Inn2POWER II - Offshore Wind Energy and Green Hydrogen

Offshore test facilities and hydrogen

(WP4)

April 2023

https://northsearegion.eu/inn2power/

Contents

Acronyms

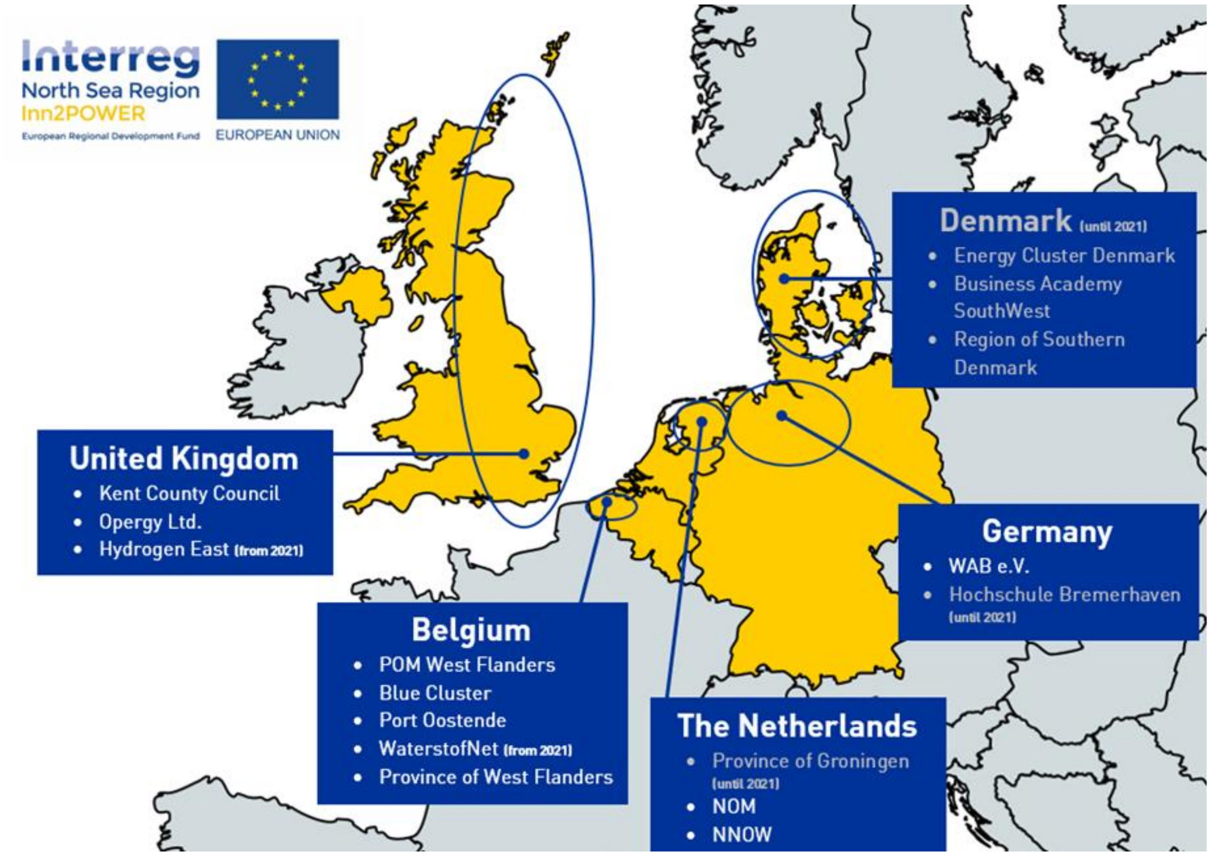
AEL	Alkaline electrolyser
BoP	Balance of Plant
CTV	Crew Transfer Vessel
DBB	Double Block and Bleed
FPSO	Floating Production Storage Offload vessel
GDPR	General Data Protection Regulation
HAZID	Hazard Identification
HAZOD	Hazard and Operability study
OWF	Offshore Wind Farm (or park)
O&M	Operations & Maintenance
O&G	Oil & Gas industry
PEM	Proton Exchange Membrane electrolyser
SOE	Solid Oxide electrolyser

Introduction

Inn2Power II - Offshore Wind Energy and Green Hydrogen

Aim of the Inn2Power project is to expand the capacity for innovation and improve access to the offshore wind industry and green hydrogen for SMEs, by connecting offshore wind and green hydrogen business in the North Sea region.

The project's vision is to strengthen the North Sea region through supporting SMEs to collaborate and enter new markets with the help of the Inn2Power's company directory, the test facility website, to gain easy access to test and demonstration facilities and to improve knowledge, skills and access to qualified staff.



This report covers the results of Work Package 4 and is available at the through Inn2POWER's website. It builds on the state-of-the-art reports from Work Package 3 (summarised in the **Green Hydrogen State of the Nations Summary report**).

