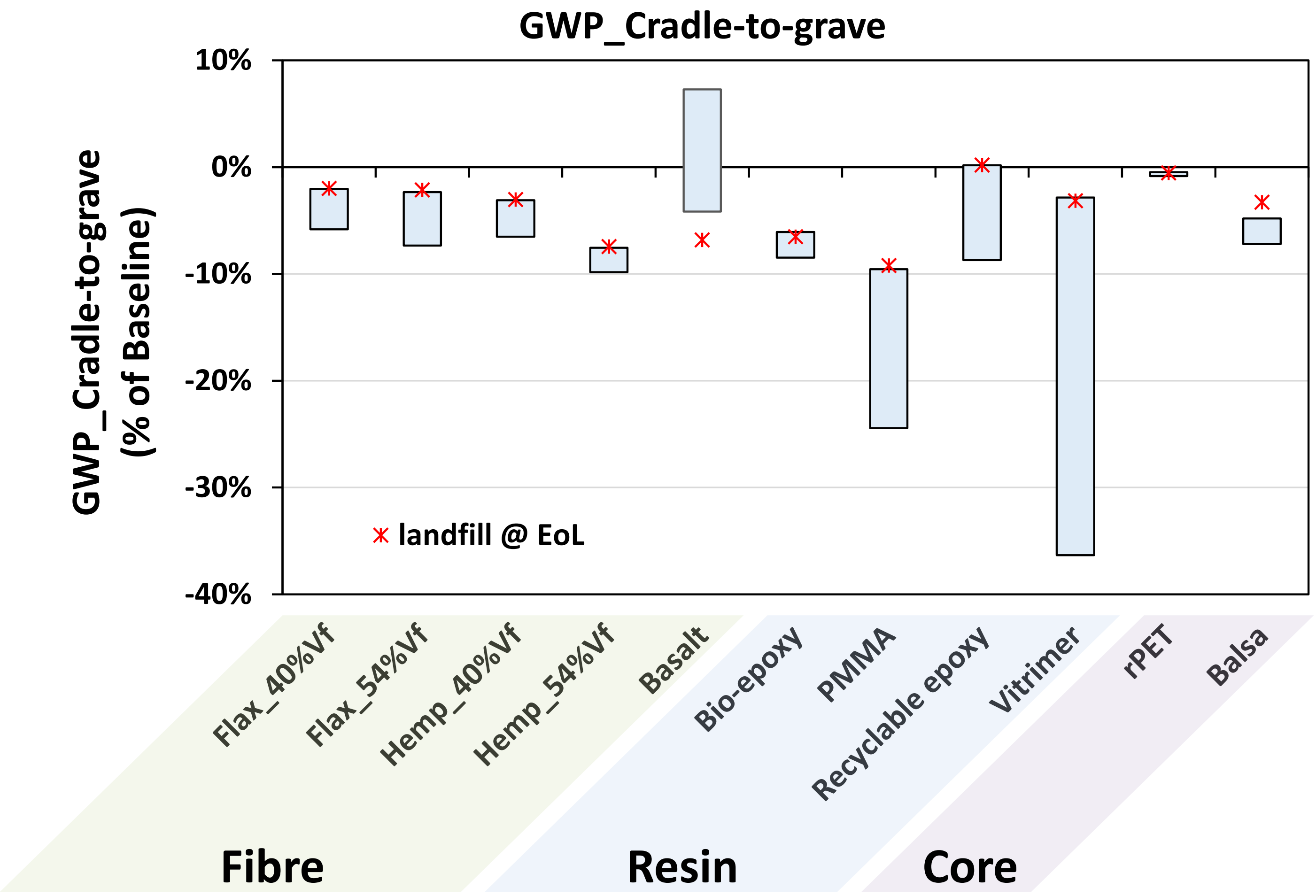
Shell_Biax-GF
Biax GFRP wrapping all around shells replaced by basalt and natural fibres

Results: Baseline vs Alternative Blade Materials



- Careful interpretation of the results: global minima may not have been identified
- Material properties based on rule of mixtures
- Blade and CO_2 mass reductions up to 9.8% and 15.3% respectively for natural fibres (Hemp_54%Vf)
- Natural fibre mass reduction is driven by improved specific stiffness compared to baseline
- Basalt fibre cost is twice the price of E- glass. Other natural fibres are more expensive and not available at the same scale
- Hemp: 4.5 km^2 of cultivated area (300 blades/year). This corresponds to the 0.03% of wheat cultivated area in UK

Lifecycle Assessment: Cradle-to-grave GWP



Almost all blade scenarios have lower cradle-to-grave GWP compared to Baseline when landfilled

Range in GWP encompasses best to worst case EoL scenarios

Energy from waste is highest GWP for most blade scenarios

Mechanical+Cement kiln recycling provides lowest cradle-to-grave GWP for blades with standard resin systems

Recyclable polymers, PMMA & Vitrimer provide greatest reduction in GWP

Summary

- Attempting to minimise CO_2 mass resulted in reduction of the blade mass in most design cases

- Most natural fibre materials indicated good potential for further use in blade manufacturing

- Best cradle-to-grave GWP achieved w/ “recyclable” resin alternatives

- New “promising” designs emerged, up to:
- **10% reduction in blade mass**
- **36% reduction in cradle-to-grave GWP**

Gaps and Challenges

- Need a better understanding of material selection on through life operation (e.g. O&M, repair, life-expectancy, fatigue, erosion/corrosion)

- Flax/hemp fibre NCF is immature and only available in twisted yarn formats – poorer fibre alignment and lower Vf

- Blade recycling technologies are immature – need more data to help make informed decision matched to specific materials

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Questions and Answers

Offshore Renewable Energy

CFA – Towers and Foundations

Dylan Duncan, Research Engineer – 12/06/2023

Credit: Siemens Gwynt y Mor

Agenda

- Cover the tower and foundation work packages in CFA
  - Review LCA methodology and scope
  - Review state-of-the-art technology, materials and assumptions
  - Summarise LCA results
- Explore what a facility might look like
  - Explore scale of the technology
  - Present and future manufacturing processes
  - Challenges and opportunities

CFA reports for both tower and foundations have been published on the ORE Catapult and Celtic Sea Cluster websites

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Project Introduction and Methodology

Identify Site Conditions → Establish Reference Structure → Lifecycle Definition → Gather Data Requirements → Final GHG Assessment

- As FOWT developments increase rapidly so does the need to decarbonise and encourage local supply chain growth

- This work follows the following steps and covers both tower and floating foundation components:
    1. Carrying out a literature review to highlight current technologies and industry/academia trends
    2. Define a reference structure and conduct a life cycle assessment (LCA)
    3. Using the LCA results, identify opportunities and challenges that can decarbonise wind turbine production and encourage supply chain development

Life cycle analysis workflow [1]

[1] Ecochain (2022). Life cycle assessment (LCA) - Complete beginner's guide. https://ecochain.com/knowledge/life-cycle-assessment-lca-guide/

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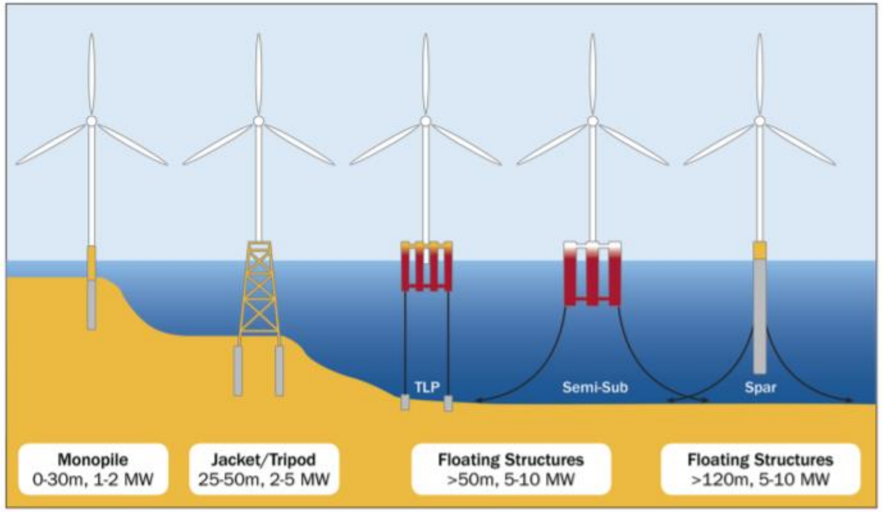
Literature Review – Structural Choices


Types of wind turbine towers [1]

- Varied number of tower designs are available
- Industry standard tubular designs were chosen for examination, lattice or hybrids were considered but determined to be too “risky”
- Range of materials were examined but comparison came down to either steel or concrete
- 15MW scale

[1] Mohammadi, M. R. S., Rebelo, C., Velijkovic, M., & Da Silva, L. S. (2017, April). The Hybrid Highrise Wind Turbine Tower Concept. In International Conference on Wind Energy Harvesting, Coimbra, Portugal.
[2] European Wind Energy Association. (2013). Deep water. The next step for offshore wind energy.



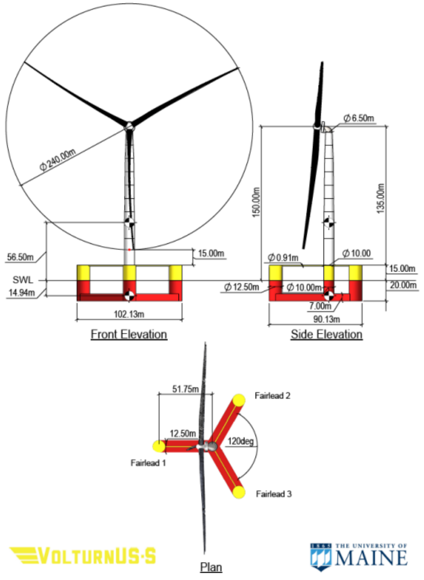
Types of offshore structure [2]

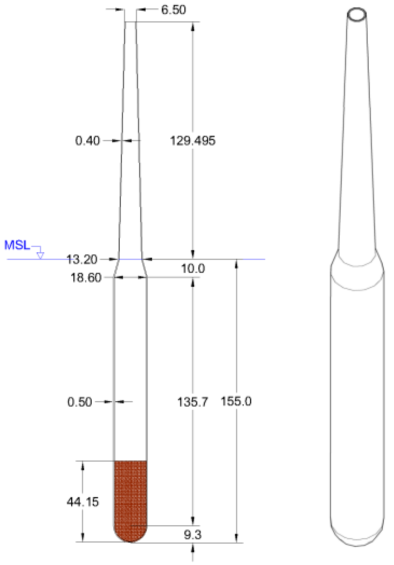
- Wide number of floater designs are available
- Semi-Sub was chosen as the structure of choice due to higher volume of reference data and lower masses in some cases
- To date only steel and concrete structures have been used
- 15MW scale

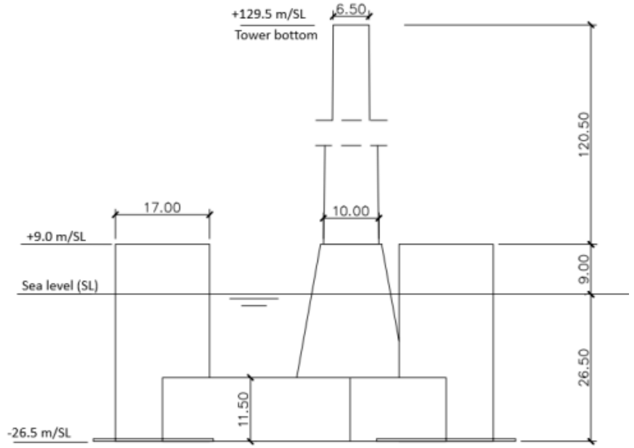
Literature Review – Materials and Chosen Design

Structure	Reference Turbine	Total Mass (t)	Concrete Mass (t)	Steel Mass (t)	Ballast Mass (t)
Steel Tower	IEA 15MW UmaineUS-S Volturn	1,263	-	1,263	-
Concrete Tower	WindCrete 15MW Spar	3,558	3,258	*≈300	-
Steel Semi-Sub	IEA 15MW UmaineUS-S Volturn	17,839	-	3,914	13,840
Concrete Semi-Sub	ActiveFloat	38,550	11,480	*≈2,000	25,070

*Assumptions on Rebar mass was also added within the LCA for the concrete structures







Left: IEA 15MW Umaine US-S Volturn Semi-Sub [1]
Middle: WindCrete 15MW Spar [2]
Right: Active Float 15MW Concrete Semi-sub [2]

[1] Allen, C., Viscelli, A., Dagher, H., Goupee, A., Gaertner, E., Abbas, N., Hall, M., & Barter, G. (2020). Definition of the UMaine VolturnUS-S reference platform developed for the IEA wind 15-Megawatt offshore reference wind turbine.
[2] COREWIND. (2020, April). *Public design and FAST models of the two 15MW floater-turbine concepts*

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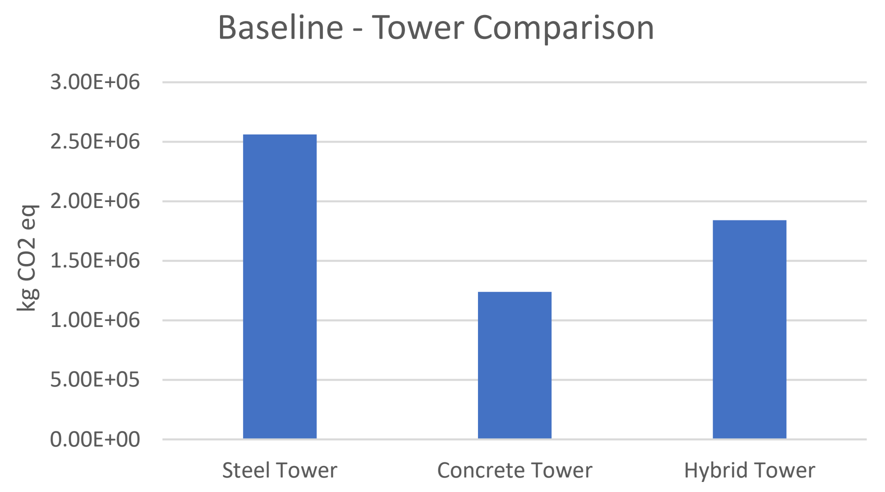
LCA Results Overview

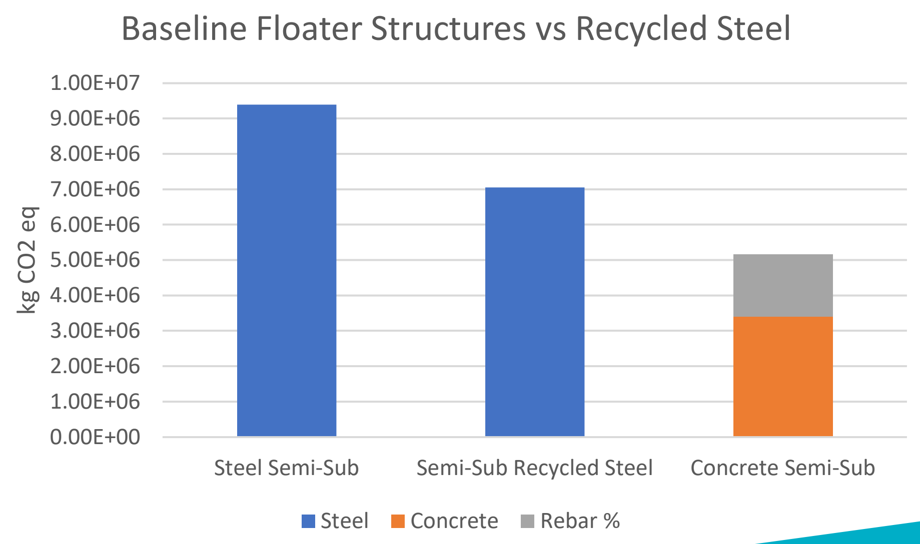
Steel vs Concrete

Material	Ecoinvent Name	Geography	Unit	kg CO2 – Eq [1]
S355 steel	Low-alloyed steel	Global	per kg	1.4521
S355 steel	Hot Rolled steel	Global	per kg	1.7159
Concrete (Cable Mat)	market for concrete block	Rest of World	per kg	0.15729

Manufacturing Processes	Material
Arc welding	Steel
Hot/ sheet rolling	Steel
Concrete- precast tower construction	Concrete

- Concrete structures outperform steel structures with a saving of around 50% CO^2 emissions (for the baseline model)
- This value can differ depending on design and % of rebar
  Carbon content of steel can play a big role in reduction, more recycled content the better
- Degree of concrete emissions also rely heavily on type of concrete used





[1] Ecoinvent (2020). https://ecoinvent.org

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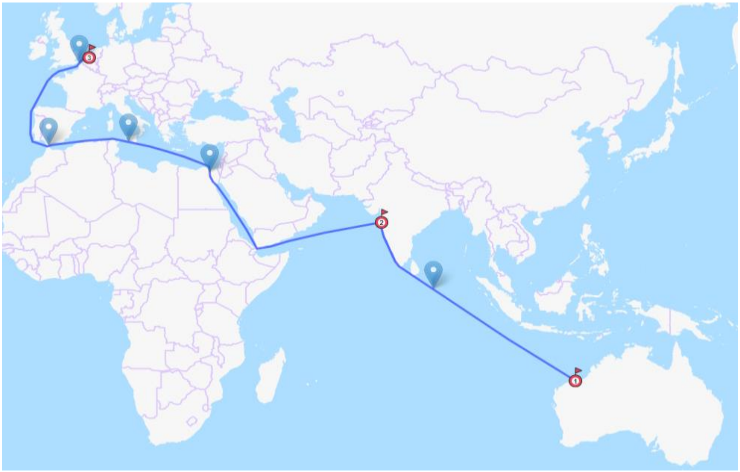
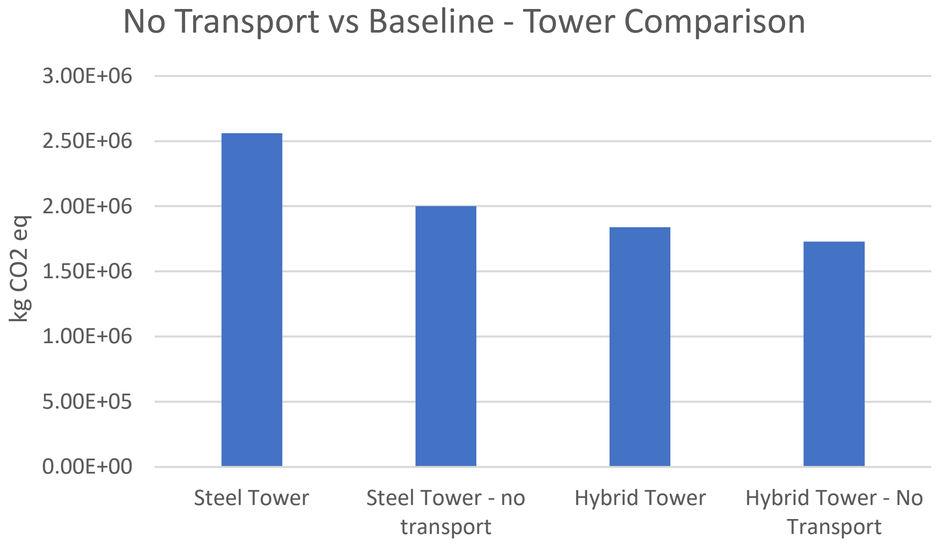
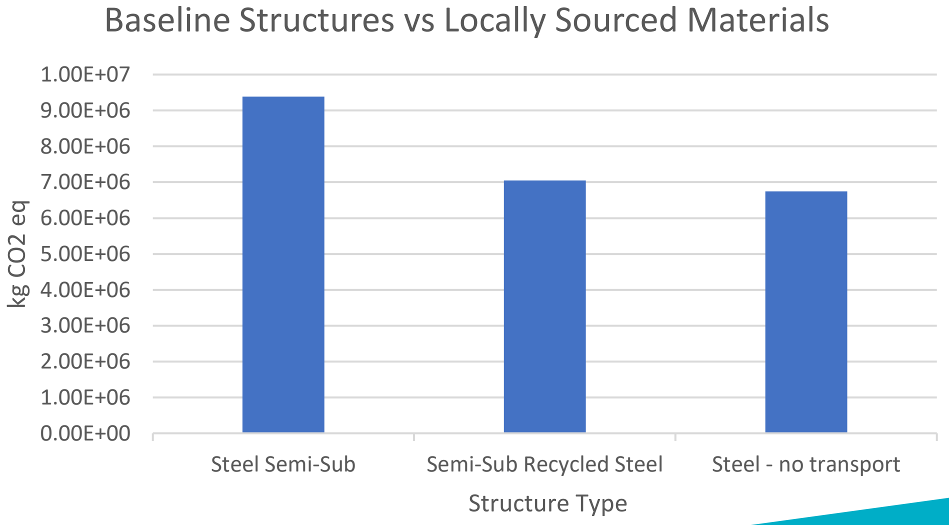
Transport Emissions – Local vs Import

- UK steel manufacturing capacity is low – hence emissions due to imports is included
- Here a scenario for steel imports from Australia was considered
- Savings as high as 20% were recorded, changes depending on mass of steel

Travel Distance (km)	11,770
Ton-kilometre (tkm)	14,865,510 (Transport, bulk, sea freight)



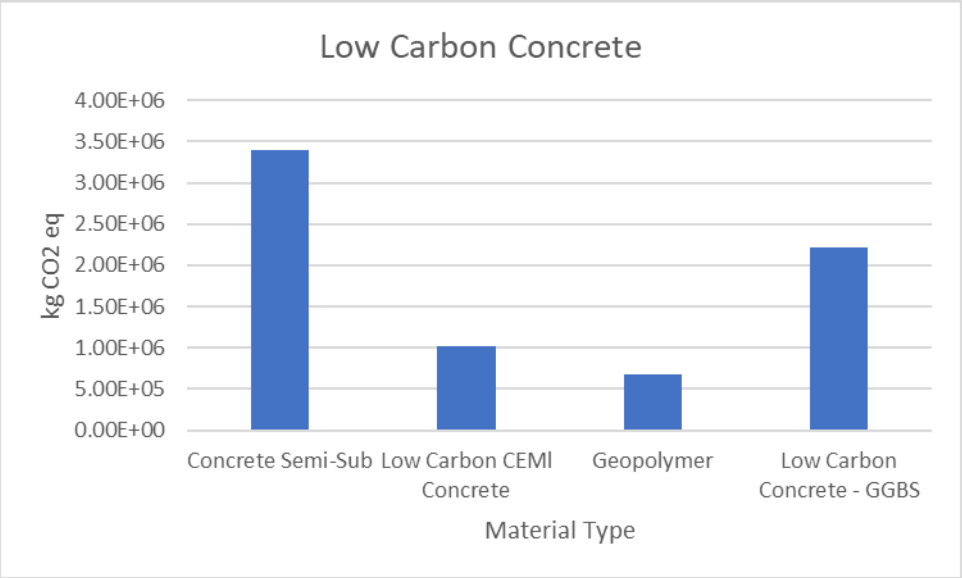




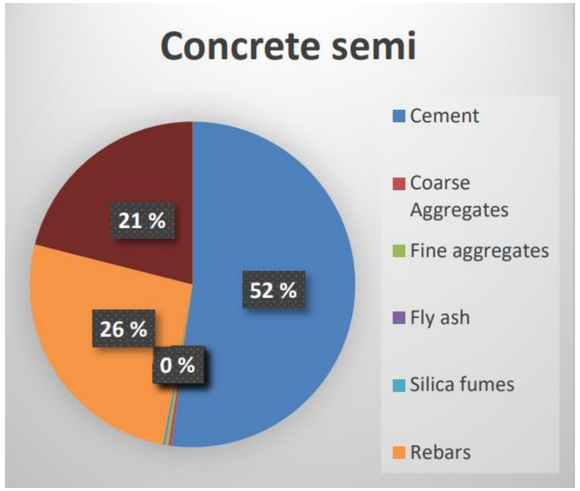
Offshore Renewable Energy

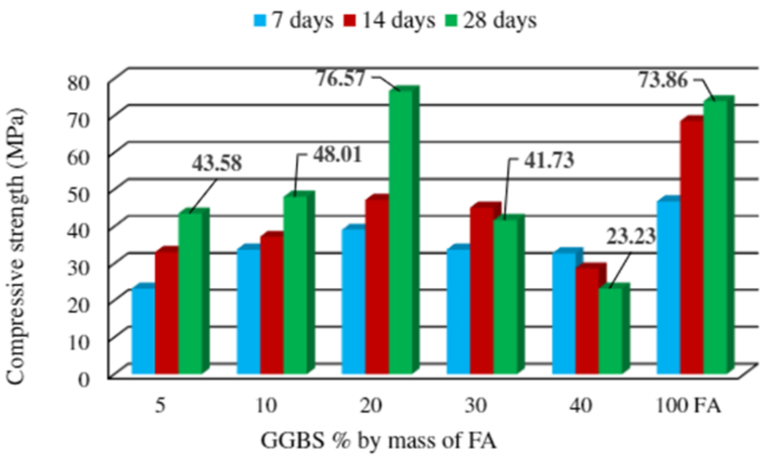
Low Carbon Solutions - Concrete

- Concrete is one of the biggest sources of CO^2 emissions in the world!
- Largely due to intensive processes used in the manufacture of cement (In this LCA: Portland cement is considered)
- Low carbon solutions largely attempt to reduce or outright replace cement content
- Potential savings as high as 80% for concrete emissions



Properties	Portland Cement	Geopolymer
CO_2 emission	800-900 kg/ton	150-200 kg/ton
Embodied energy	4000-4400 MJ/ton	2200-2400 MJ/ton
Water requirement	≈600 litres/ton	≈450 litres/ ton





Left: % breakdown of concrete emissions [1]
Middle: Compressive strength of a GGBS solution [2]
Top: Table comparing geopolymer and Portland cement emissions [3]

[1] DNV. (2022, February). Comparative study of concrete and steel substructures for FOWT.
[2] Bouaissi, A., Li, L., Al Bakri Abdullah, M. M., & Bui, Q. (2019). Mechanical properties and microstructure analysis of FA-GGBS-HMNS based geopolymer concrete. *Construction and Building Materials*, *210*, 198-209. https://doi.org/10.1016/j.conbuildmat.2019.03.202
[3] Kumar, S., & Kumar, R. (2014). Geopolymer: Cement for low carbon economy. *Indian Concrete*, *88*(7), 29-37

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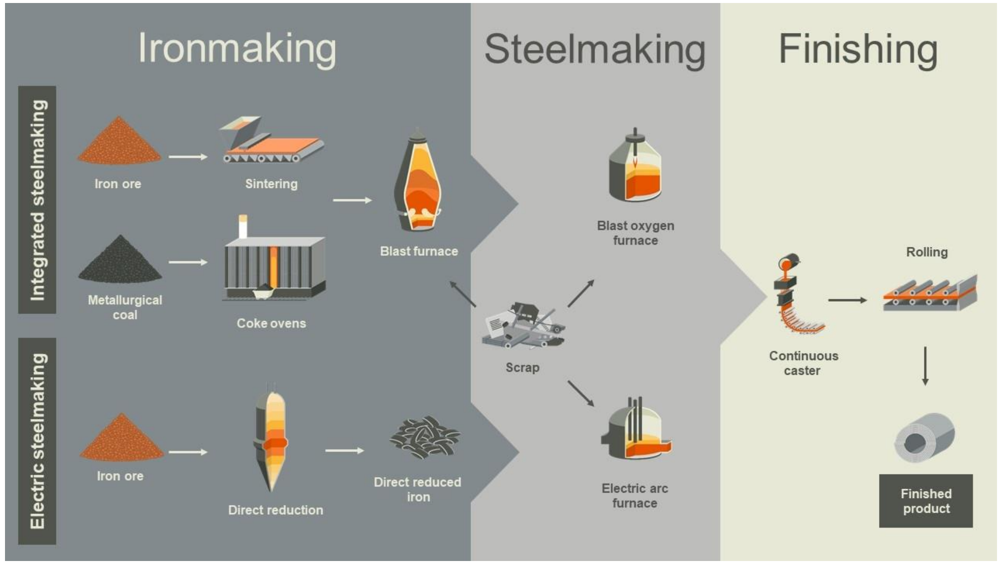
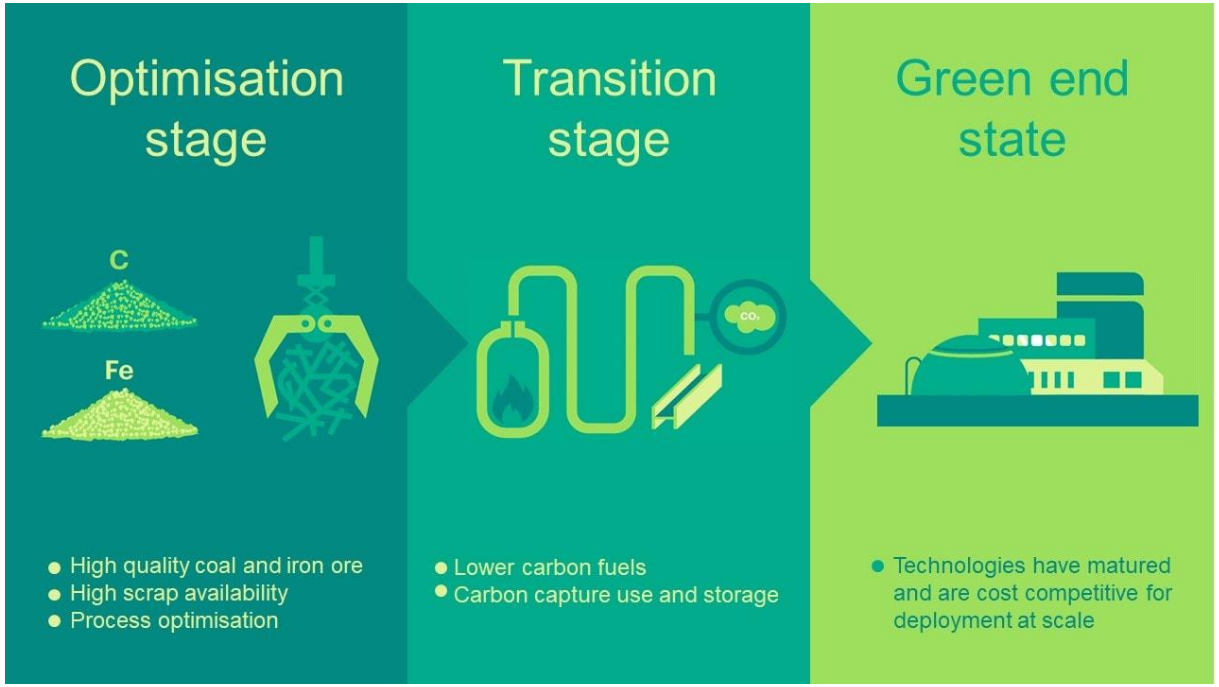
Low Carbon Solutions - Steel

- Steel making process is highly intensive and for the purposes of reducing CO² need to be improved
- New technologies and fuel inputs can help reduce fuel consumption whether it be carbon capture storage (CCS) and alternative fuels such as hydrogen





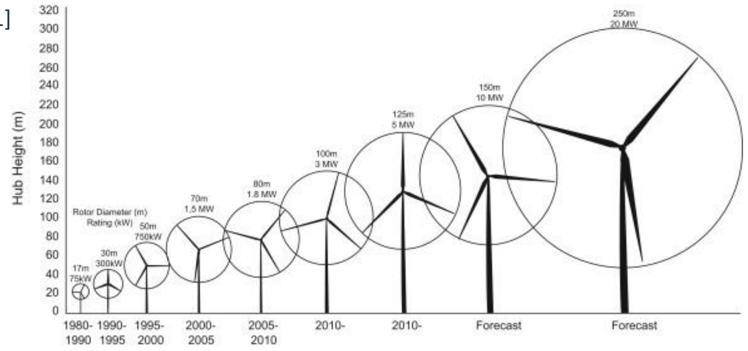
Top left: Steelmaking process [1]
Right: Steel decarbonization framework [1]

[1] Ellis, B., & BHP. (2020, November). *Pathways to decarbonisation episode two: Steelmaking technology*. https://www.bhp.com/news/prospects/2020/11/pathways-to-decarbonisation-episode-two-steelmaking-technology

Scale of Technology

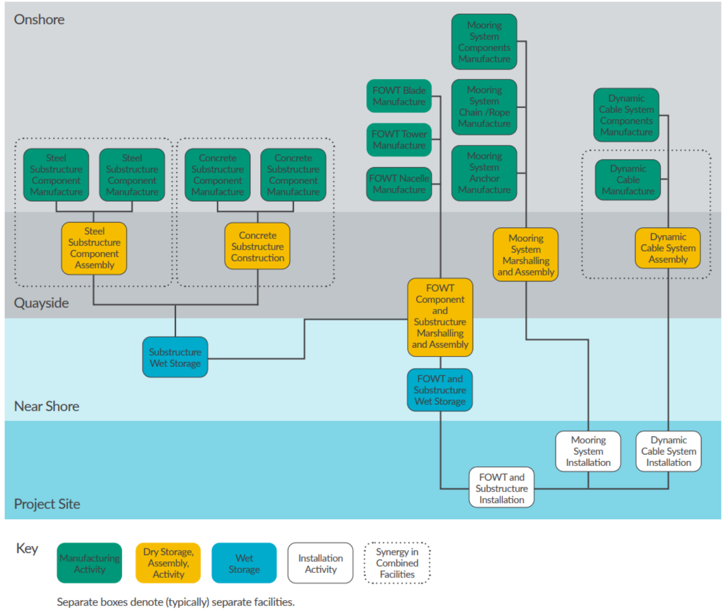
- Wind turbines are getting larger and with that, so does the size and complexity of the manufacturing facilities required to build them
- A portside facility will need to account for each sub-component and be ready for varying scales of turbines
- Planning and communication will be key

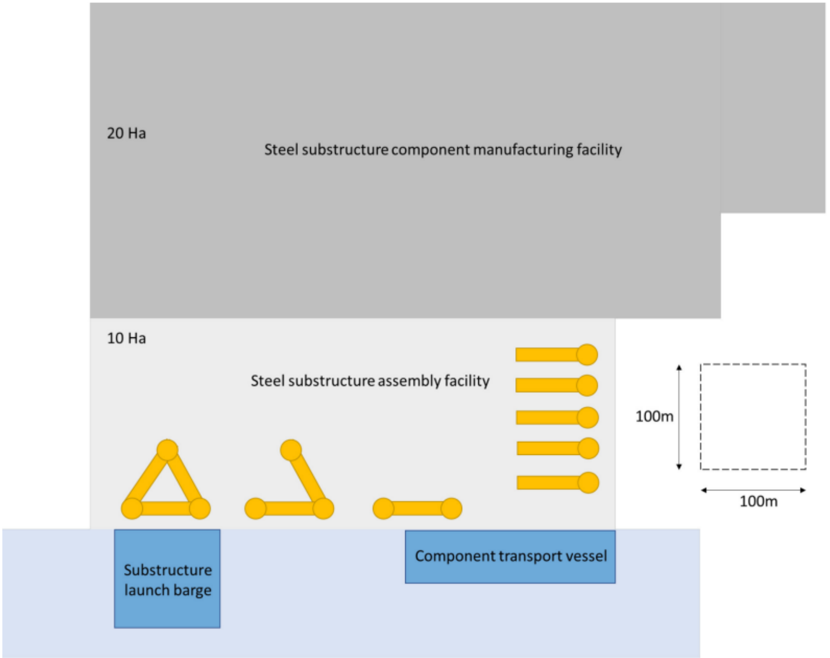
[1]



[2]

[3]

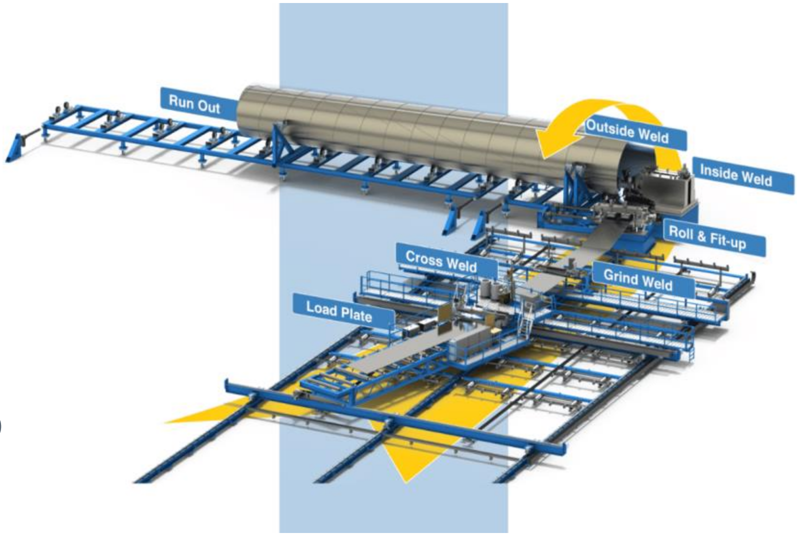




[1] Tabassum-Abbasi, Premalatha, M., Abbasi, T., & Abbasi, S. (2014). Wind energy: Increasing deployment, rising environmental concerns. *Renewable and Sustainable Energy Reviews*, *31*, 270-288
[2] Transverse load-out supports semi-submersible floating wind farm. (2019, November 6). Wind Systems Magazine
[3] ORE Catapult. (2022, May). Strategic Infrastructure and Supply Chain Development.

Manufacturing Processes

- Steel structures are typically made with a combination of rolling and welding processes
- Concrete structures are often made through slip forming processes
- Effort ought to be made in keeping manufacturing as close to quayside as possible
- Green steel showcases a key opportunity for reducing emissions
- New processes such as 3D printing may help further streamline manufacturing



Top Left: Spiral welding turbine tower manufacturing process [1]
Top Right: Process for manufacturing green steel [2]
Bottom: 3D printing concrete structure [3]

[1] GE installs world's first spiral-welded wind turbine tower. (2023, February 27). New Atlas. https://newatlas.com/energy/keystone-spiral-welding-wind/
[2] Greensteel. (2020, December 8). LIBERTY Steel UK. https://libertysteelgroup.com/uk/greensteel/
[3] Apis Cor. (2017, February 22). Youtube https://www.youtube.com/watch?v=xktwDfasPGQ

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Challenges and Opportunities

Opportunities

- Material choice has a big role in emissions reduction
- Local manufacturing can reduce emissions and bring in further opportunities
- New technologies such as low carbon materials, hydrogen and novel manufacturing processes could pave the way for both FOWT developments and other industries
- New, more optimised designs could pave the way for mass and emissions reductions

Challenges

- Can the supply chain support this demand?
- Need to support the development of new technologies
- Can ports (particularly in the Celtic Sea) accommodate these structures?
- Need to clarify technology choices for planned developments
- Securing investment

Conclusion

- Emissions are largely caused by manufacturing which is driven by material selection
- Concrete structures show noticeable potential for carbon savings
- Low carbon alternatives can have a substantial impact – ideally low carbon solutions for both steel and concrete should be explored
- Cutting down transportation emissions through more local content can also make a noticeable difference
- Optimising designs through material selection, manufacturing and detailed analysis can also lead to a reduction in material masses. Particularly, visible with steel structures.

Questions and Answers

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Morning Wrap Up

Julie Taylor

Celtic Sea FLOW – potential range of regional manufacturing opportunities.

Afternoon Session - 14:00-15:30PM

Monday 12 June 2023

Cornwall FLOW Accelerator

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UNIVERSITY OF EXETER

UNIVERSITY OF PLYMOUTH

HM Government

European Union European Regional Development Fund

CELTIC SEA CLUSTER

Welcome

Julie Taylor – ORE Catapult South West Innovation Manager

Catapult
Offshore Renewable Energy

Welcome

- Housekeeping
- Webinar session will be recorded
- Questions – Use Zoom Q&A function, not Chat
- Slides – Will be uploaded to Celtic Sea Cluster website: https://celticseacluster.com/
- Timetable

Timetable

PARTICIPANTS/PRESENTERS	ORGANISATION	TITLE	MINS	START	END
		AFTERNOON SESSION			
Julie Taylor	**ORE Catapult**	Welcome. Housekeeping, Outline of afternoon.	5	14:00	14:05
Simon Cheeseman	**ORE Catapult**	Reprise of key issues from morning session. CFA & CSC.	10	14:05	14:15
Tom Quinn	**ORE Catapult**	FLOW in the Celtic Sea. Size & Scope. Update on leasing and CfD rounds.	15	14:15	14:30
All		Q&A	5	14:30	14:35
Scott Davie	**ORE Catapult**	Anchoring & Mooring Systems	15	14:35	14:50
All		Q&A	5	14:50	14:55
Bradley McKay	**ORE Catapult**	Electrical Infrastructure	15	14:55	15:10
All		Q&A	5	15:10	15:15
Julie Taylor	**ORE Catapult**	Wrap Up. Next Steps.	10	15:15	15:25
Total			85		

Offshore Wind and FLOW Context

Simon Cheeseman – ORE Catapult South West Programme Manager

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Simon Cheeseman

- Work for Offshore Renewable Energy Catapult, South West Programme Manager running offices in Cornwall and Devon. Delivering strategy to accelerate floating wind in the Celtic Sea.
- Background is managing complex, multi partner, multi million-pound projects in renewables in public and private sectors.
- Sit on Board of the Celtic Sea Cluster and represent ORE Catapult on the Celtic Sea Developers Alliance.

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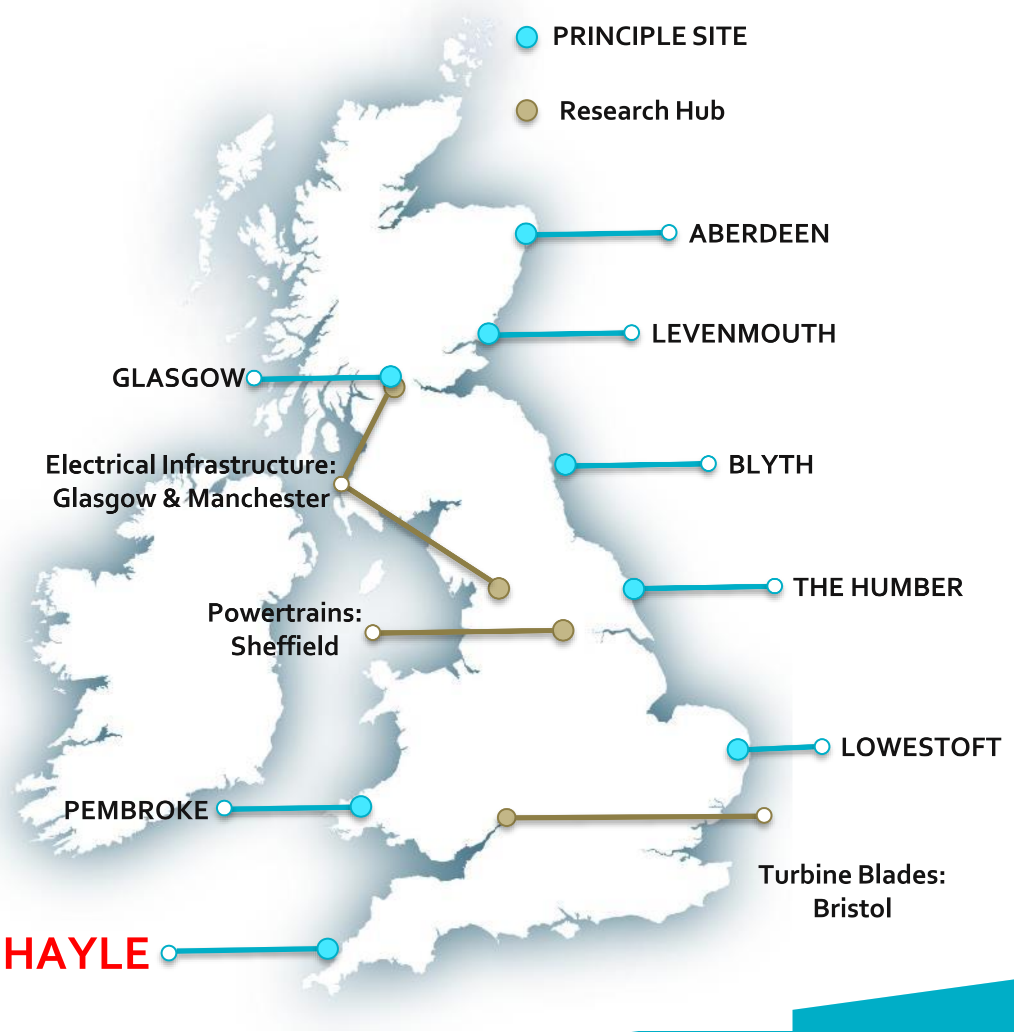
About ORE Catapult

Our Mission:

Deliver the UK's largest clean growth opportunity by accelerating the creation and growth of UK companies in offshore renewable energy.

1. 300+ staff including engineering and research experts with deep sector knowledge
2. Independent and trusted partner
3. Work with industry and academia to commercialise new technologies
4. Reduce the cost of offshore renewable energy
5. Deliver UK economic benefit



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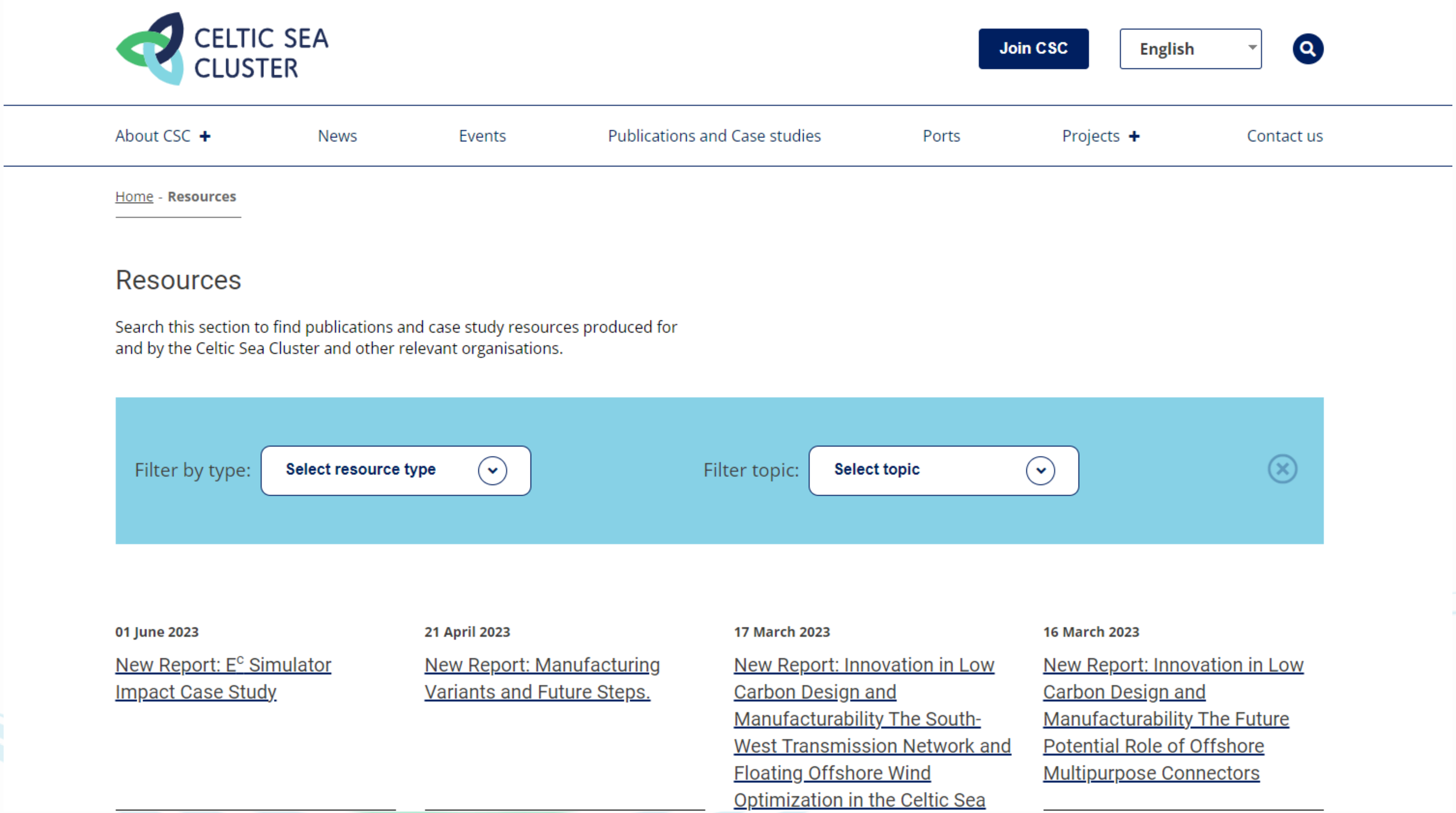
Celtic Sea Cluster Publications and Case studies [Resources]



Global offshore wind growth

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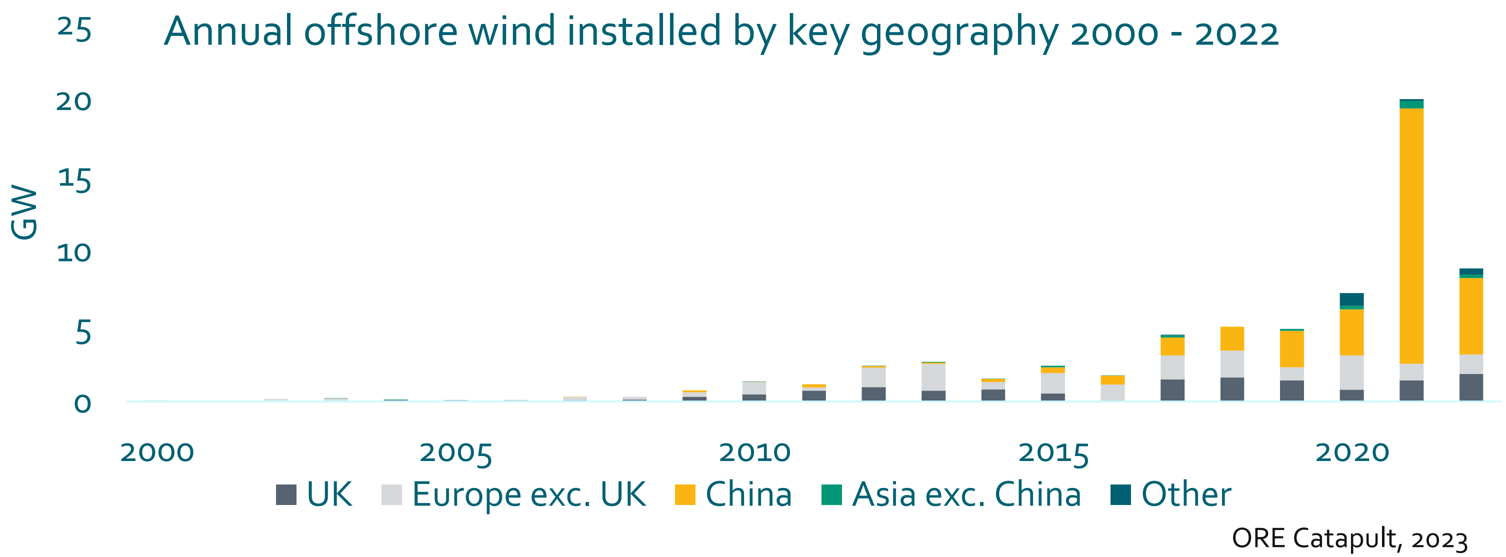
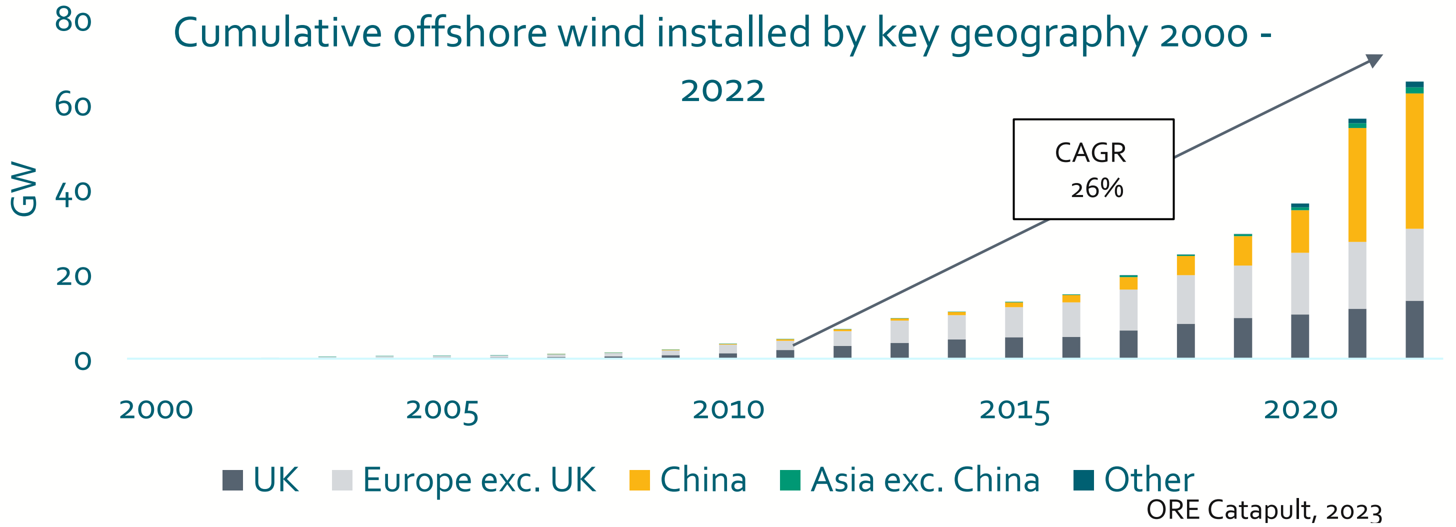
Offshore wind global capacity to date





- Up to 2015, offshore wind very much a European play
- Generally, countries building on existing onshore wind expertise
- China overtook the UK as the world's leader in offshore wind capacity after installing 16.9GW in 2021.