Work Package 4 - Offshore test Facilities and hydrogen

Part of the Inn2Power project is to gain more insight in the demand and supply side of offshore test facilities that are active in green hydrogen, currently or in the near-future. This centred around questions such as what type of services and features are present or needed, what role play harbours in this context, and what roadmap could be developed to integrate and optimise this cross section of offshore test facilities, harbours in the North Sea region and green hydrogen development.

As mentioned, this Work Package builds on the excellent work done in Work Package 3, where green hydrogen state-of-the-nations reports are delivered, describing and referring to several national support policies.

Noted should be that the focus is specifically on the *offshore* side of green hydrogen, as this Work Package is part of the Inn2Power project. Recognised is that currently there are greater opportunities *onshore*, that offshore co-location with power generation is under development. But the ambitious targets and high demand for green hydrogen production and offshore wind generation, certainly in the North Sea region, justify a look into the offshore side of this. Various options and co-location considerations are included in this Work Package.

The scope and approach are described in the following paragraph.

1 - Scope and Focus

Test facilities scope:

1. Offshore production [export of H_2 a/o electrical] (taking projected bulk scale factors into consideration: predominantly floating wind)
2. Intermediate storage (offshore and at landfall or harbour)
3. Transmission pipeline (offshore to landside)
4. Shipping (interfacing and short-distance usage, like with CTVs; liquid hydrogen/ammonia bulk shipping excluded here)

Test facilities focus:

1. Near/offshore based (type(s) of facility)
2. Short/medium-term tests; long-term demo's
3. Materials, components, units of BoP (scaled/complete systems)
4. Certification services/non-certified services
5. Additional services (modelling, test protocols/harmonisation, design services, project management, etc)

Test facility primary system's focus:

1. Wind turbine generator and tower (wave loading, fatigue, capacity factor, scale)
2. Sub-structure (semi-submerged, other)
3. Mooring and anchors (depth, seabed, spacing in OWFs)
4. Electrolysis (PEM predominantly, other like SOE possibly): footprint, weight, pressure, efficiency, cycle speed, purity, safety (gas, fluids, H_2 & O_2), maintenance, certification in floating conditions
5. Electrolyser key components: compressors, liquefiers, stacks, membranes, plates, ancillary components, dryers, filters, separators, gasholders/tanks, electrical supply equipment, safety & control systems
6. AC-DC rectification / Typical 66kVAC (or higher)
7. Desalination/direct inlet (modest capacity v.v. shipping or O&G platforms): O&M, brine dispersal
8. Seawater lifting/pumping (modest capacity id.)
9. Stand-by power (critical systems, long-term back-up options in weather window limits)
10. Risers (flexible, (un)bonded, inner coatings, new materials)
11. Export compression and pipeline (H_2 embrittlement, leakage, compressor types, fittings)
12. Storage: offshore, landfall (cycling, rapid depressurisation, offshore certification)
13. Inter-array cabling (as in existing OWFs)
14. Export transmission (as in existing OWFs)
15. Offshore substation (as in existing OWFs) / Electrolyser island/FPSO (concentration risks)
16. Quay/pontoon/vessel DBB connections (proven technology)
17. Integrated control systems, storage options, transmission/transport options
18. Cross-cutting: safety and related (O&G) regulation (HAZID/HAZOP, etc)

Demand side query:

- To specify demand for test/demo infrastructure, by any stakeholder interested in services of a test/demo facility (in cross-section of offshore wind and green hydrogen)
- Specifications of demand: list of type of features/facilities, timing, location, fee type, un/certified, etc
- Primary system interest: similar list as above

Supply side query:

- For any existing test facility (existing or under development or planned; stand-alone/integrated in company; commercial/subsidized basis)

- Specifications of offered services: list of type/characteristics, location, fee type, un/certified, services
- Primary system's focus: similar list as above

2 - Survey setup and planning

Aim was to attract as many as possible responses from the members of the national and regional sector clusters in the Inn2Power project consortium. Therefore a concise, easy to fill out design was chosen, with an estimated fill out time of no more than 10 minutes. The data plan was developed in accordance to the GDPR rules.

The design and pre-testing was conducted in collaboration with the involved sector clusters. Opening of the survey was announced with targeted emails to all members of the clusters. Targeted reminder emails were sent out.

Total survey population was 1,230 across all sector clusters. After two rounds of reminders and an extension of the response period, the response rate was still very low. The final response rate was 2%, with an overrepresentation from one project country. Therefore, the result was regarded as non-representative and statistically invalid.

3 - Targeted semi-structured interviews setup and planning

Given the low response rate of the survey among the members of the clusters of this project, it was decided to conduct a small series of short, semi-structured interviews with key stakeholders, within the given scope and focus. The key stakeholders were identified in collaboration with the project sector clusters and a short list was agreed and distributed among the clusters.

The following queries were developed as a guide for the interviews.