- UK share of capacity falling from peak 53% in 2012 to 21% in 2022
- Total Europe share falling from 91% in 2012 to 47% in 2022
- CAGR* from 2010 to 2020 of 27%

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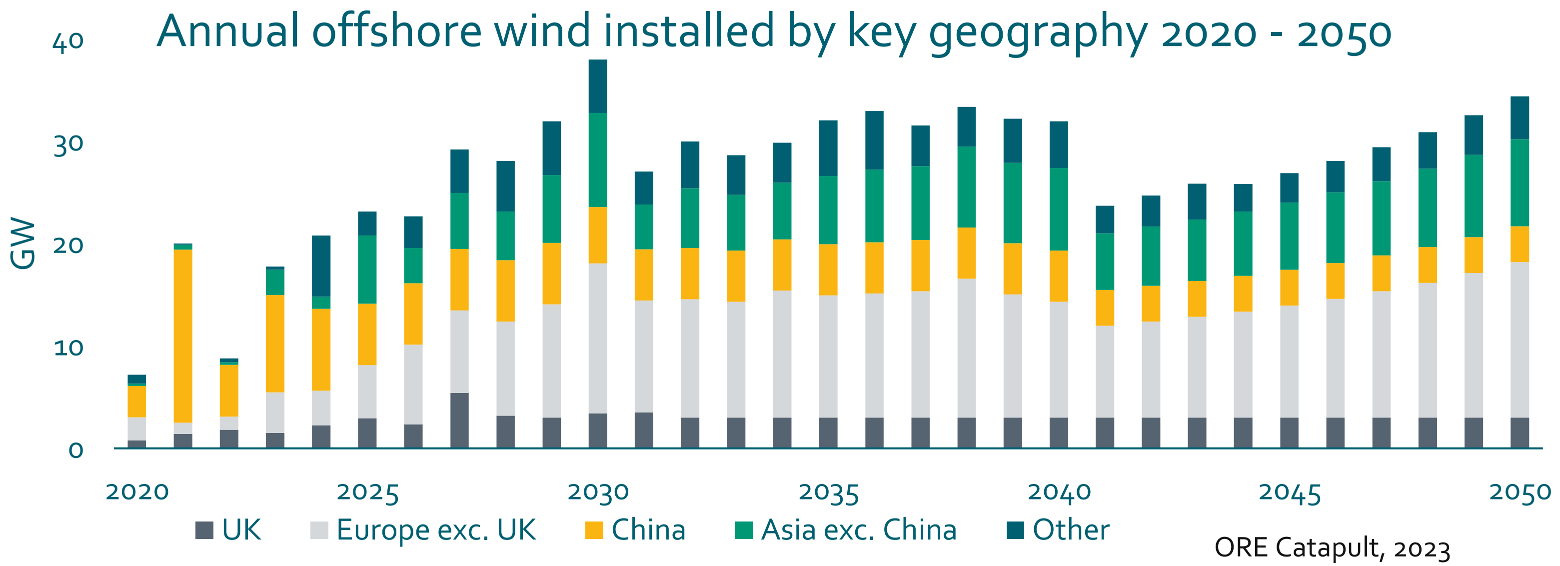
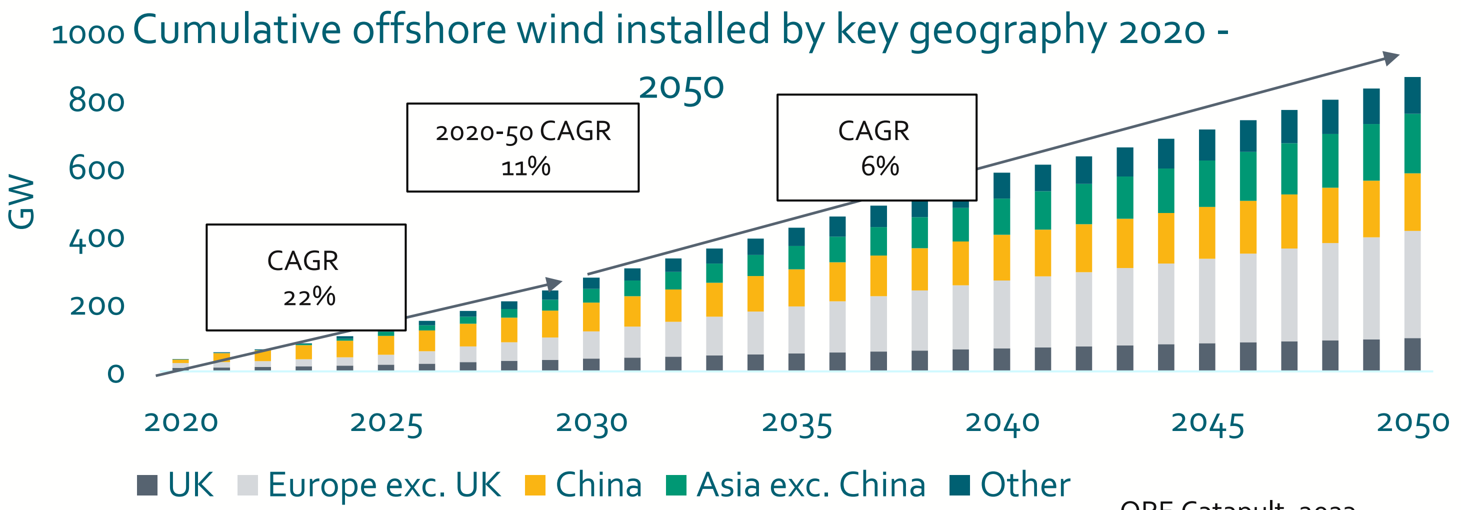
Offshore wind global capacity forecast



ORE Catapult, 2023



ORE Catapult, 2023

- Our forecast assumes a near-term push to achieve 2030 targets
- Annual installations increase from ~9GW in 2022 to 38GW in 2030 and 34GW in 2050

- Total Europe share falling from 47% in 2022 to 39% in 2050
- China share drops from peak of 49% in 2022 to 20% by 2050
- Other markets grow share from 2% in 2022 to 13% by 2050

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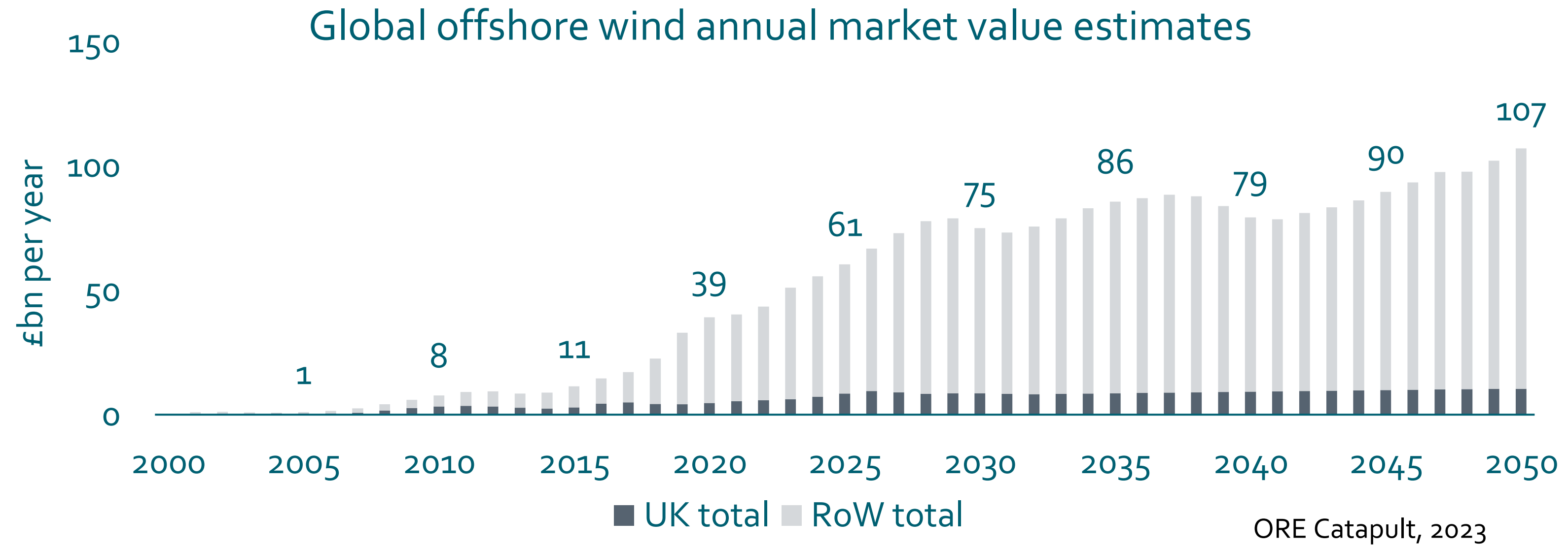
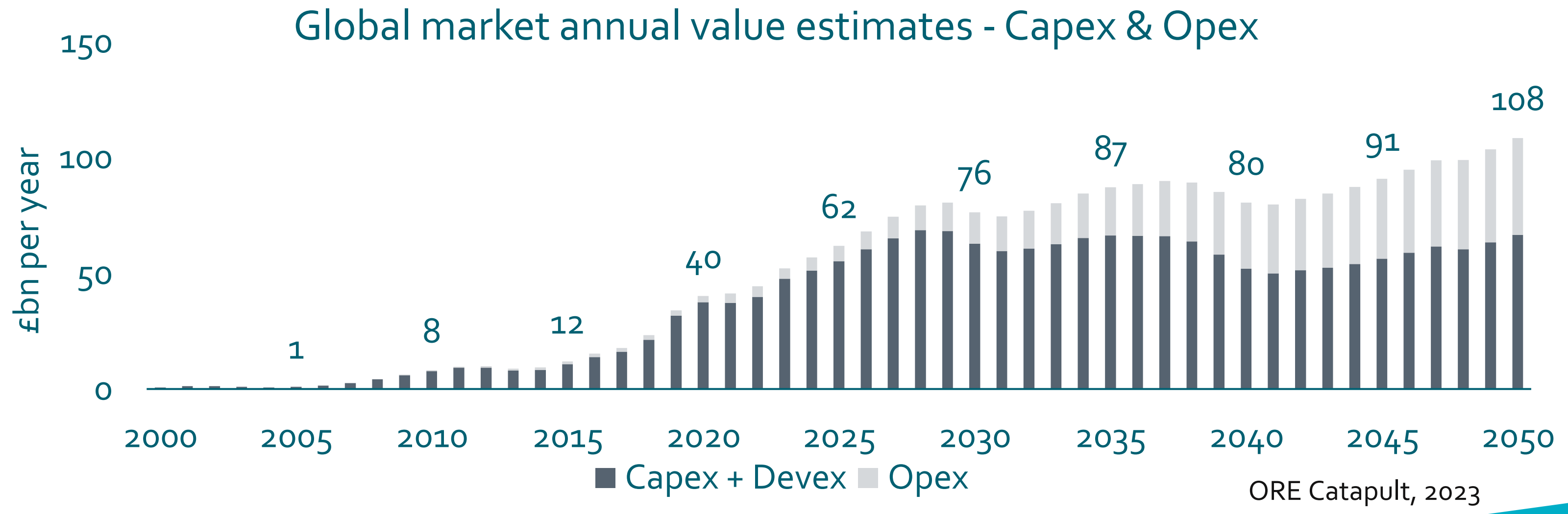
Offshore wind global market value estimates





- Near doubling of market value from 2020 to 2030 due to ramp-up to 2030 targets
- Market value reaches £107bn per year by 2050 – slower increase due to more gradual ramp-up and cost reductions

- Capex always forms largest share of value while building out
- Opex taking increasing share as installed base grows
- Continuous pipeline important for short-term construction jobs

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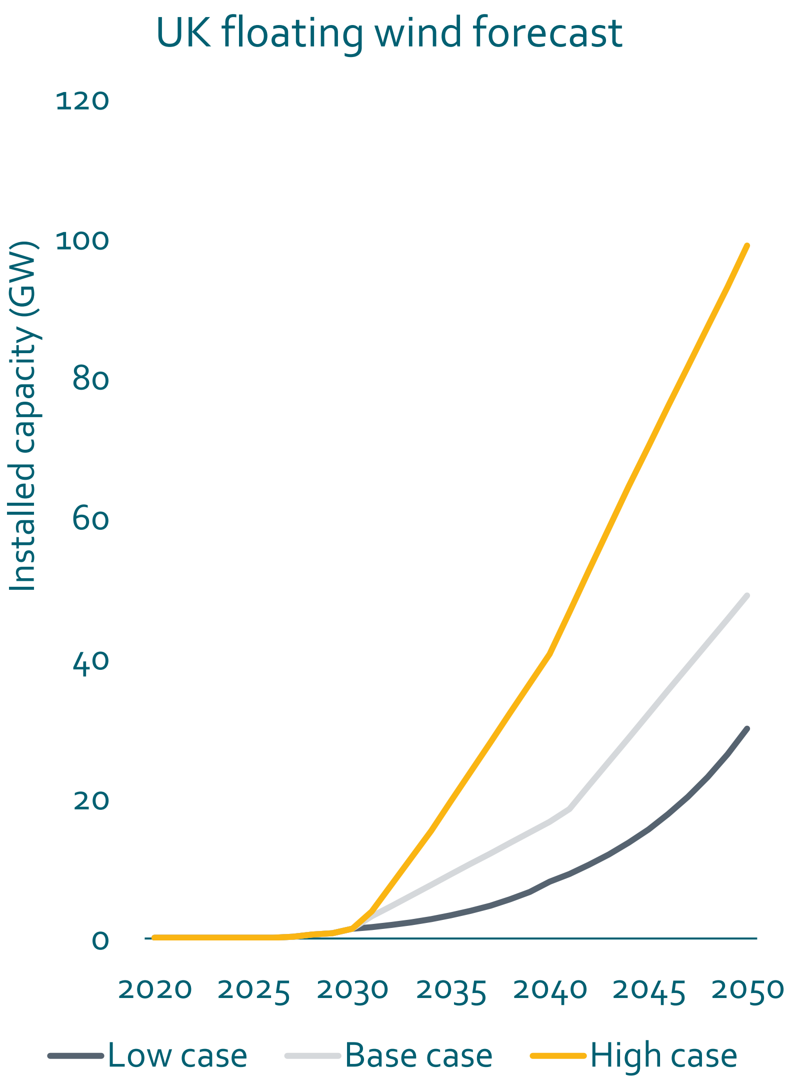
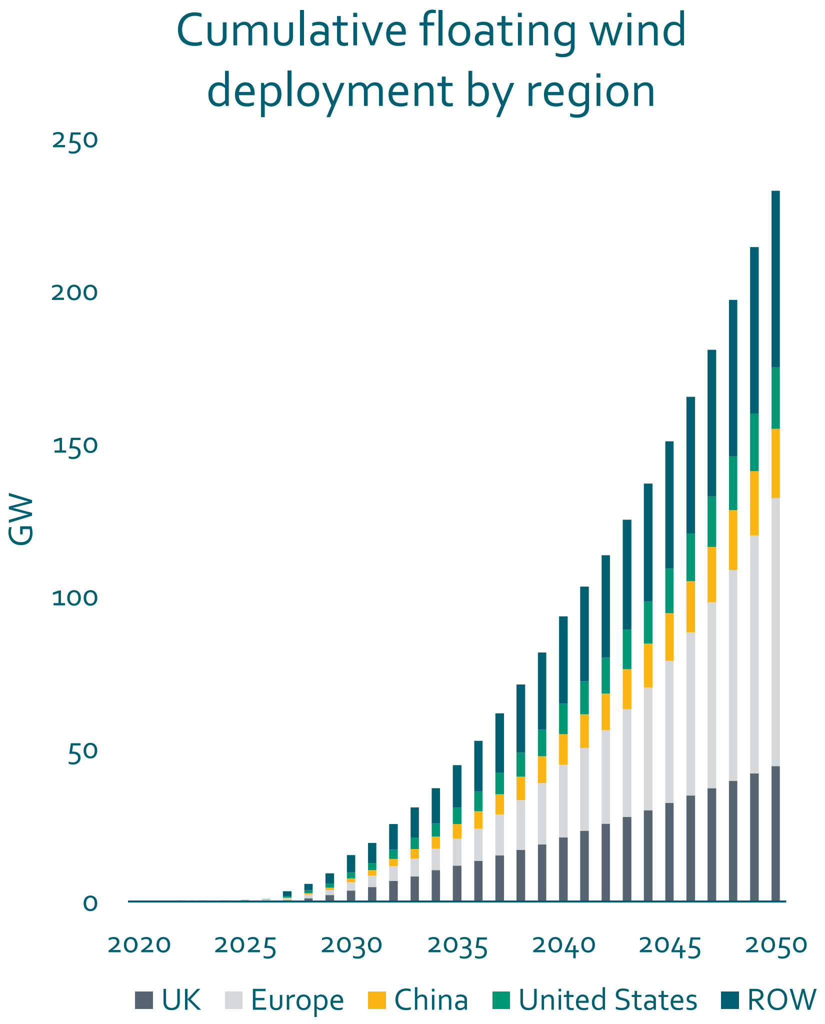
Floating wind is expected to take off from a standing start





ORE Catapult, 2023

- ScotWind leasing round allocated nearly 17GW to floating offshore projects.
- March 2023 saw the announcement of 5.4GW of floating wind lease capacity from the INTOG round.
- Scotland is expected to be one of the largest markets in the world for floating offshore wind with planned projects currently making up 31% of the global floating pipeline.
- The UK has a target of 5GW of installed floating wind capacity by 2030.
- Forecasts for the UK market depend on total OSW deployment – geographical constraints are not an issue.

- Europe is expected to be a first-mover in floating wind as it was with bottom-fixed
- Elsewhere, the west coast of US, Japan, S. Korea and Taiwan are likely to be core floating wind markets

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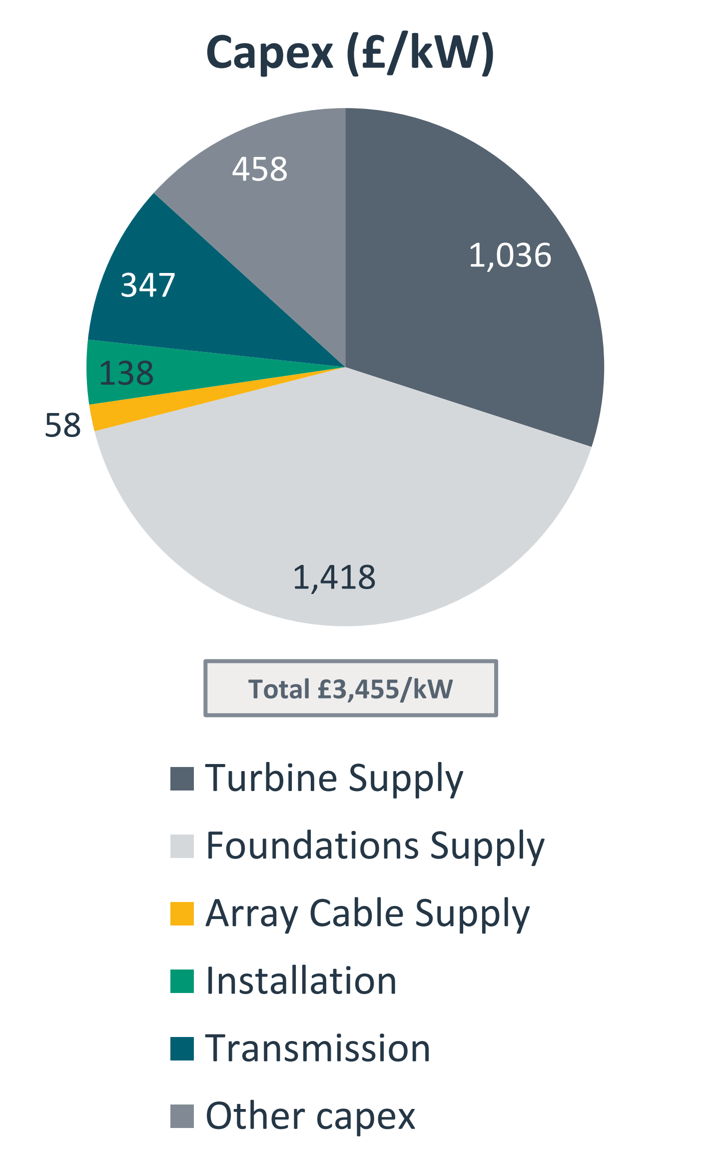
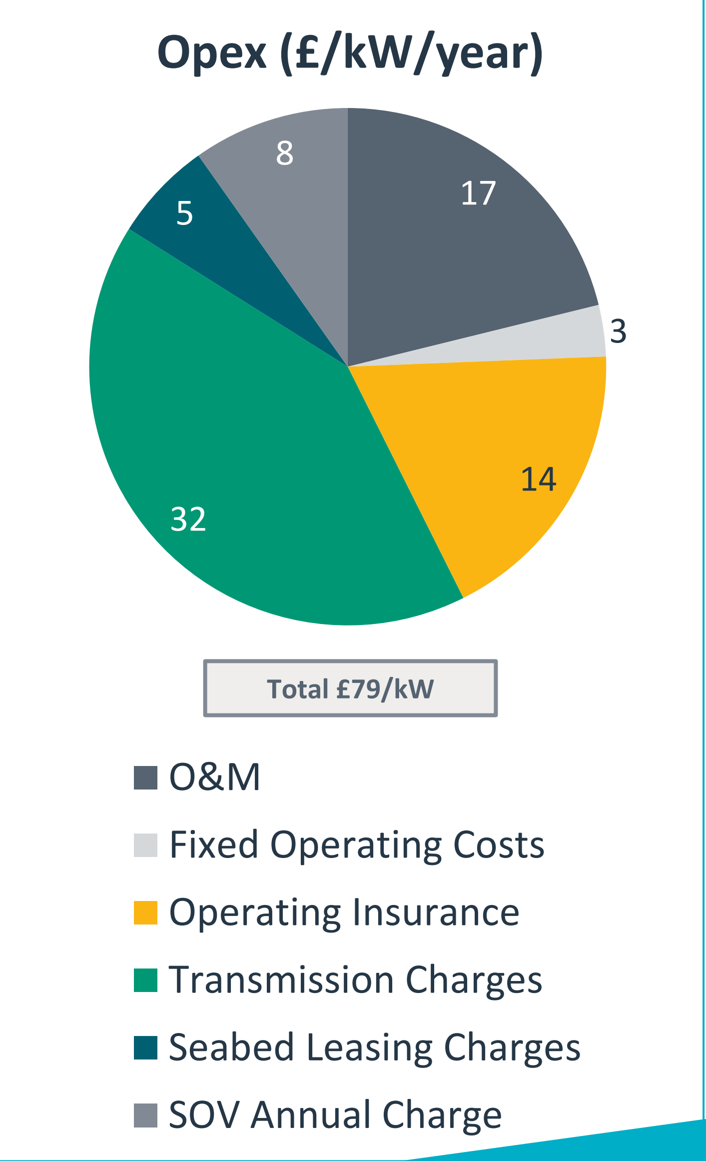
2030 Reference Site (Floating)

Scenario Definition	Unit	2030 Ref Site
Turbine numbers	#	67
Turbine rating	MW	15MW
Windfarm capacity	MW	1,005MW
Mean wind speed at hub height	m/s	10.52
Turbine foundation type	text	Semi-sub
Array cable type	kV	66kV
Transmission System Type	#	HVAC
Water depth	metres	98
Distance to O&M port	km	100
Distance to cable landfall	km	85
O&M Vessel Strategy	text	SOV





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Marine Operations Laboratory to understand DP & Marine Simulations constraints & future ports, vessel and marine operations needs

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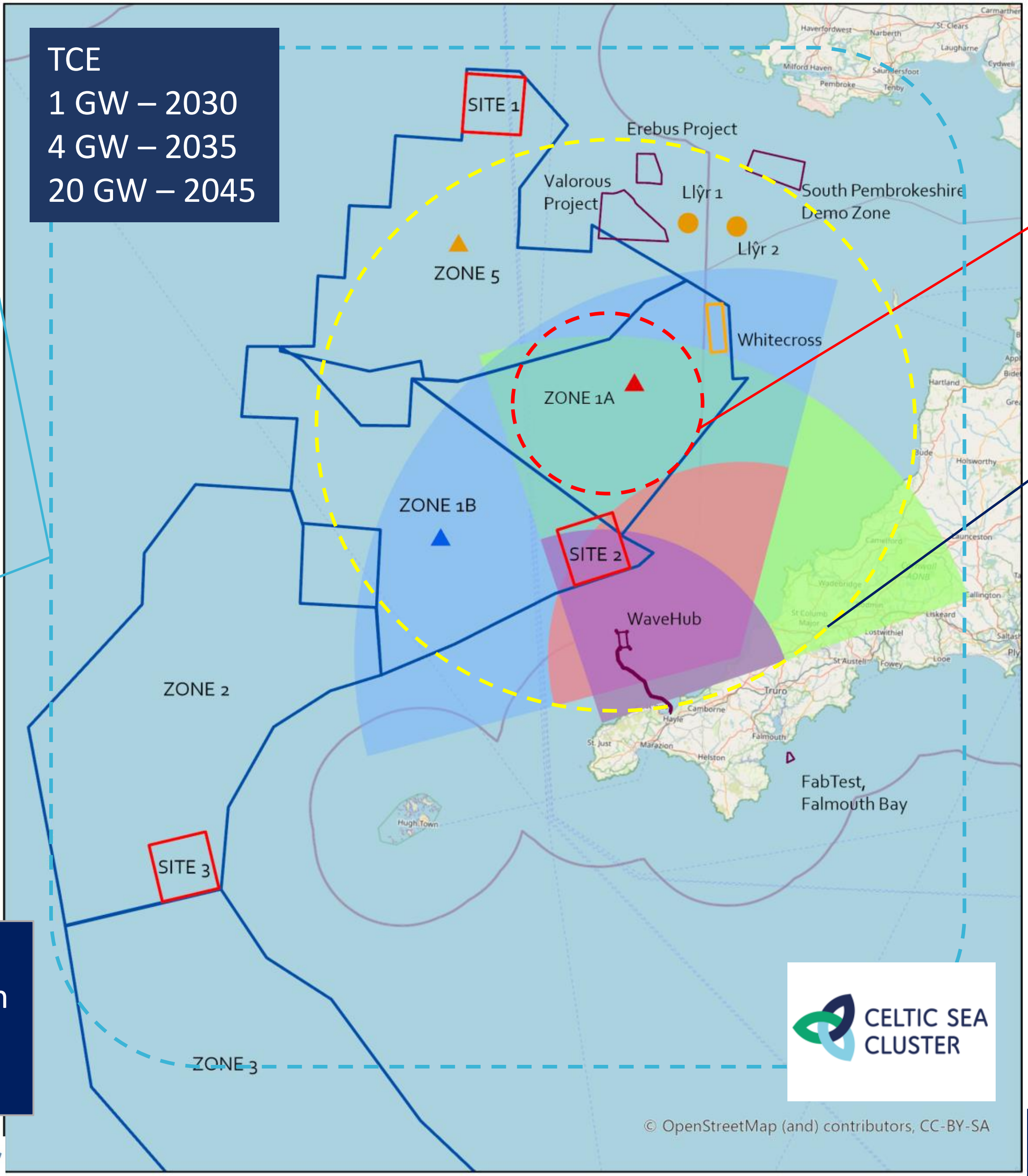
Ec simulator to output: Levelized Cost of Energy (LCOE) Levelized Cost of Carbon Abatement (LCCA) and Energy returned for Energy Invested. Will model virtual sites and help define key assumptions for FLOW in the 2030's.

UNIVERSITY OF EXETER



12 months wind resource acquisition by Flidar commencing March 2022

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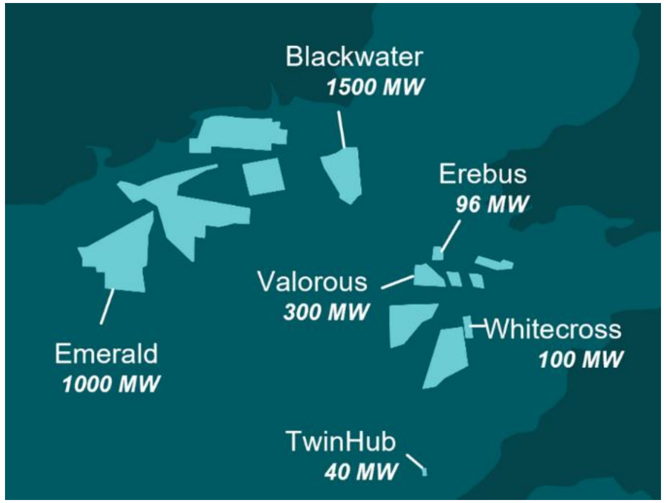
Understand how we can reduce carbon associated with EIA's, drive local solutions, accelerate the development phase



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Low Carbon materials & fabrication. Looking at blades, towers, foundation and electrical infrastructure and understanding the local opportunity

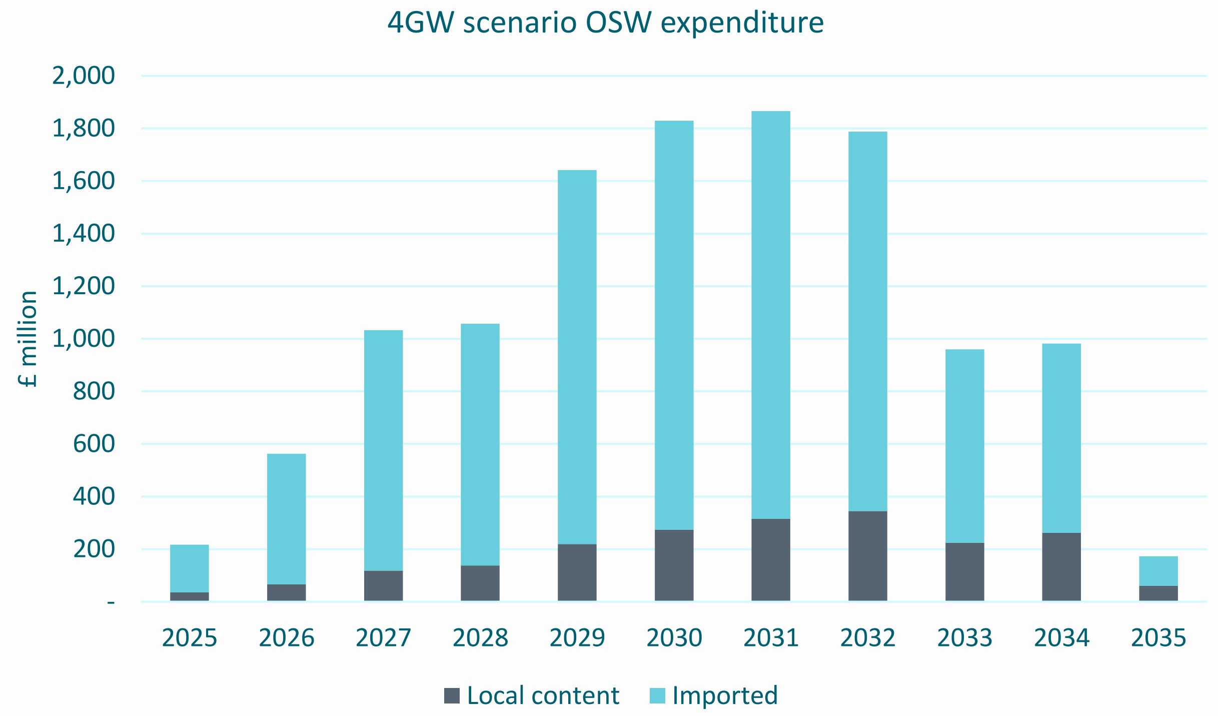
Cornwall FLOW Accelerator

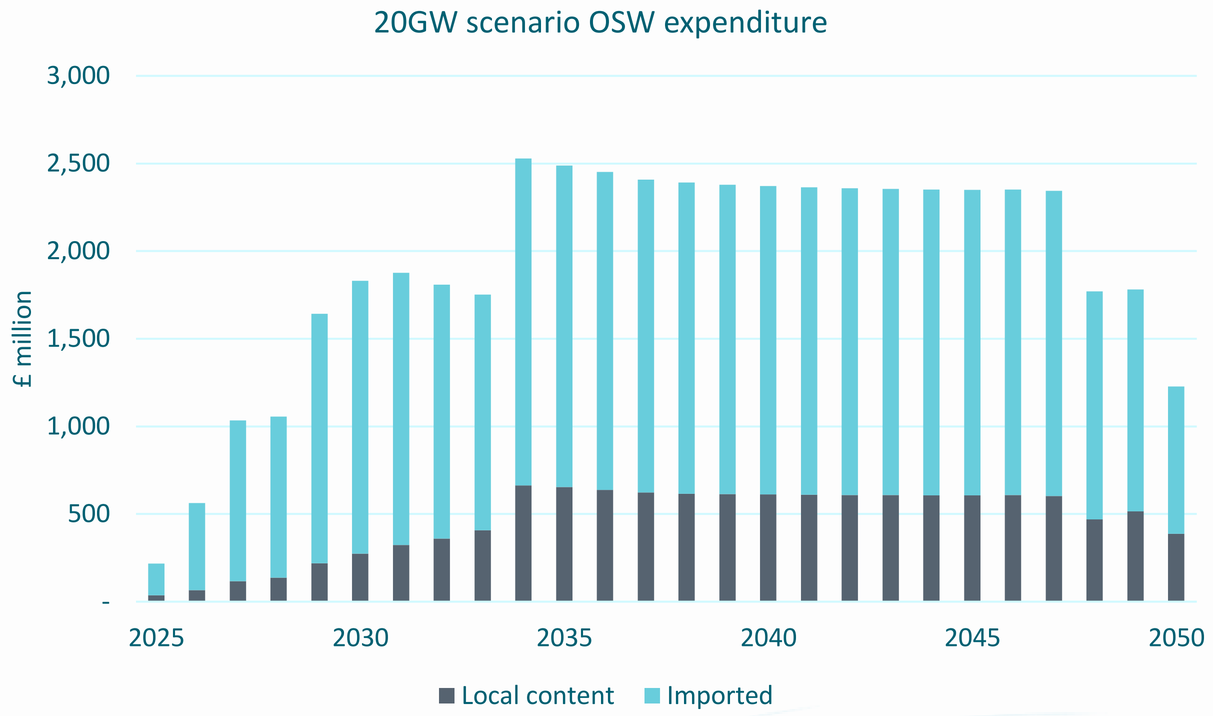
CATAPULT Offshore Renewable Energy

Tom Quinn

Offshore Renewable Energy

Market opportunity for the Celtic Sea region





Components	Unit	4GW case	20GW case
Turbines / substructures	*#*	235	1,035
Mass of substructures	*tonnes*	837,000	3,877,000
Mooring lines	*km*	600	2,600
Anchors mass	*tonnes*	24,200	120,000
Array cables	*km*	580	2,900
Export cables	*km*	1,100	5,200

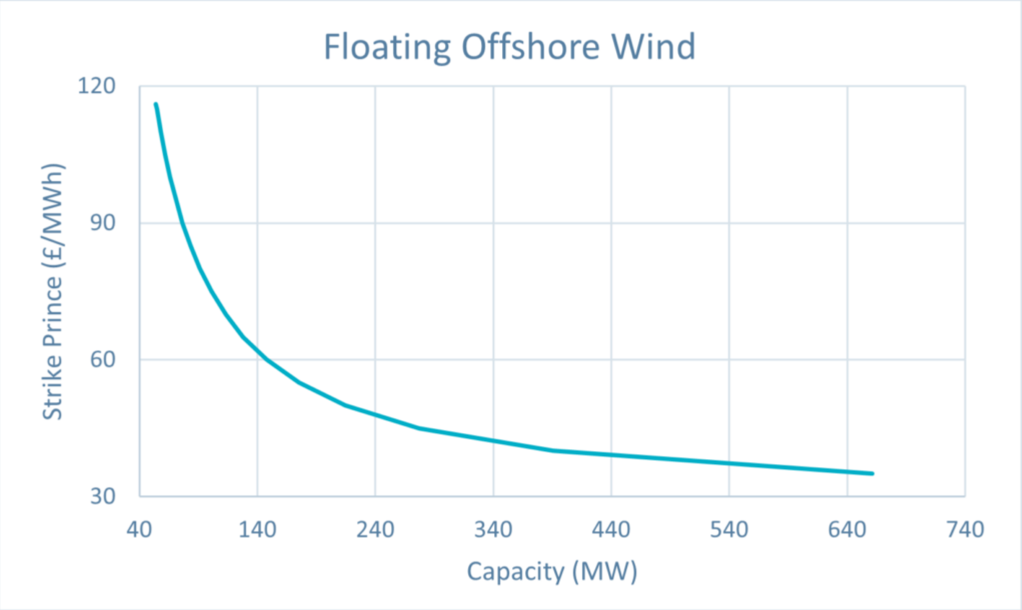
CfD auctions putting pressure on developers

Issues

- CfD auctions to be run annually
- Current auction (AR5) has FOW competing with other "emerging" tech in Pot 2 such as biomass, geothermal, wave & tidal.
- Auction Pot 2 budget of £25m (£35m minus £10m ringfenced for tidal) allows for ~40-150MW of FOW depending on strike price bid if FOW outbids other tech
- FOW maximum strike price of £116/MWh (2012 terms, ~£155 today) will be a challenge for some developers

However…

- Budgets for future rounds will likely increase to allow for greater FOW deployment
- Non-price criteria may be included in future CfD rounds



Questions and Answers

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FLOATING OFFSHORE WIND
CENTRE OF EXCELLENCE

Delivered by CATAPULT Offshore Renewable Energy

Carbon Emission Reduction in Mooring Systems for FLOW

Scott Davie

Floating Wind Engineer

Offshore Renewable Energy Catapult

Photo courtesy of Principle Power. Artist: DOCK90

Why look for low carbon mooring solutions?

- With the huge growth planned for Floating Offshore Wind (FLOW) there will be increased demand for materials and manufacturing

Estimated mooring component requirements:

4GW in the Celtic Sea (2023 Leasing Round)	20GW in the Celtic Sea (2050 Target)
~ 500 km mooring lines	~ 2,500 km mooring lines
~ 250,000 Tonnes of chain	~ 1,250,000 Tonnes of chain
~ 1,000 anchors	~ 5,000 anchors
> 24,000 Tonnes of anchors	> 120,000 Tonnes of anchors

- Current mooring design components and manufacturing methods are carbon intensive


Image Courtesy of Offspring International

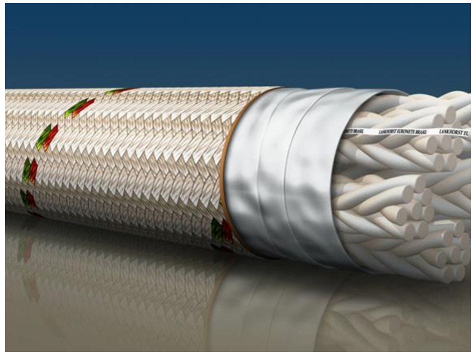
Image Courtesy of Lankhorst Offshore

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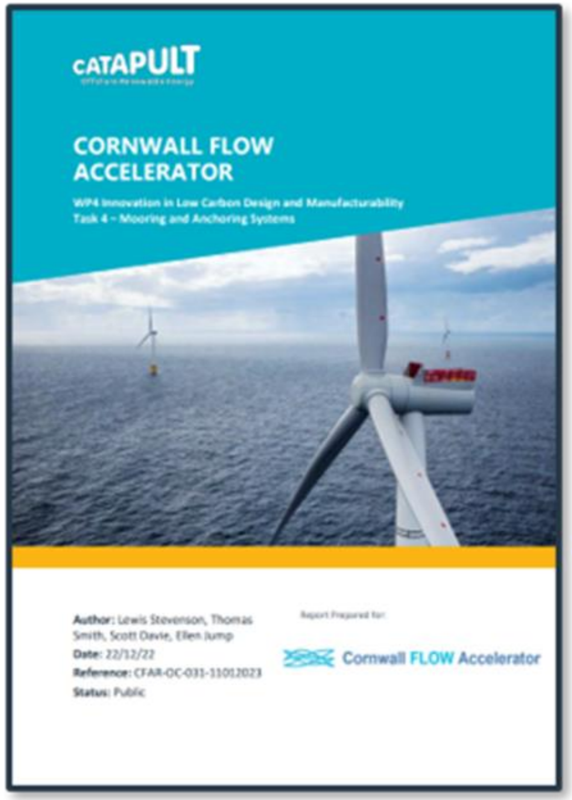
Overview of low carbon mooring & anchoring study



Aims

- To calculate the carbon emissions using Life Cycle Analysis for:
  - Conventional mooring materials and configurations used in FLOW so far
  - Potential alternative mooring materials and configurations to be used in FLOW in future
- To identify opportunities for low carbon design and manufacture for the local supply chain

Report from the study is available on the ORE Catapult and Celtic Sea Cluster websites

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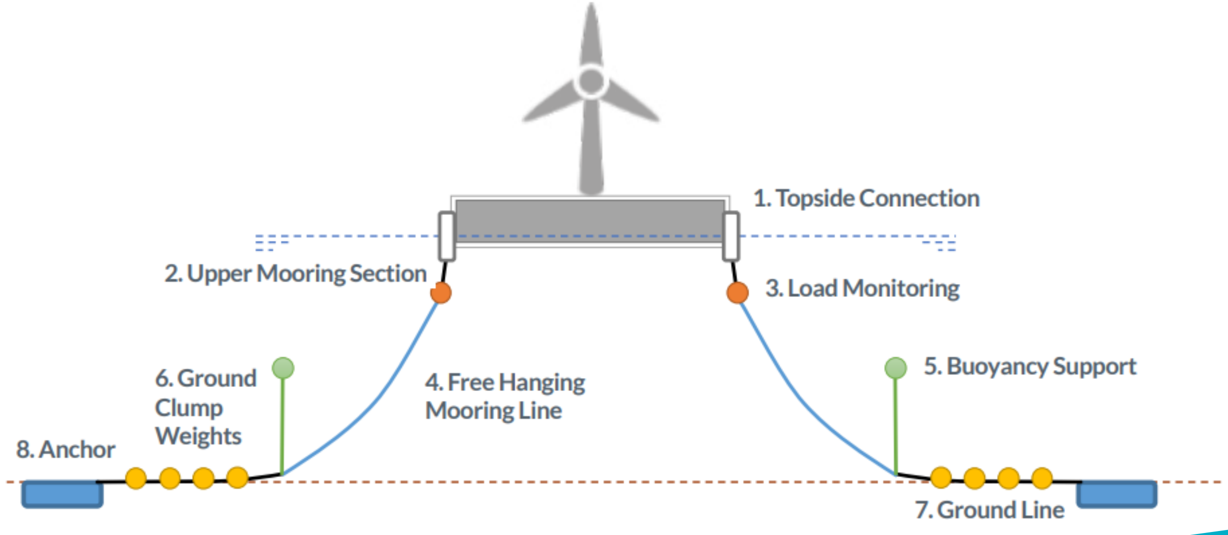
Mooring System Component Breakdown

- Lines
  - Chain
    - Studlink
    - Studless
  - Steel Wire Rope
    - Sheath Spiral Strand
    - 6 x 36 core
  - Synthetic Rope
    - Polyester
    - HMPE
    - Nylon
    - Novel
- Anchors
  - Drag Embedment
  - Piled
    - Driven
    - Drilled
  - Vertically Loaded
  - Suction Bucket
  - Gravity
- Jewellery
  - Buoyancy Modules
    - Inline Clamshell
    - Inline Link
    - Pendant
  - Ballast Modules
    - Feedthrough
    - Clamshell
  - LRDs
  - Joining links
    - H-links
    - Pear links
    - Anchor shackles
    - Bow/D shackles
- Installation Aids
  - Tensioning
    - Temporary
    - Permanent
  - Reaction Anchors
  - Temporary Buoys
  - Mooring Connectors
    - Fairleads
    - Mooring Connector
    - Chain Stoppers



Key consideration for study:

- Mooring line materials
- Anchor types
- Supporting Mooring Jewellery

Carbon Emission Life Cycle Analysis (LCA)

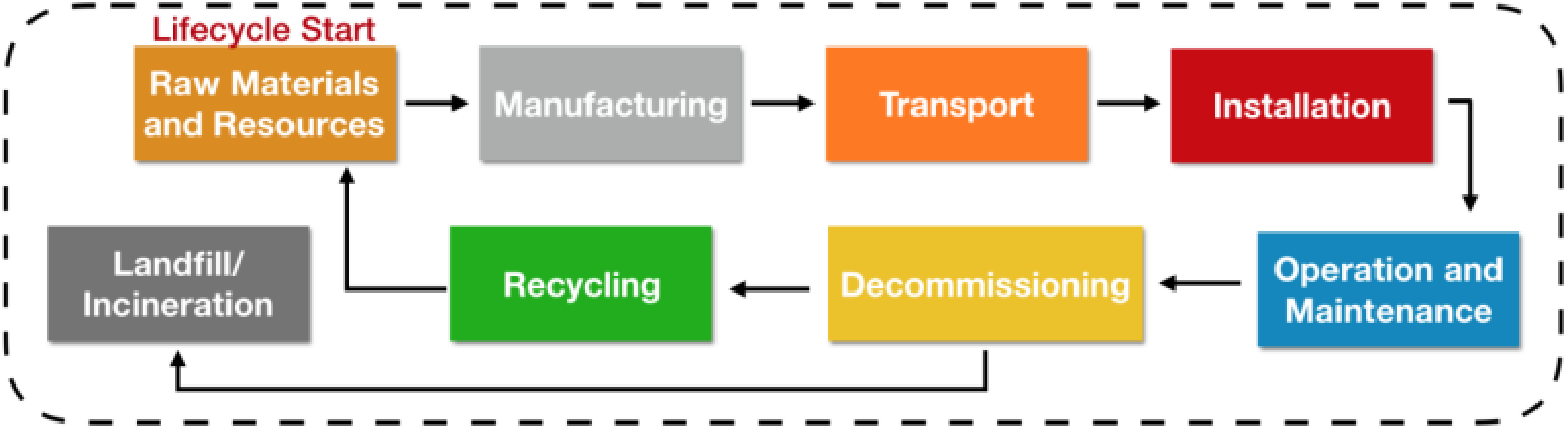


Image Courtesy of University of California

- Each stage can be broken down into a series of processes
- Lack of available information to fully calculate the carbon emissions for O&M and end of life stages
- The energy and materials required for each process must be identified
- Carbon Emissions were calculated in tonnes of carbon dioxide ($TeCO_2e$) per turbine

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Process Example – Steel Chain Manufacture

Starting with extruded steel bar…

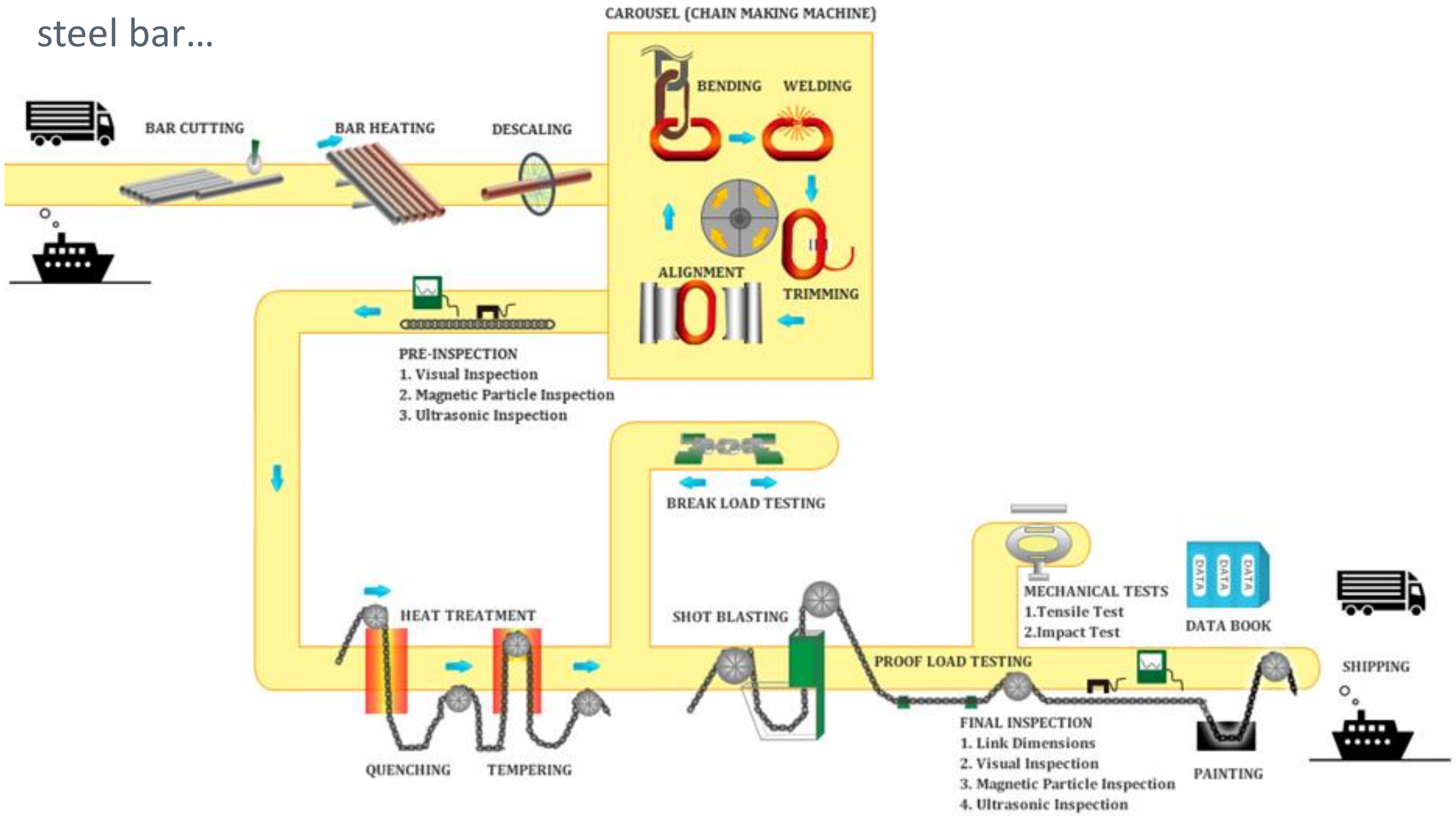


Image Courtesy of Hamanaka Chain (Adapted)

Key carbon emitting processes:

- Steel bar production from raw material
- Bar cutting and heating
- Carousel Processes
- Heat treatment and Shot Blasting

Emissions = carbon intensity of process x mass of material produced

Wind Farm Site Design Requirements

Indicative Wind Farm Site Characteristics:

- 100m water depth
- Various seabed conditions

Image Courtesy of World Atlas

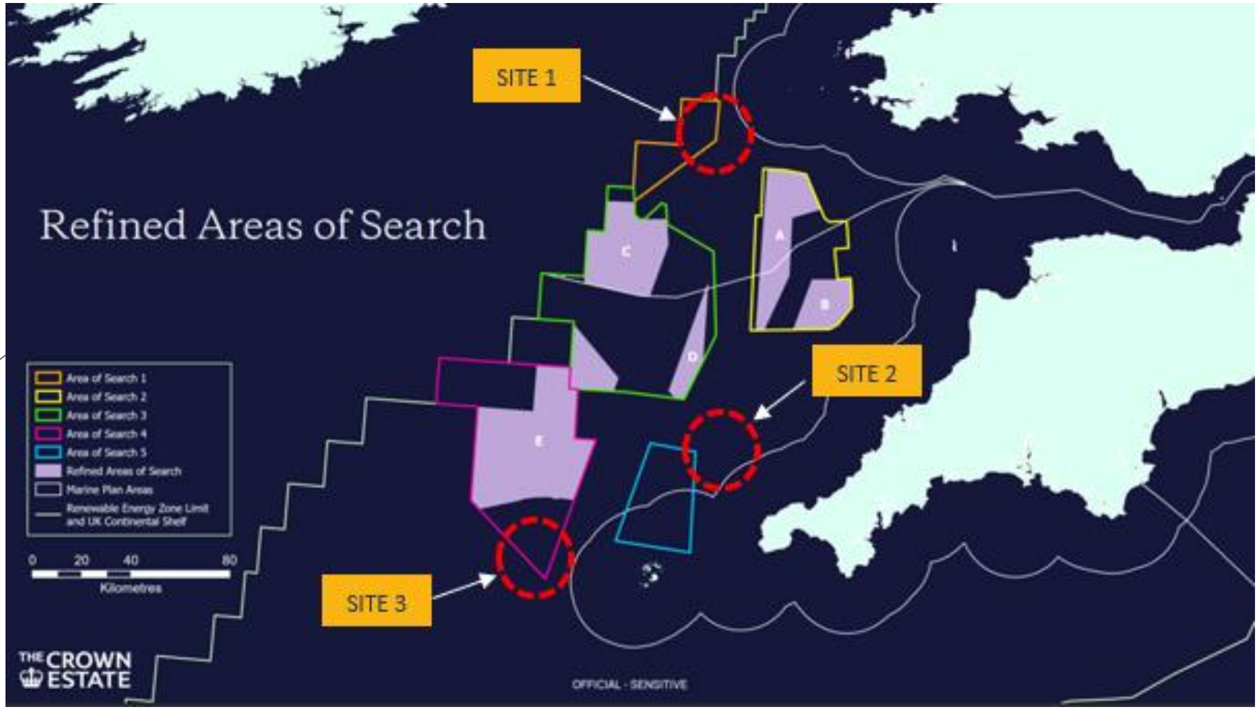
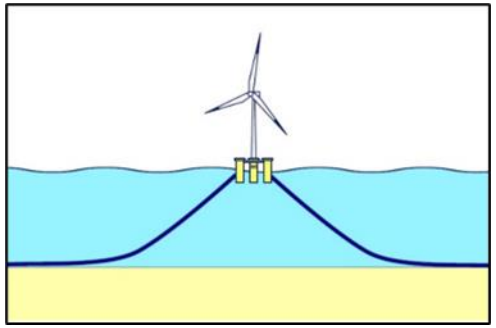


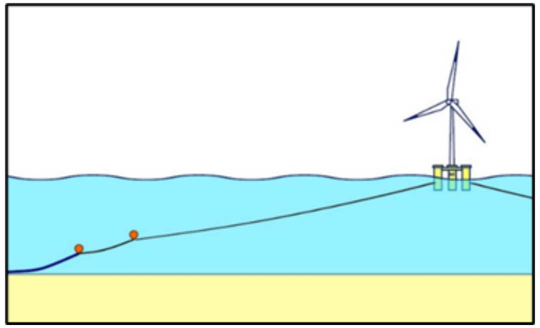
Image Courtesy of The Crown Estate

Conventional Mooring Configurations – 15MW Semi-Sub

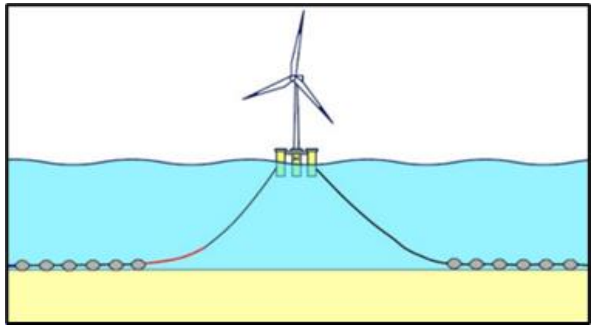
Configuration Name	Line Type	No. of Lines	Total Chain Length (m)	Chain Size (mm)	Rope Length (m)	Rope Diameter (mm)	Ancillaries	Anchor Type	Anchor Sizing (Te)
Catenary A (3-line)	Chain	3	750	152	-	-	-	Drag Embedment	30
Catenary B (6-line)	Chain	6	750	132	-	-	-	Drag Embedment	23
Catenary C (9-line)	Chain	9	750	112	-	-	-	Drag Embedment	12
Semi-taut (Buoyant)	Chain, Synthetic Rope	3	400	152	150	230	Buoyancy Modules	Drag Embedment	15
Ballasted	Chain, Synthetic Rope	3	400	152	150	220	Clump Weights	Drag Embedment	12
Taut	Chain, Synthetic Rope	3	50	152	350	200	-	Suction Bucket	113



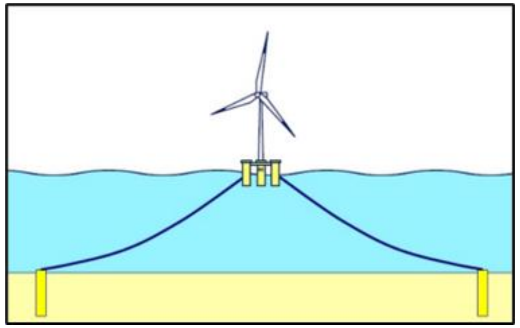
Catenary



Semi-taut (Mixed Buoyant)



Ballasted



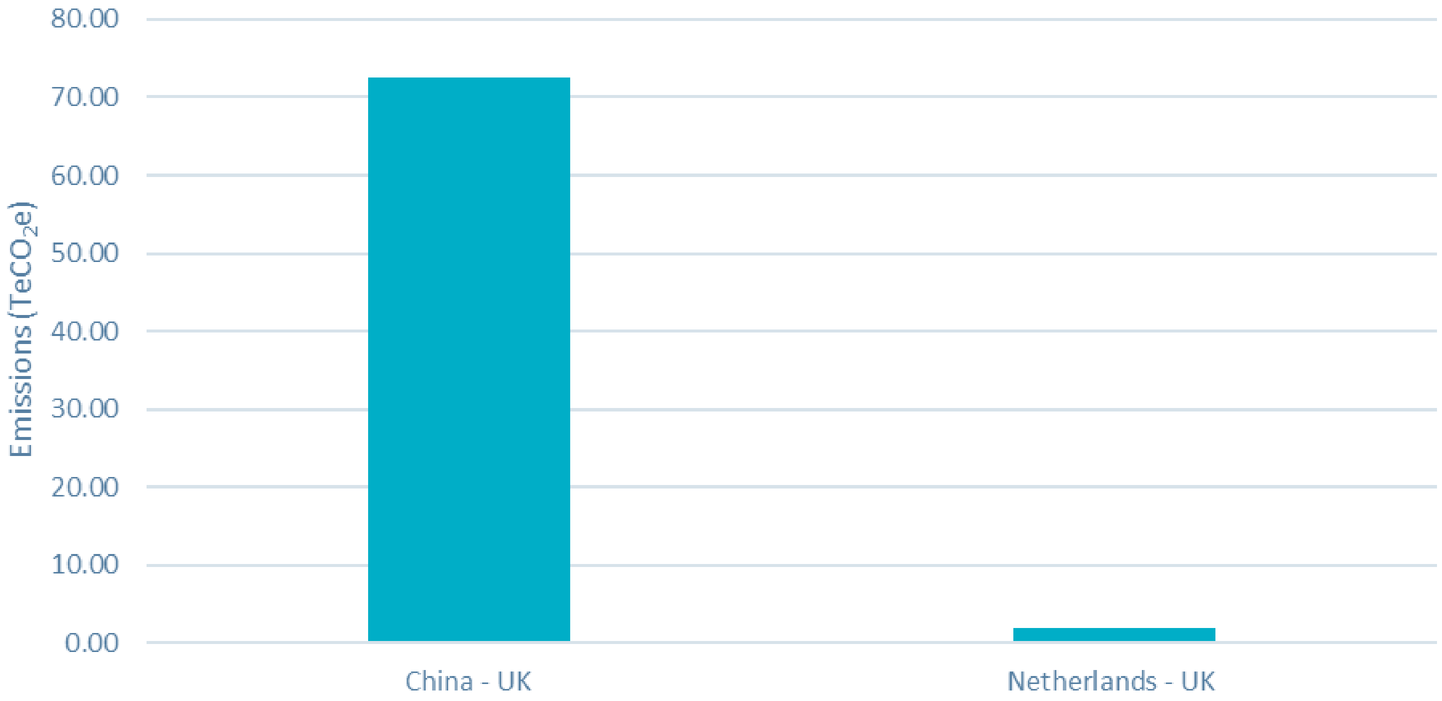
Taut

Images Courtesy of FMS and Morek

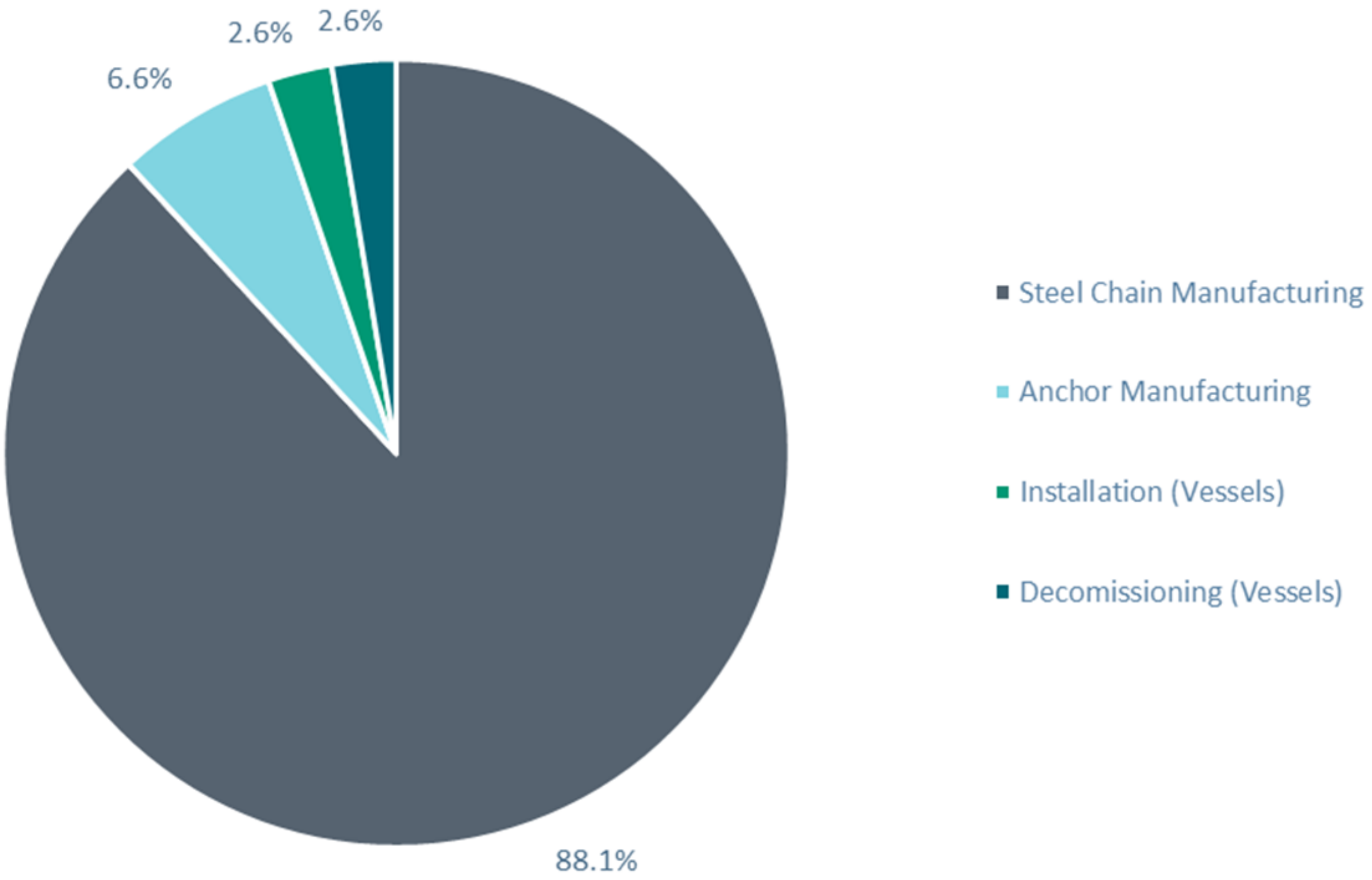
Transportation – Carbon Emissions Results

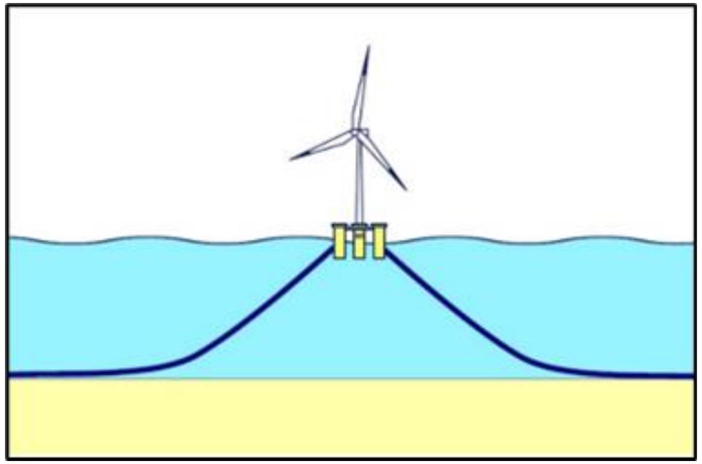
Port Route	Country	Sea Route Distance
Rotterdam - Southampton	Netherlands - UK	487km
Guangzhou – Southampton	China - UK	19,031km

- Approximately 375 tonnes of imported steel is required for the fabrication of a single steel chain mooring line and anchor
- Transportation from China produces approximately 40 times more carbon emissions
- Import emissions are often not accounted for



Conventional 3-Line Catenary A - Carbon Emissions Results





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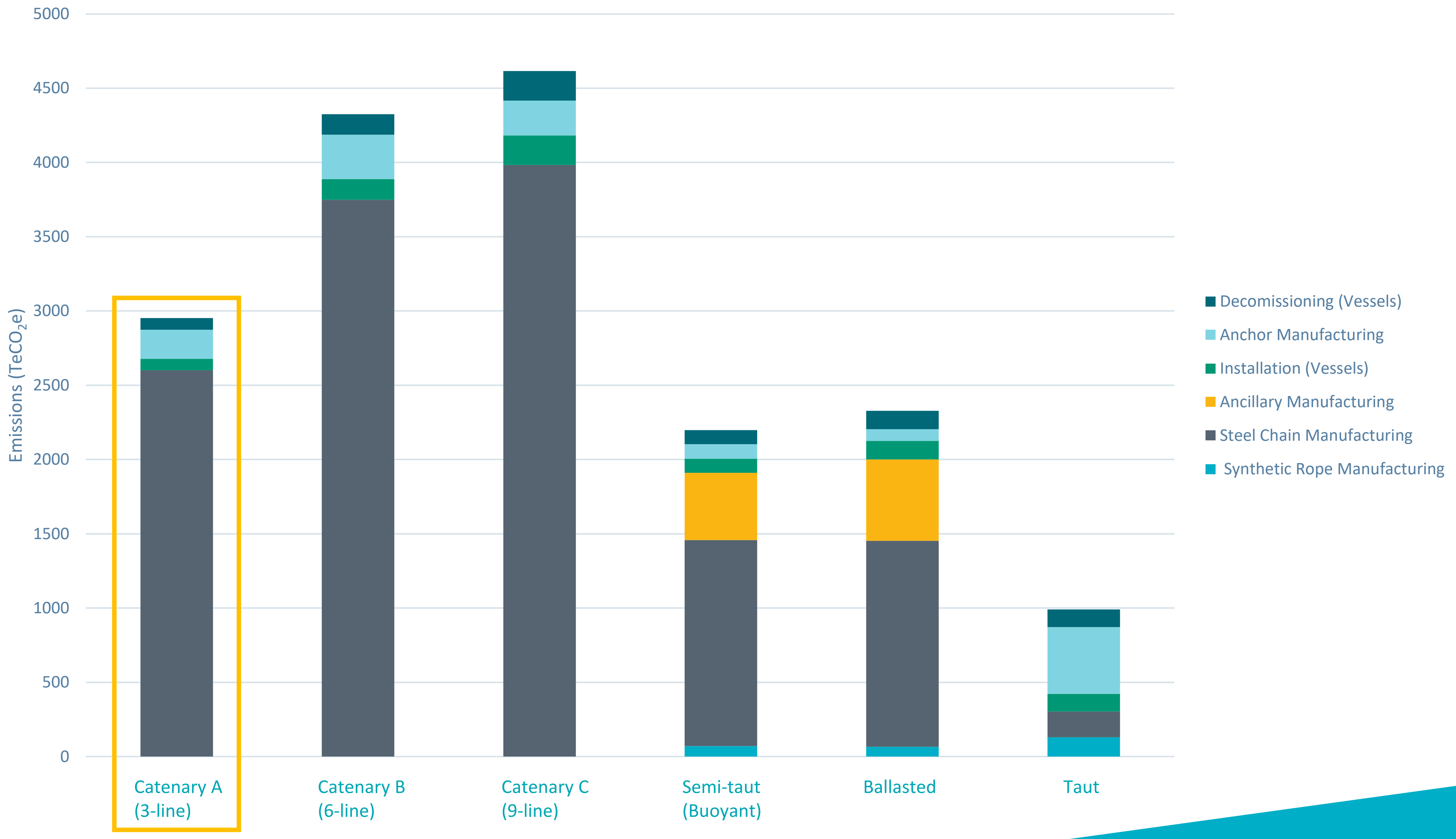
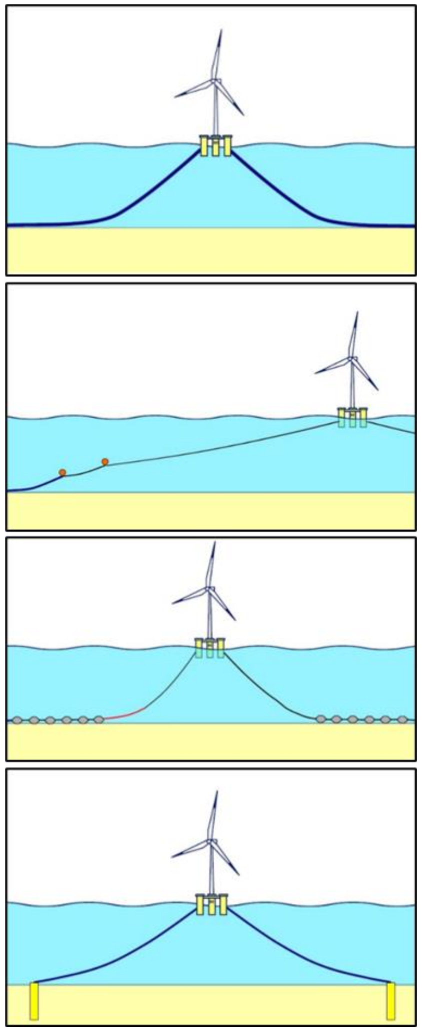
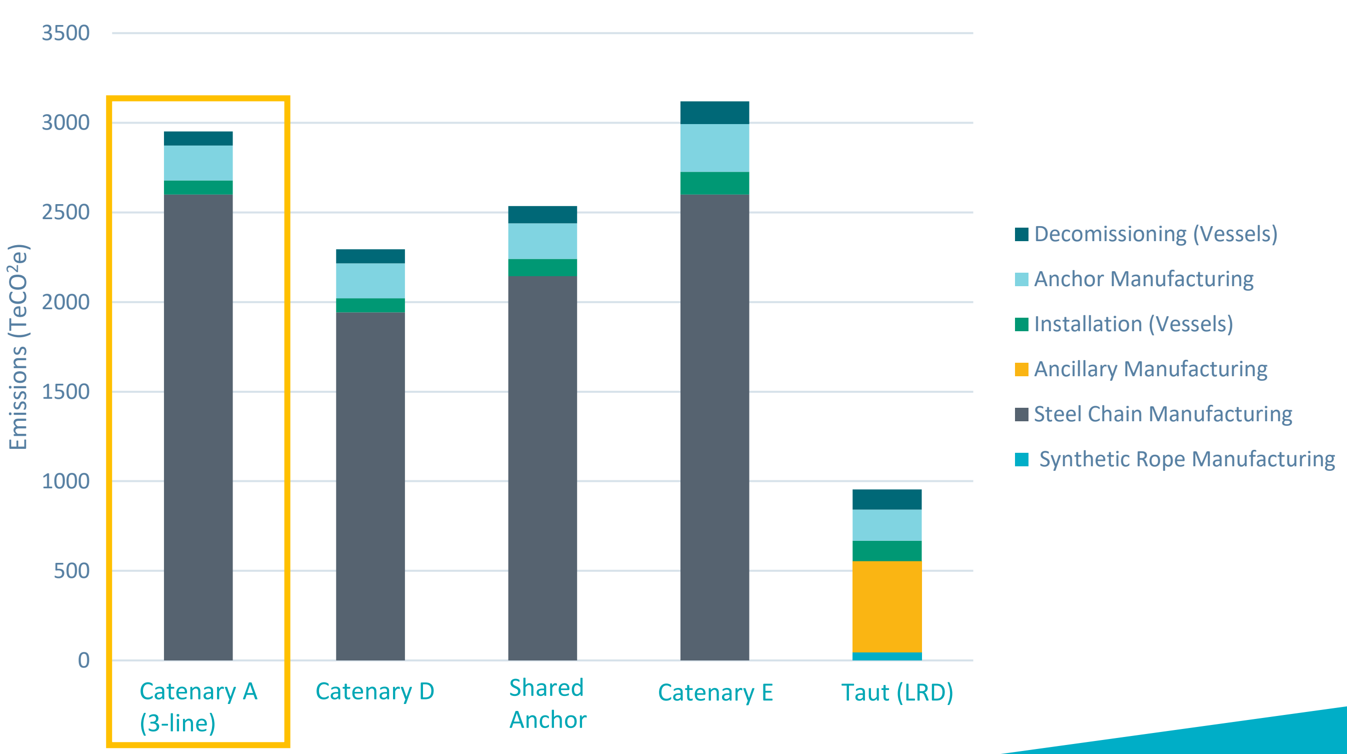
Base Case Configurations - Carbon Emissions Results

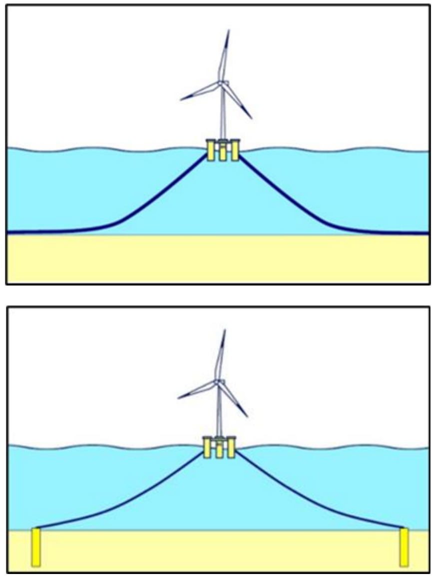




Alternative Configurations - Carbon Emissions Results

Configuration Name	Line Type
Catenary A (3-line)	Basic 3 line steel chain catenary base case
Catenary D	Catenary with ground chain of a reduced diameter
Shared Anchor	Catenary with shared anchors and reduced ground chain diameter
Catenary E	Catenary A with driven pile anchors instead of DEAs
Taut (LRD)	Fully optimised configuration with LRDs, suitable for typical catenary scenario





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Key Findings from Study

Mooring system design carbon emission reduction opportunities:

- Reduced use of steel results in the highest carbon saving
- Increased use of synthetic rope and use of mooring ancillaries such as LRDs in mooring configuration
- Transitioning away from catenary mooring configurations to shorter and lighter semi-taut and taut systems
- Exploring different anchor solutions and shared anchors

Manufacturing and supply chain carbon emission reduction opportunities:

- Utilising raw materials and components manufactured with recycled or “green” materials and clean energy sources
- Reducing imports and transportation distance of finished components (increased local content)

What does this mean for the local supply chain?

Near-term pipeline opportunities

- Developing synthetic rope technology and manufacturing capability
- Opportunity to develop novel anchor solutions

Far-term pipeline opportunities

- Manufacturing novel anchor solutions
- Development of green manufacturing facilities
- Use of green materials (recycled steel, bio synthetics)

What does this mean for local ports?

- Use of synthetic rope instead of chain will enable greater storage and mobilisation capabilities for local ports

- This may also be the case for novel anchor solutions that are not a heavy-duty as traditional anchor types

Questions and Answers

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Offshore Renewable Energy

Bradley McKay – Research Engineer Electrical

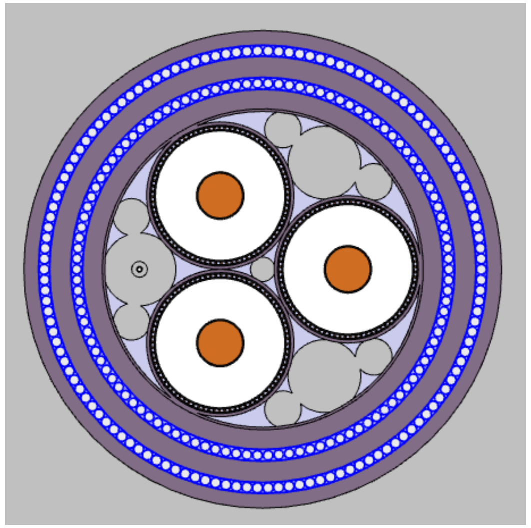
BSc Hon, MSc

12.06.2023

Cables & Floating Offshore Wind Transmission 2023

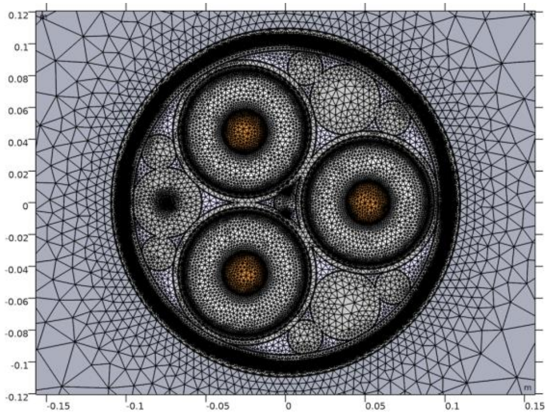
Electrical Key Conclusions Offshore

1. 132 kV identified as next array operating voltage
2. There is an urgency to making the transition to 132 kV by bringing the suppliers & developers together in the same room
3. 132 kV offers significant cost savings



Further work will be required to address uncertainty in 132 kV array cables

1. Improved understanding on the requirements for 132 kV array cables
2. Gaps have been identified in existing testing standards
3. Accelerate and de-risk the transition to 132 kV (subsea substations plug-&-play, and dynamic cable failure & fatigue)
4. Understand costs & availability (for e.g., copper vs aluminium)
5. Agree on installation methods & power losses (HVAC versus HCDC)



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Abstract

“net zero” by 2050

Circa 50 GW
currently UK peak electricity demand

20 GW by 2045
of floating offshore wind capacity in the Celtic Sea

4 GW by 2035
of floating offshore wind capacity in the Celtic Sea

1 GW by 2030
of floating offshore wind capacity in the Celtic Sea

Submarine cables
area of risk for offshore wind farms making up 75-80% of insurance claims

Challenges dynamic cables & redundancy
dynamic nature of floating offshore wind electrical infrastructure

Aim:

This session will discuss some of the latest work ongoing within ORE Catapult and introduce some of the key challenges foreseen in the floating offshore wind South-West electrical infrastructure to expedite FOW in the Celtic Sea.

Agenda:

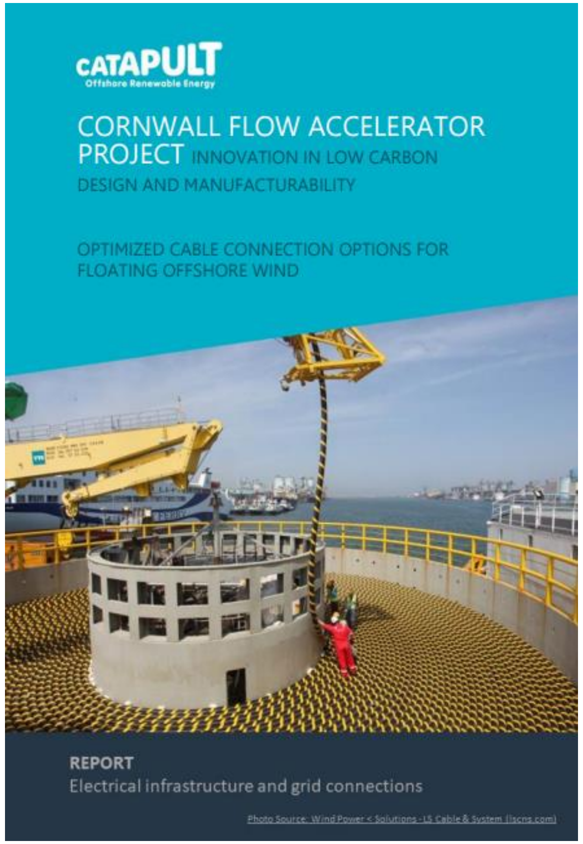
1. Celtic Sea electrical grid challenge
2. Transmission scenarios
3. Installation methods
4. Power output
5. Connectors
6. HVAC versus HVDC

Celtic Sea Floating Wind: October 2022 update | Celtic Sea Floating Wind: October 2022 update (thecrownestate.co.uk)
Submarine Cable Consulting & Market Intelligence | 4C Offshore

ORE Catapult Cornwall FLOW ACCELERATOR Published Reports (2022/2023)

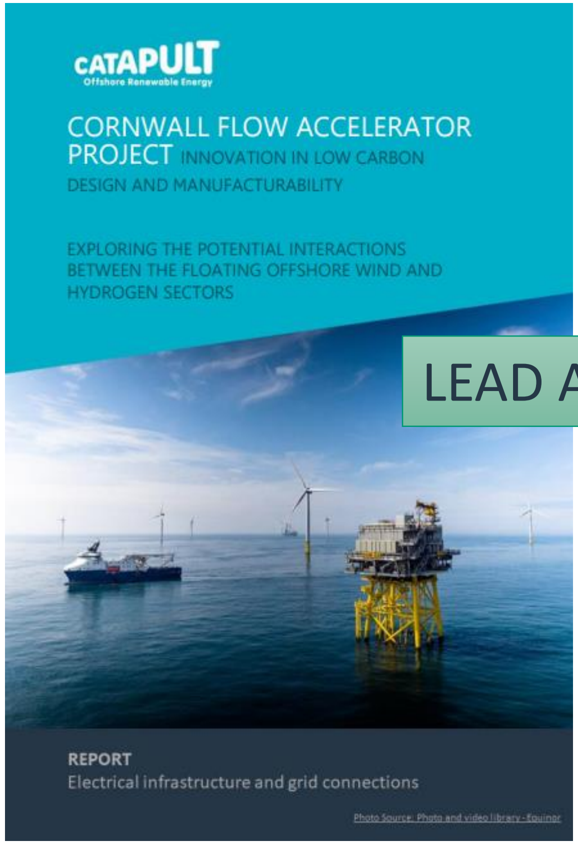
Title: A1 Optimized cable connection options for floating offshore wind

Ref: CFAR-OC-028-03102022



Title: A2 Exploring the potential interactions between the floating offshore wind and hydrogen sectors

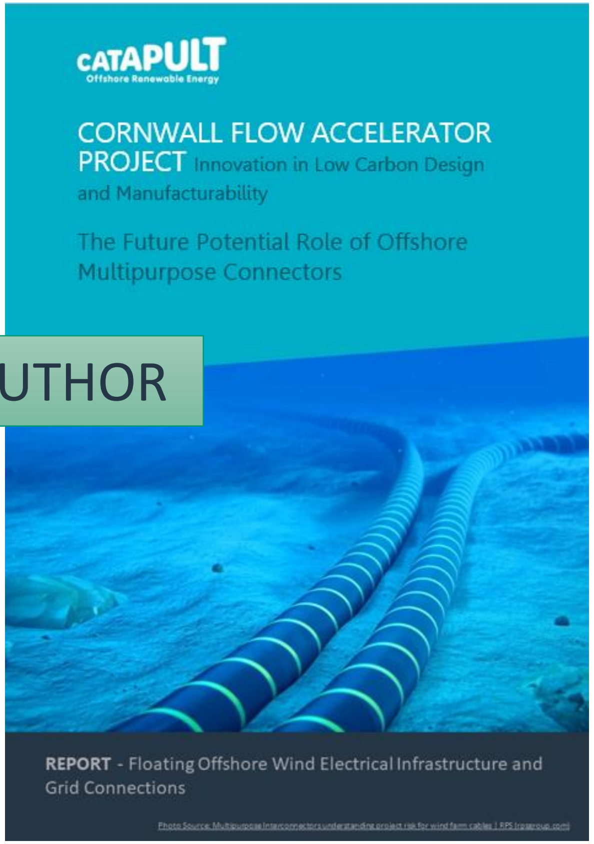
Ref: CFAR-OC-027-04102022



LEAD AUTHOR

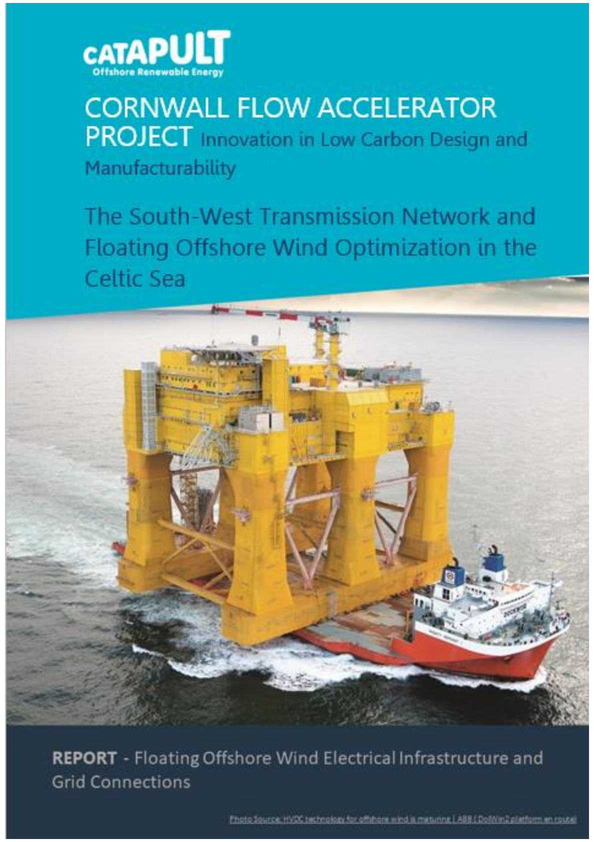
Title: A3 The future potential role of offshore multipurpose connectors

Ref: CFAR-OC-038-16032023



Title: A4 The South-West transmission network and floating offshore wind optimization in the Celtic Sea

Ref: CFAR-OC-039-17032023



DELIVERED BY Cornwall FLOW Accelerator

CELTIC SEA CLUSTER

HM Government

European Union European Regional Development Fund

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Celtic Sea Cluster Publications and Case studies [Resources]

https://celticseacluster.com/resources/

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17 March 2023

New Report: Innovation in Low Carbon Design and Manufacturability The South-West Transmission Network and Floating Offshore Wind Optimization in the Celtic Sea

16 March 2023

New Report: Innovation in Low Carbon Design and Manufacturability The Future Potential Role of Offshore Multipurpose Connectors

09 March 2023

FLOW NOW! – 28th February 2023

09 March 2023

Concrete for FLOW Workshop 17th October

04 October 2022

Exploring the Potential Interactions Between FLOW & Hydrogen Report

Publication

03 October 2022

Optimised Cable Connection Options For FLOW Report

Publication

16 May 2022

Cornwall FLOW Accelerator Project – Low Carbon Manufacturing Reports

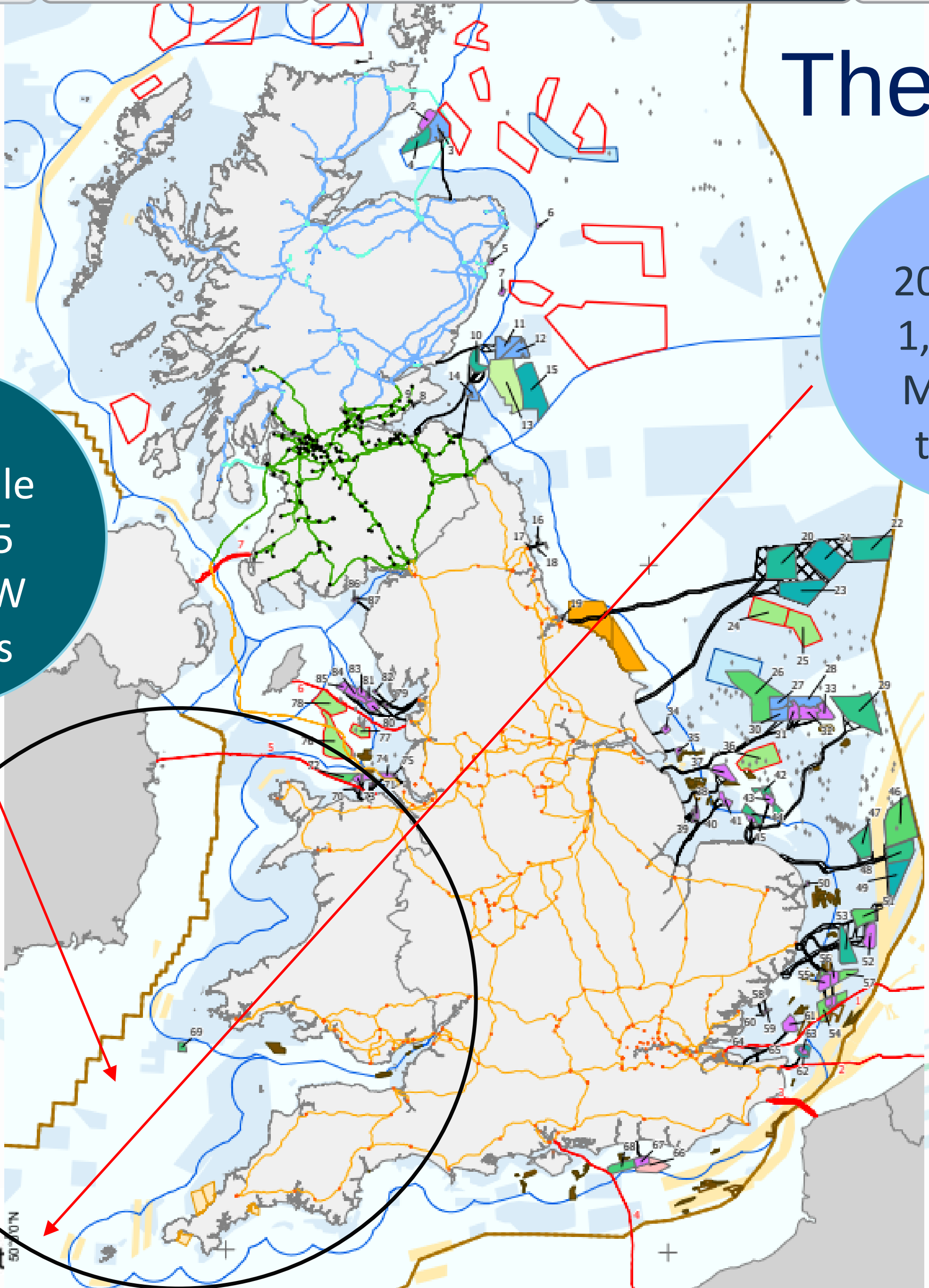
Publication

29 April 2022

Celtic Sea Ports, Engineering and Infrastructure

Publication

The grid challenge for Celtic Sea



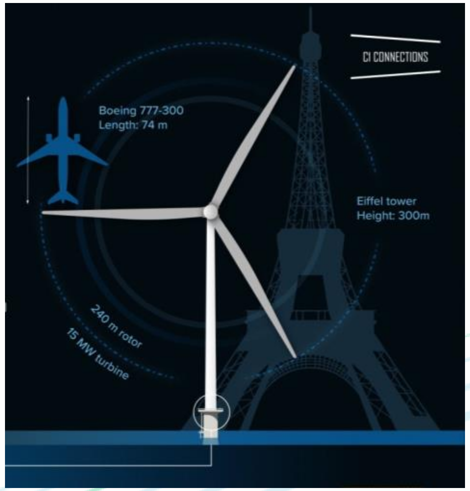
4 GW
2035 Scale
266 x 15
MW FOW
turbines

20 GW
2045 Scale
1,333 x 15
MW FOW
turbines

Offshore Transmission Network Review generation map

https://www.gov.uk/government/publications/offshore-transmission-network-review-generation-map

THE CROWN ESTATE



AMBITIOUS
OTNR
TRANSMISSION
SYSTEM

Our challenge to upgrade the electrical infrastructure transmission to achieve 4 GW by 2035

HM Government

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CELTIC SEA CLUSTER

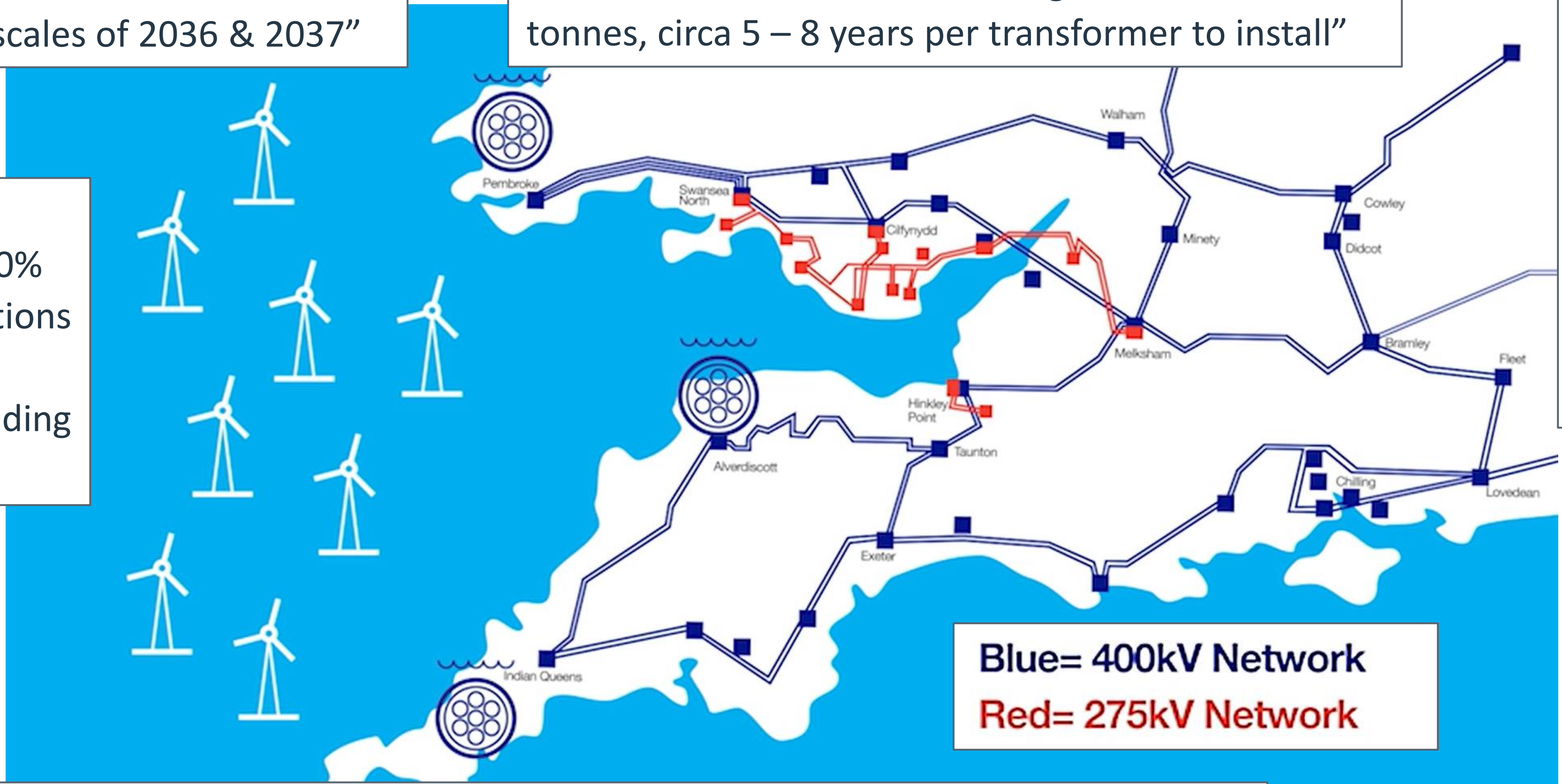
National Grid Electricity System Operator & IET(E&T)

According to:

IET(E&T) "Transmission connection dates extended to timescales of 2036 & 2037"

IET(E&T) "Supergrid 400 kV transformers are huge electrical infrastructure that weight several hundred tonnes, circa 5 – 8 years per transformer to install"

IET(E&T)
"Approximately 80% of the 300 substations across England & Wales need upgrading ***~ £31 bn***"



October 2022 Uncertainty (NGESO – South Wales & South-West Regions)

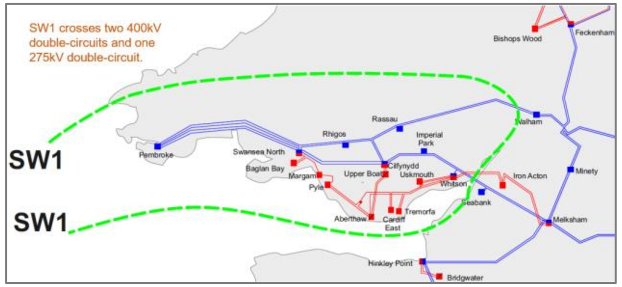
- 27.4 GW signed generation contracts
- 10.9 GW out for signature
- 5 GW in application process

IET(E&T) "Slowing investment, physical reduction of rate of RE installed capacity to the Grid – put the UK behind the curve to meet 2035 Energy Security Targets"

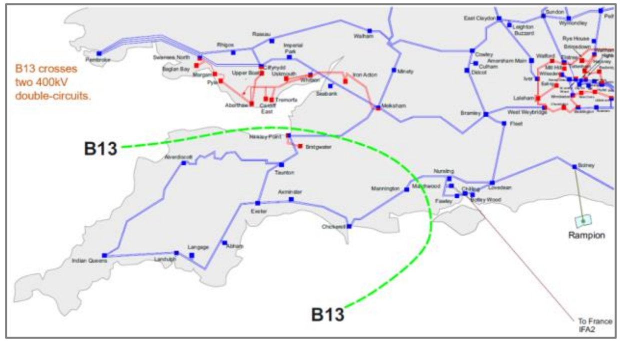
IET(E&T) "To reach our net-zero targets for more quicker RE connections – **<u>3 things are needed</u>** – **1.** continued focus on innovation & flexibility **2.** investment & overhaul to enable network capacity in anticipation of future need **3.** a coordinated & accelerated planning system"

Source1: The Institution of Engineering and Technology (Engineering & Technology) March 2023
Source2: Regional updates | National Grid ET

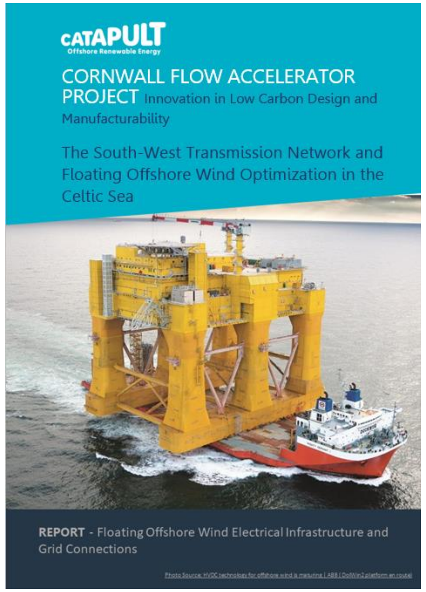
ORE Catapult CFA & HND Alternative Scenarios & PDZ (research 2022/2023)

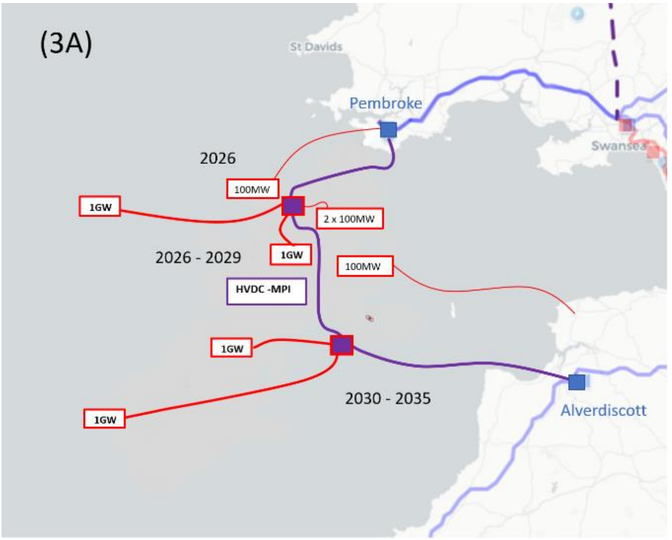


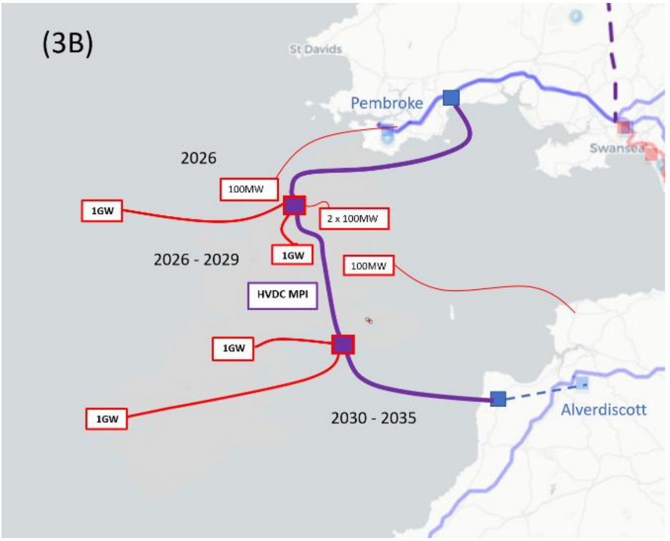
South Wales (SW1) - 400 kV ring (Walham to Pembroke)



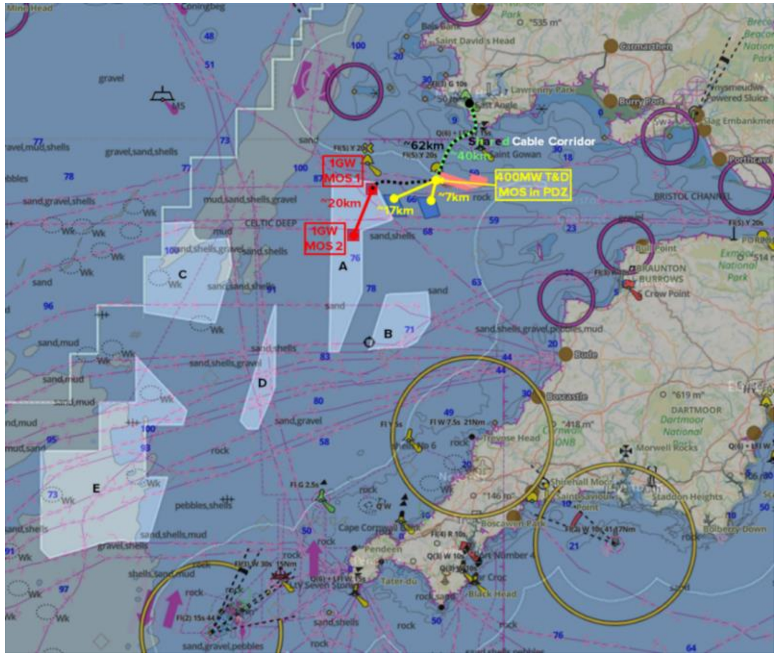
South-West (B13) crosses two 400 kV double-circuits







Beyond 2035 HVDC Interconnector Scenarios



The Crown Estate – Refined Areas of Search using the Pembrokeshire Demonstrator Zone (PDZ) or also known as Multipurpose Offshore Substation (MOS)

Question: How can the industry integrate future floating wind developments into the South-West and South Wales energy network?

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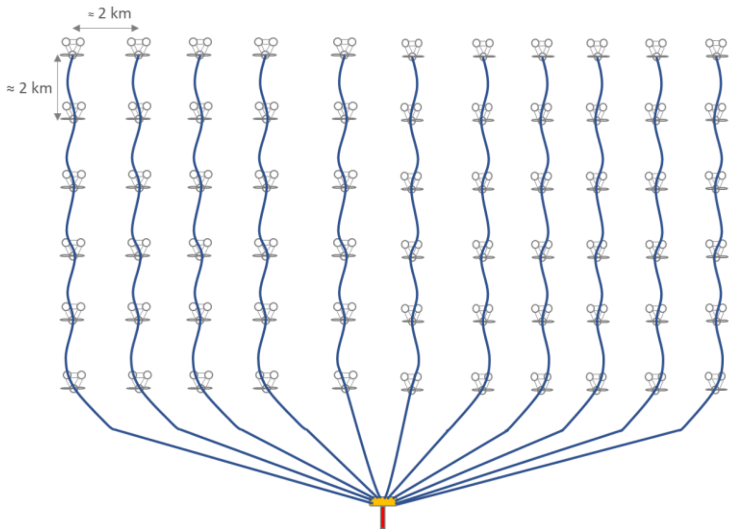
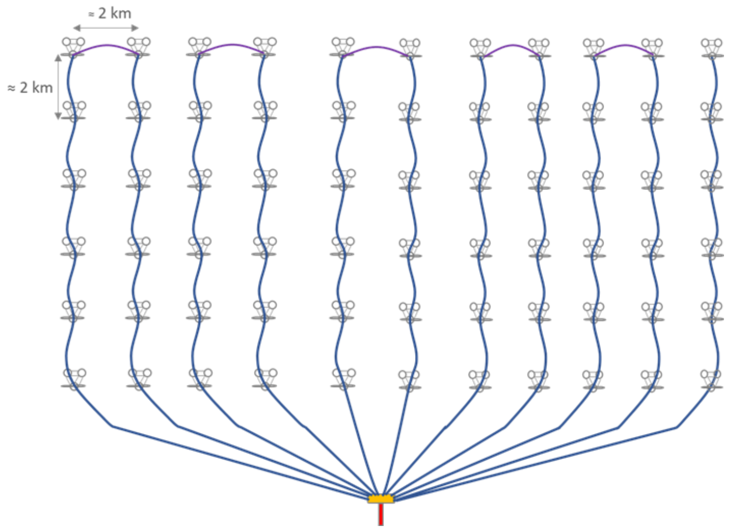
ORE Catapult CFA Offshore Wind Array Configurations (research 2022/2023)

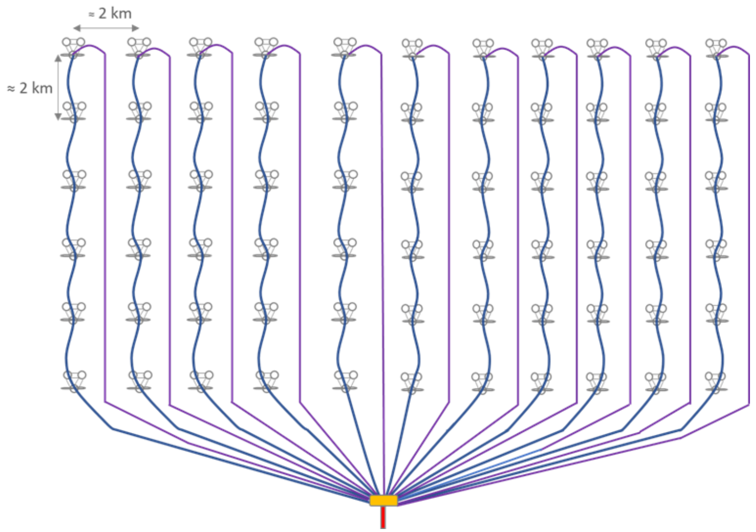
1: Non-Redundant Daisy Chain Layout



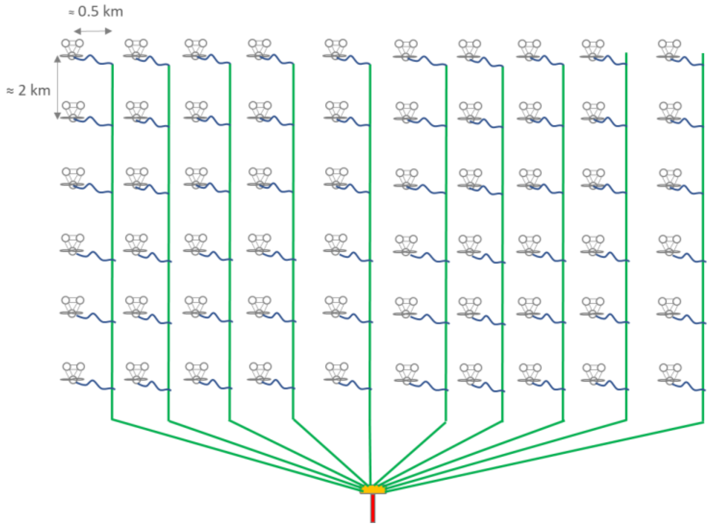
2: Daisy Chain Ring Layout



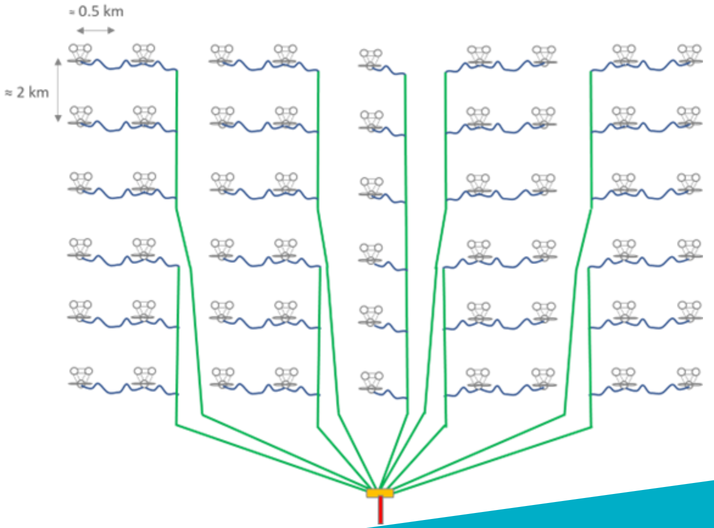
3: Daisy Chain Return Layout



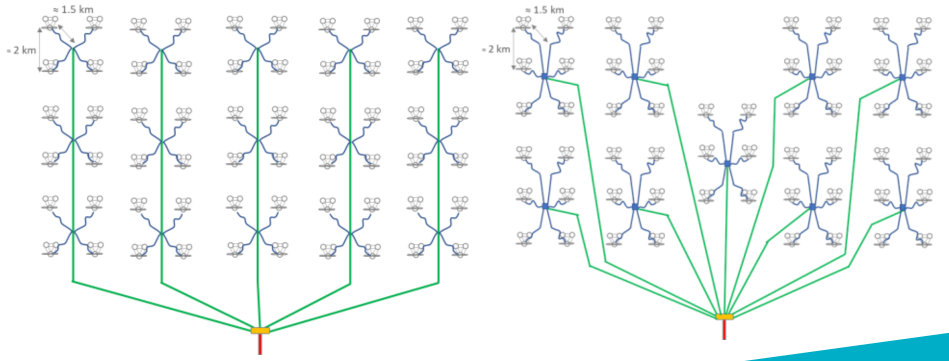
4: Fishbone Layout



5: Fishbone-Daisy Chain Hybrid



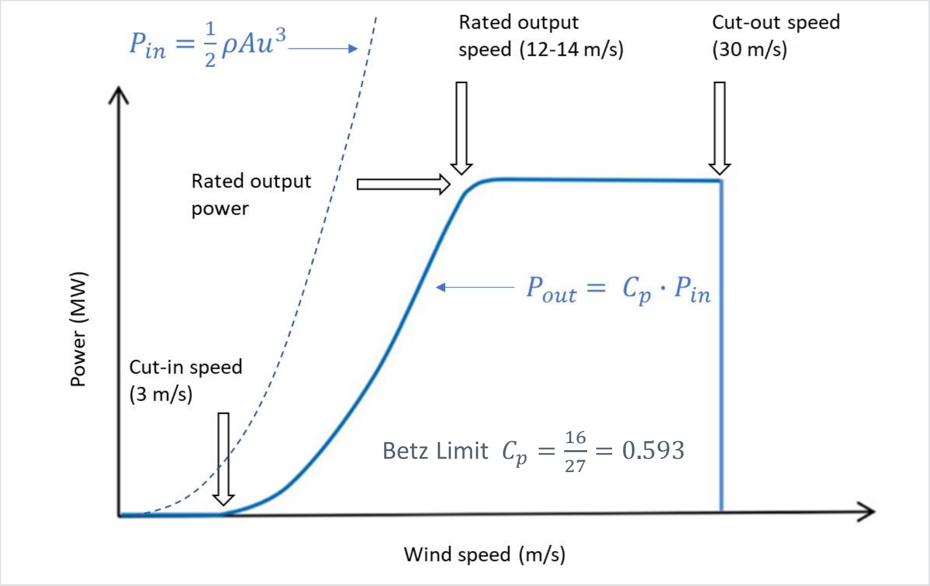
6: Star layout (four & six-connection groups)

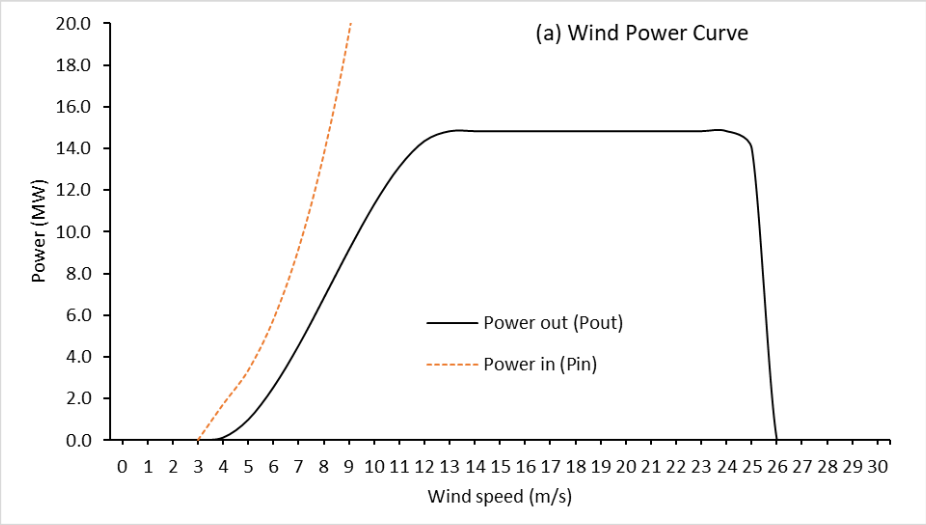


CFA Electrical Power Output (research/reports 2022/2023)

Power output from 15.0 MW turbines

P_{in} is so effective, due to the power of wind that varies with velocity cubed

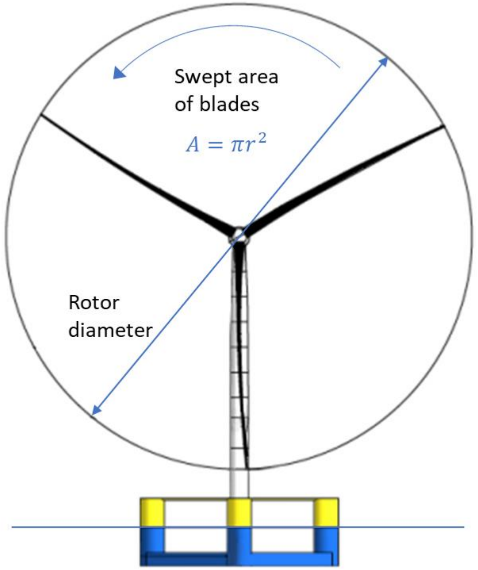




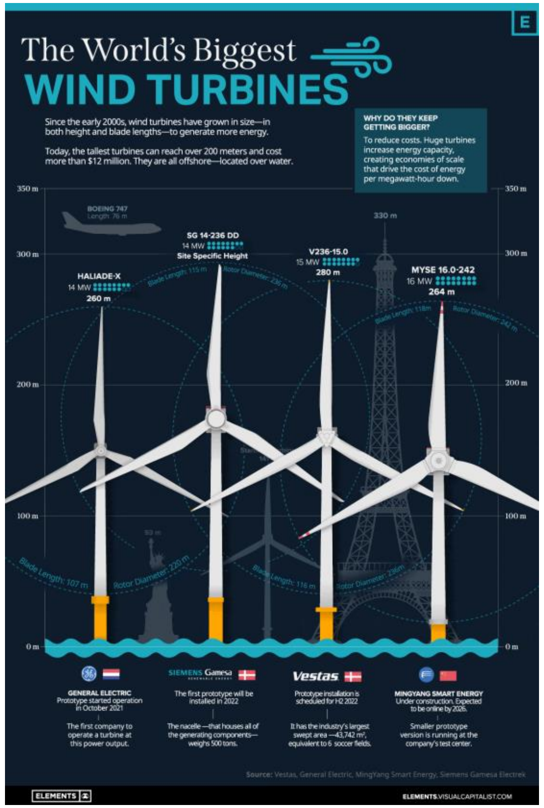
[Specifications](#)

- Model V236 **236 m,** rotor diameter **115.5 m** blades
- Swept area **43,744 m^2**
- Total height from sea level **280 m**
- Blade mass **65 mt**
- Rotor–nacelle assembly mass **1,017 mt**
- Platform mass including the ballast **34,387 mt**
- Turbines spaced at **8x** the rotor diameter (wake effect) circa **2 km**

Available or 'theoretical' electrical power output



iPS Baltics - Stiesdal Tetrasub design at one of the main squares in Copenhagen – Rådhuspladsen (110 m long / 35 m high)



[Animation: Visualizing the World's Biggest Wind Turbines (visualcapitalist.com)](#)

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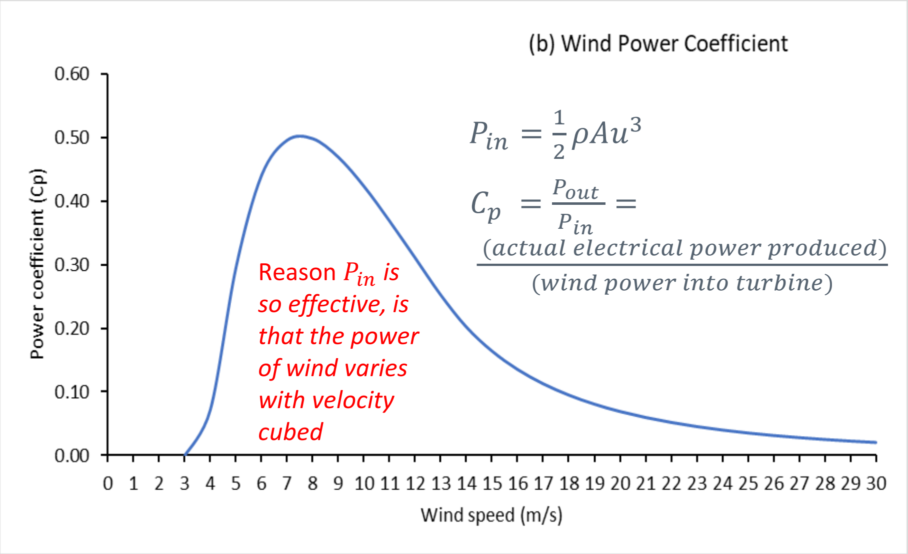
CFA Electrical Power Output (research/reports 2022/2023)

Power Curve 15 MW wind turbine representing power and wind speed

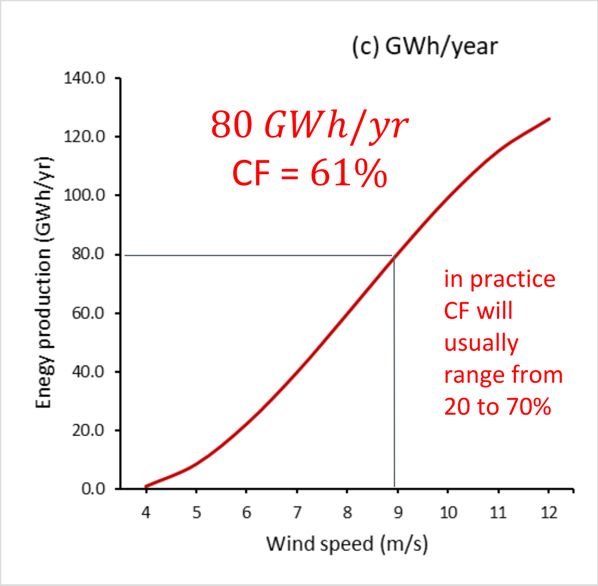


$$P_{in} = \frac{1}{2}\rho A u^3$$

$$C_p = \frac{P_{out}}{P_{in}} = \frac{(actual\ electrical\ power\ produced)}{(wind\ power\ into\ turbine)}$$

Wind Turbine Power Coefficient (C_P) a measure of WT efficiency

Actual electrical power output (Rate of electricity production in *GWh/yr*)

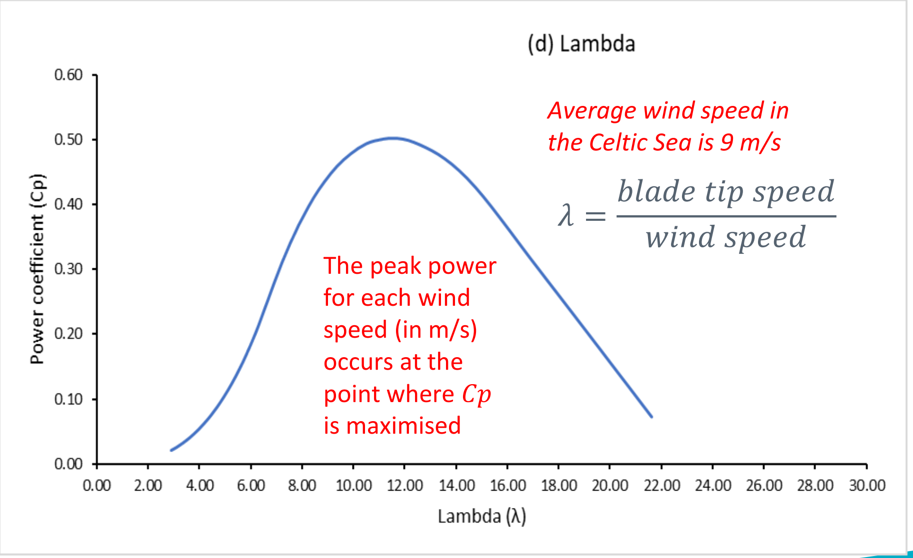


$$Energy = P_{out}\ x\ time\ (8{,}760)$$

$$CF = \frac{P_{out}\ (actual\ energy\ output)}{P_{out}\ (maximum\ possible\ output)}$$

$$I_n = \frac{P_n}{\sqrt{3}\cdot U_{correct}\cdot pf} = \frac{15MW}{(1.732\cdot 125.4kV\cdot 0.95)}\ x10\ WTs = 727\ A$$

De-rating factors: cable buried in seafloor at a **1 m** depth; seabed soil temperature **15° C**; soil thermal resistivity **0.7 K.m/W**



$$\lambda = \frac{blade\ tip\ speed}{wind\ speed}$$

Tip speed ratio lambda (λ) a WTs optimum value

Power losses for 495 MW wind farm @ 15 MW wind turbines

- **132 kV**, three core CSA at **800 mm²** submarine inter-array cable
- Resistivity of copper **1.77x10⁻⁸ Ω.m** string length **20 km**
- Therefore, the required current flowing through the conductors is calculated below as **73 A** per turbine, and **727 A** for 10 turbines in a string that will be used in this example.

CFA Electrical Conductor Power Losses (research/reports 2022/2023)

495 MW wind farm layout of 33 by 15 MW FOWTs connected via 132 kV copper dynamic inter-array cable

Electrical Conductor Power Losses

Standards Question:

For a **132 kV** cable rated string, the maximum number of 15 MW FOWT's allowable is 10 (based on the industry standard equates to less than **160 MW**)

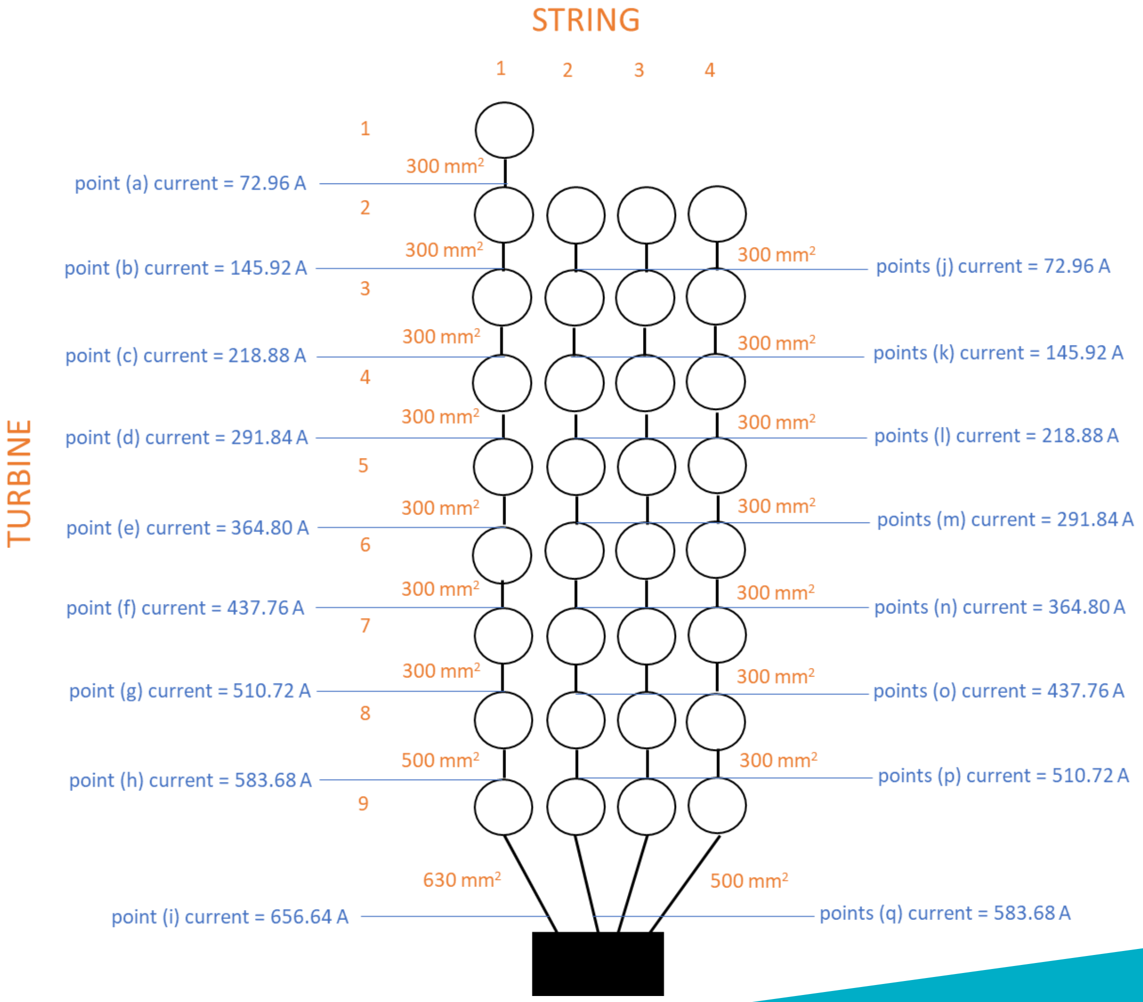
Power cables have resistance, therefore power lost in the conductors can be calculated as for simplicity:

- $P = I^2R$ with R as the resistance of the cables and I as the current that passes through them
- Power at the load is $P = UI$, so if the voltage U increases by $2x$, only half the current I will be needed to deliver the same power

$$I = \frac{P}{U} = \frac{135\ MW}{132\ kV\ or\ 66\ kV} = 1\ kA\ or\ 2\ kA$$

- Therefore, in $P = I^2R$, if half the current passes through the same conductors, the system will lose only a quarter of the power

$$P = I^2R = 1\ MW\ to\ 4\ MW$$



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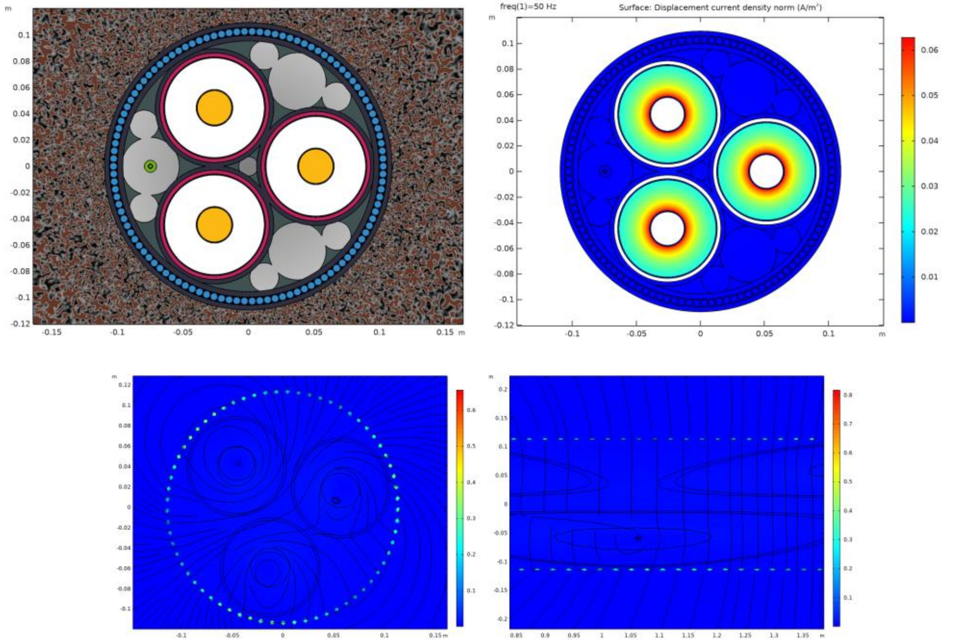
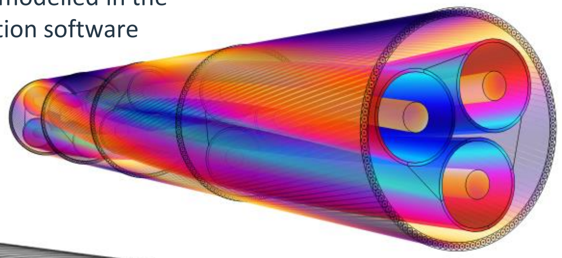
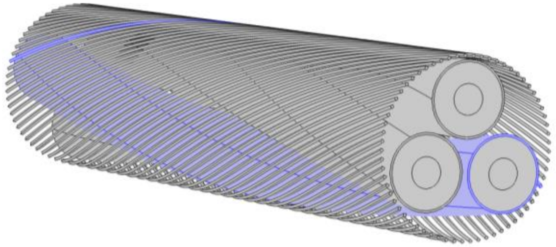
Dynamic Cable Power Losses (research 2023)

Remember **132 kV**, HVAC three core CSA at **800 mm²**



Christopher (2021) A 3D cable modelled in the COMSOL Multiphysics® simulation software





Conductor Losses *(result from Joule heating of electrical currents in the conductors)*:

$P_{core} = nRI^2 = circa\ 35\ W/m$

Screen Losses *(caused by circulating currents, only occurring in AC cables)*:

$P_{screen} = n\lambda_1 RI^2 = circa\ 0.04\ W/m$

Armour Losses *(only applicable to AC cables)*:

$P_{armour} = n\lambda_2 RI^2 = circa\ 2\ W/m$

Dielectric Losses *(electrical power that is wasted by heating the dielectric in the electric field - energy losses occur at the constant and variant current in the dielectric:*

$W_{d_t} = 3W_d = circa\ 1.3\ W/m$

$$P_{total-losses} = P_{core} + P_{screen} + P_{armour} + W_{d_t} = 0.9\ MW$$

(Is this significant over 24 km?)

power factor is: $PF = \frac{P\ (actual)}{S\ (apparent)}$

$$= \frac{149.1\ MW}{157.9\ MVA}$$

$$= 0.94$$

Power Factor	Explanation
Good	- 0.95
Poor	0.95 - 0.85
Bad	0.85 and below

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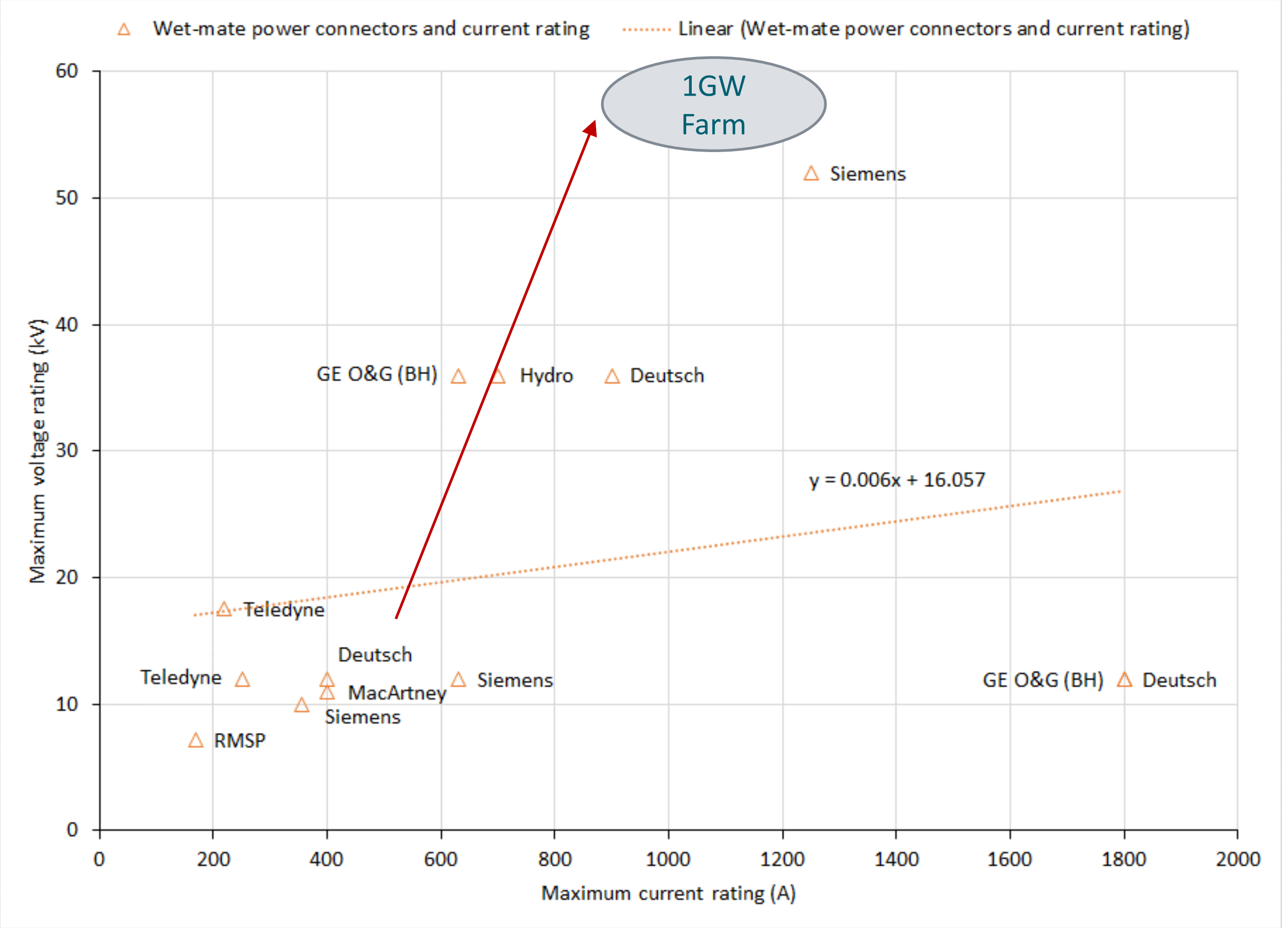
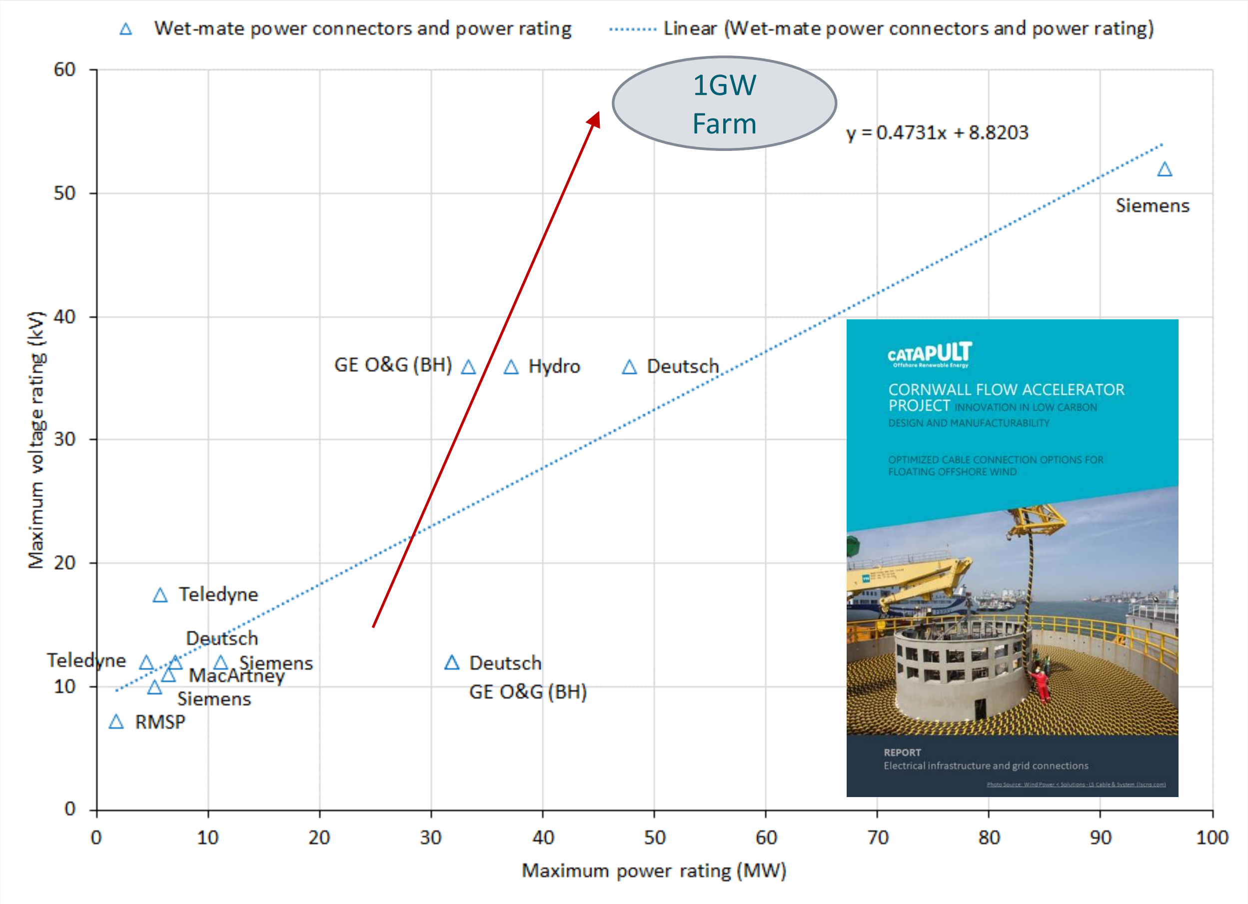
CFA wet mate connectors voltage & current (research/reports 2022)

Comparison of different types of high voltage wet mate connectors from manufacturers (wet mate or dry mate connectors)

Next question:
Is the industry moving from 66 kV to 132 kV for dynamic cables and what are the timescales when the TRL is low?





$P = \sqrt{3} \; x \; U \; x \; I \; x \; Cos\theta$

where, $PF = Cos\theta$

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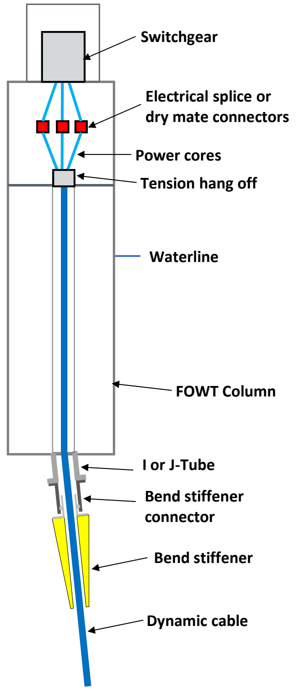
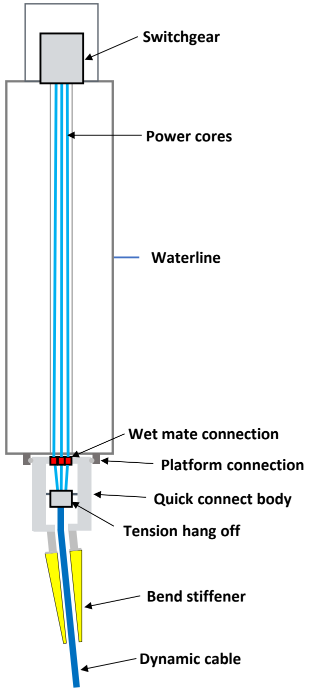
ORE Catapult Future FOW Projects and Cable Focus (2023)

Dry Platform Connection



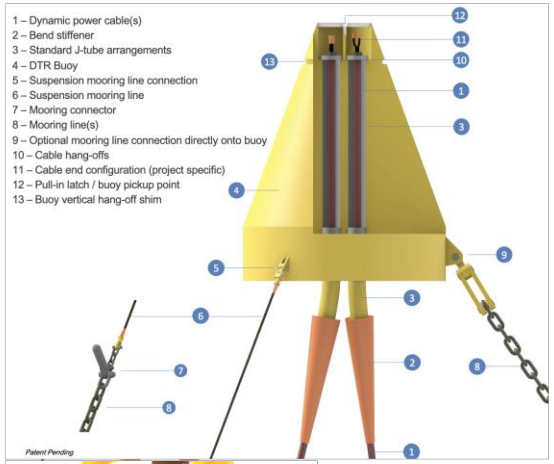
Wet Mate Connection

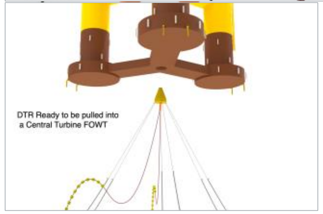


Disconnectable Dry Spliced Connection (Principal Power)

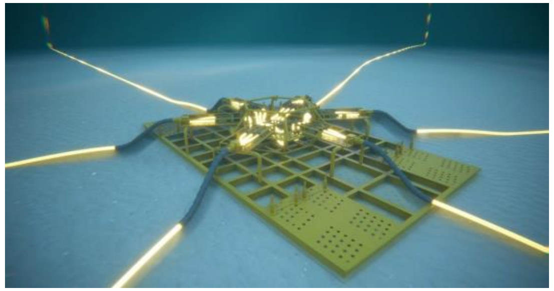
Floating Wind - SBT Energy (sbt-energy.com)

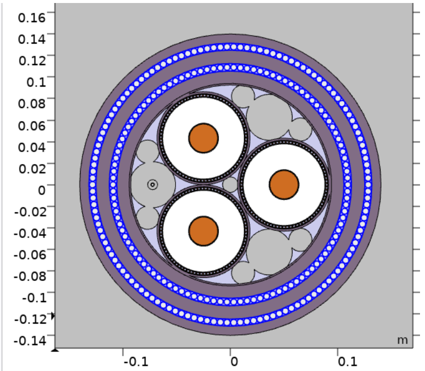
Wet Mate Turret Buoy (SBT Energy)

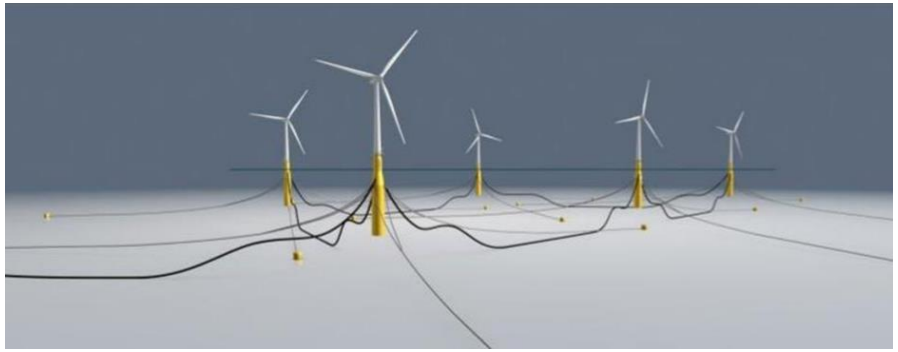




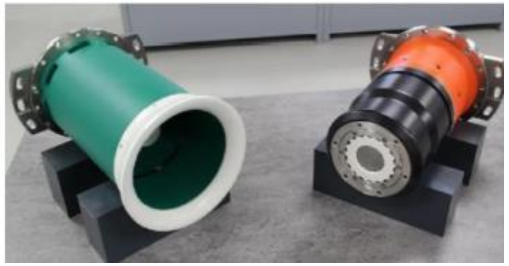
Subsea Junction Box with wet mates (Siemens / Subsea 7)





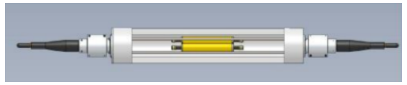


Single Phase Wet Mate Connector (Siemens)
36 kV qualified, 66 kV in qualification, 132 kV Early concept



Dry Mate Connector (ETA)
66 kV & 132 kV qualified & proven

Spliced Connection (J+S)
66 kV & 132 kV qualified and proven



Cables are expensive to install and maintain, as well as difficult to analyze experimentally - FUTURE DEVELOPMENT: to use electromagnetics modeling to:

(1) Test cable designs virtually, (2) visualize how different cable parameters affect core, screen, armor, and dielectric losses, (3) predict cable performance in different installation conditions

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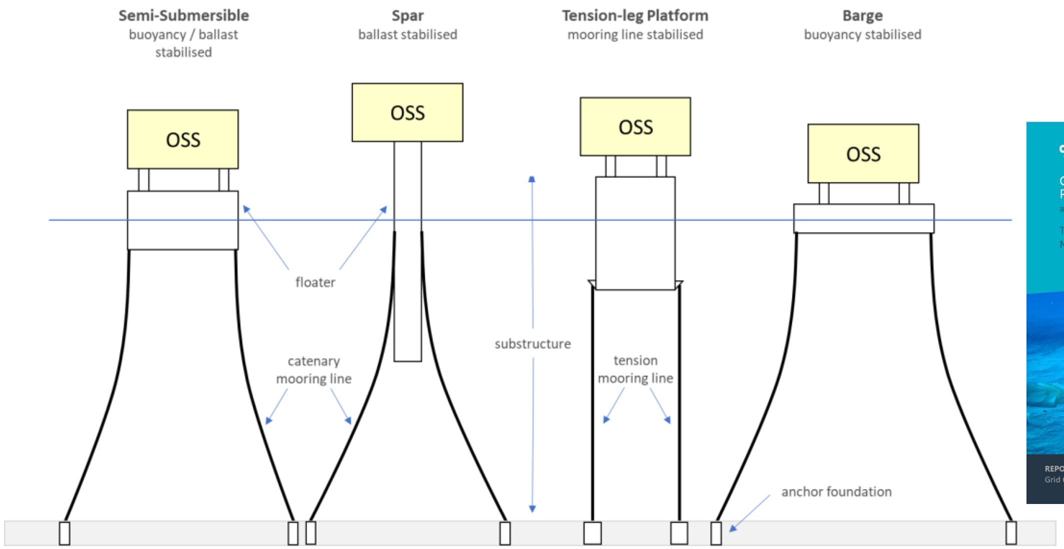
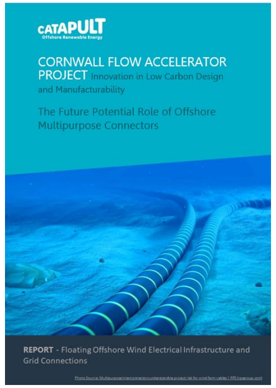
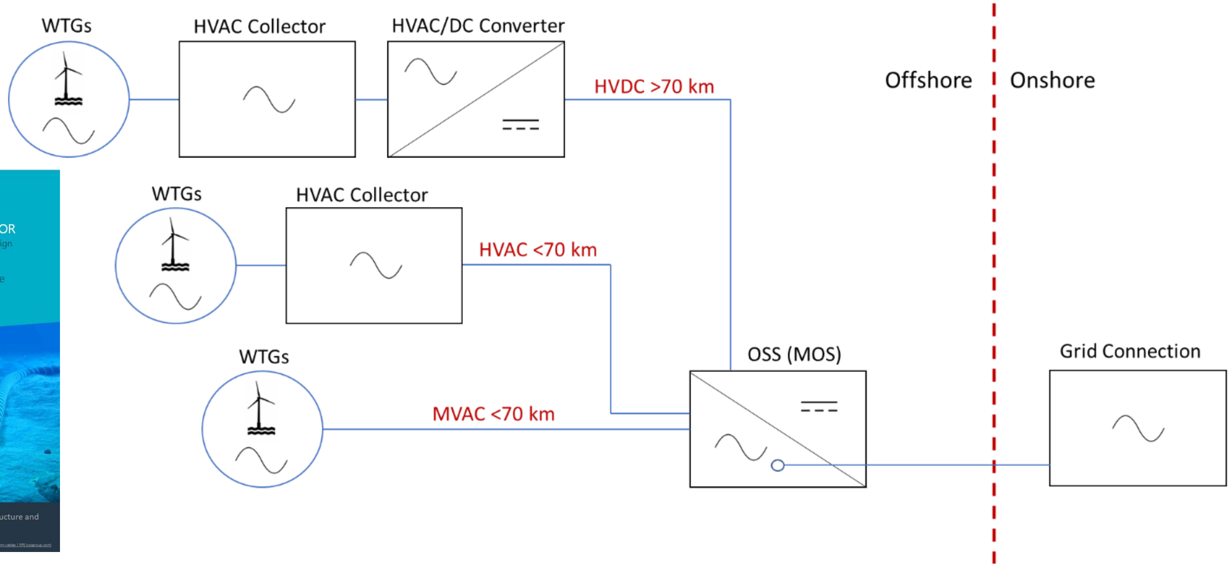
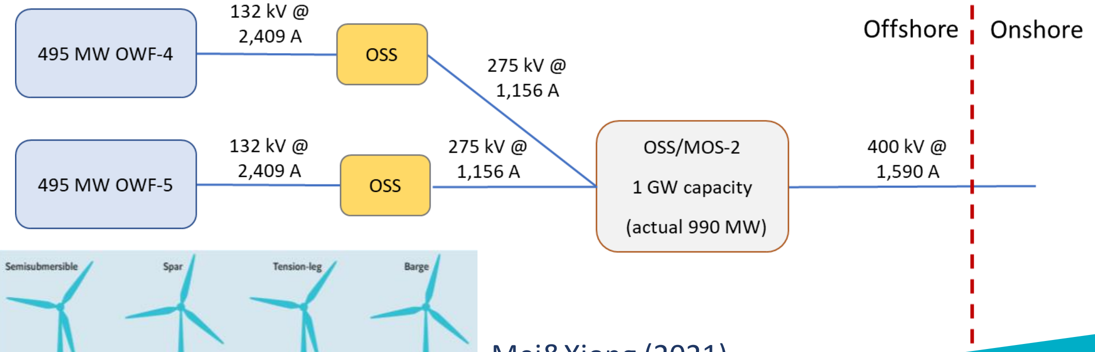
ORE Catapult CFA multipurpose offshore substations (research 2022)

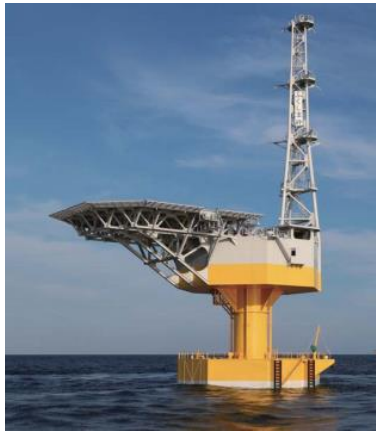
Multipurpose offshore substations could be the technical solution as a shared asset for connecting floating offshore wind projects in the Celtic Sea. To overcome grid constraint and reduce uncoordinated cable landfalls in a response to the rapid emergence sector.



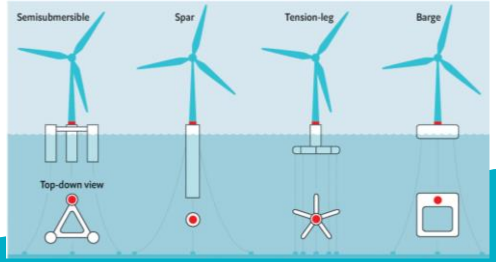








The 'Fukushima Kizuma' floating offshore demonstration substation project in Japan, rated at 25 MVA, (and right) FOSS being towed out to site (now decommissioned)



Mei&Xiong (2021)

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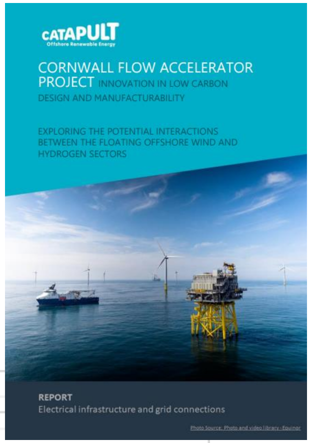
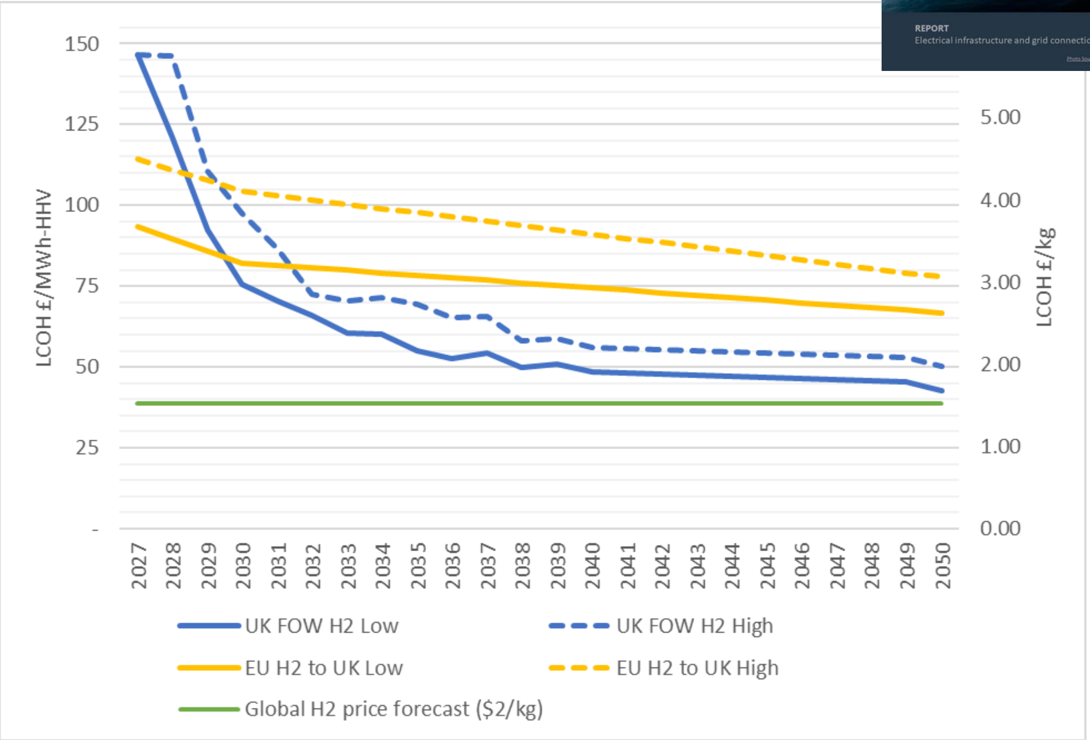
ORE Catapult CFA Types/colours of hydrogen (research 2022)



List of specified hydrogen colours by original energy source, process, and outputs.

Specified hydrogen colour	Produced using	Process	Outputs
Green	Renewable energy and water	Electrolysis	Hydrogen and oxygen
Blue	Methane and water	Steam-methane reforming with water gas shift reaction with CCS	Hydrogen and carbon dioxide, some of which is captured and stored
Pink	Nuclear power and water	Electrolysis	Hydrogen, oxygen, and radioactive waste
Yellow	Grid electricity and water	Electrolysis	Hydrogen, oxygen and potentially radioactive waste and carbon dioxide, depending on grid mix
Grey	Methane and water	Steam-methane reforming with water gas shift reaction	Hydrogen and carbon dioxide
Turquoise	Natural gas	Pyrolysis	Hydrogen and solid carbon
Brown	Brown coal, water, and oxygen	Gasification with water gas shift reaction	Hydrogen and carbon dioxide
Black	Black coal, water, and oxygen	Gasification with water gas shift reaction	Hydrogen and carbon dioxide

By 2050, ORE Catapult have predicted the cost of UK FOW-produced green hydrogen should fall to £1.50 – 3/kg



An interesting argument is we think it would be hard to put an electrolyser offshore. We all think this is a relatively new field, and, tentatively, perhaps the current industry is thinking of offshore wind to electrolysis projects in the short term are going to have onshore electrolysers.

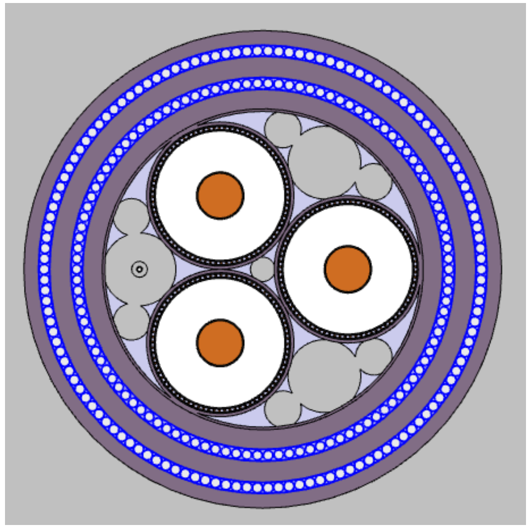
Cables & Floating Offshore Wind Transmission 2023

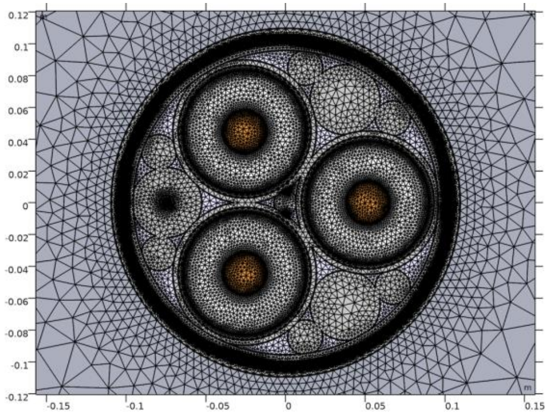
Electrical Key Conclusions Offshore

1. 132 kV identified as next array operating voltage
2. There is an urgency to making the transition to 132 kV by bringing the suppliers & developers together in the same room
3. 132 kV offers significant cost savings

Further work will be required to address uncertainty in 132 kV array cables

1. Improved understanding on the requirements for 132 kV array cables
2. Gaps have been identified in existing testing standards
3. Accelerate and de-risk the transition to 132 kV (subsea substations plug-&-play, and dynamic cable failure & fatigue)
4. Understand costs & availability (for e.g., copper vs aluminium)
5. Agree on installation methods & power losses (HVAC versus HCDC)





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Questions and Answers

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Afternoon Wrap Up

Julie Taylor