Interview queries:

1. What developments do you foresee in the next 5 years (in volume terms of blue & green H_2; in your region & country)?
    - In offshore production [H_2 a/o electrical]
    - Intermediate storage (offshore and at landfall side or harbour)
    - Transmission pipeline (offshore to landside)
    - Shipping (import from other continents / short-distance applications (e.g. CTVs to wind parks)
    - What specifically is foreseen in your region/country with regard to offshore wind and H_2 testing/demo's
    - Do you use certain reference projections (reports), if so which ones

2. What demand do you foresee in offshore test infrastructure in the next 5 years (planned demo's, private investment projects, or with public funding)?
    - What funding / investment volume do you foresee is happening/planned already
    - Type of projects/services
    - What primary sub-systems get/require most attention? (see above list *primary system's focus*); please specify further if possible
3. What is your ideal test infrastructure for offshore wind and green H_2 (separate or combined for in the next 5 years)?
    - What do you wish to see in terms of available services
    - What specifics do you wish (scope, size, sub-system focus, test protocols, validation standards, otherwise)
4. What type of support policies are in most need in the context of the Inn2Power project context?
    - Cross-border regulation, certificates and (technical) standards: please specify if possible
    - Financial, risk-taking coverage, insurance challenges: please specify if possible
    - General public engagement, NIMBY risks: please specify if possible
    - Other support policies: please specify if possible

A total of nine interviews were conducted, across all project countries. On request responses were anonymised.

4 - Adjustment note

A late adjustment in the overall budget from the Interreg North Sea Region funding secretary let to a condensed set of deliverables in this Work Package 4, of which the result is this report.

The findings of these research queries are presented in the following paragraph *Results*.

Results

The depth of information that could be abstracted from the semi-structured interviews varied, some containing more detail while other stayed at a more generic level. Overall was stated that green hydrogen demand will increase and that with the ongoing developments in green hydrogen, the need for test facilities will increase. How offshore hydrogen test facilities could be conceptualised is still largely open and in an early stage. Green hydrogen production through electrolysis is seen as technological mature at land-based locations, though the costs are still a challenge. Cost factors that were mentioned include the cost of renewable energy supply, the electrolysis technology and scale, and the energy transportation vector.

Offshore green hydrogen production has its own challenges. With the near shore sites for wind energy with bottom-fixed turbines in mostly shallow water primarily being used to produce and transmit electrical energy, it is likely that large-scale *floating* wind will be *coupled* with hydrogen production to meet the demand. This is further strengthened by the fact that 80% of the global wind resource is located far shore in deep water, where more stable and high capacity factors can be reached. Floating offshore wind turbines have already proven high levels of technology readiness, but lack high commercial readiness levels. The same applies to offshore green hydrogen production, at both fixed – and floating structures.

In the interviews are references made to three platform concepts: (i) decentralised electrolysers (in the turbine or at the turbine's floater), (ii) centralised large electrolyser(s) interconnected to the electrical substation(s) of a wind park, and (iii) centralised large electrolyser(s) (in array) on an energy island. These concepts can also be found in various reports and articles.[1] Each concept has its advantages and disadvantages, that could be further researched in offshore test facilities. An overview of these main challenges is presented in the below table 1.

Platform concept comparison			
Decentralised		**Centralised**	
Advantages	**Disadvantages**	**Advantages**	**Disadvantages**
Use of existing electrolyser technology	Electrolyser response to offshore conditions need validation	Scale of hydrogen equipment may lead to higher efficiency and lower Opex	No redundancies, but likely to need on-site personnel
Relatively more manageable in failure events	Complexity of system integration	Easier failure management	Higher asset risk due to concentration of electrolyser(s)

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[1] See e.g.: Ibrahim ea (2022), *Dedicated large-scale floating offshore wind to hydrogen*, https://doi.org/10.1016/j.rser.2022.112310; and: TNO (2022), *Offshore hydrogen for unlocking full energy potential of the North Sea*.

Platform concept comparison			
Decentralised		**Centralised**	
No additional balance of plant required	Challenging O&M processes	Easier O&M processes as turbine and hydrogen equipment are more separated	Additional platform to centralise, likely with high Capex
Brine discharge can be more diffuse			Brine discharge impact is higher due to centralisation
	Energy vector decentralised	Energy vector centralised	

Table 1 – Modified from Ibrahim ea (2022)[1]

One useful dimension to prioritise an innovation programme in green hydrogen, also for a test facility in an offshore setting, is the cost breakdown of offshore hydrogen production, centralised or decentralised. In the interviews is mentioned a need for innovation programmes that accelerate the cost reduction. A system cost breakdown shows that most can be gained from a focus on the electrolyser. Good support documentation is available.[2]

Accommodating best fitting green hydrogen production technology to an offshore environment leads currently to Proton Exchange Membrane (PEM) electrolysers, possibly followed in the near-future by Alkaline electrolysers (AEL), once various operational parameters have been improved and made suitable for an offshore environment. The reduction or prevention of the use of critical materials is an important factor here, and may even lead to other types of electrolysers. Various studies have developed useful overviews of proposed activities to improve the performance, that can be tested and demonstrated at offshore test facilities.[3] For electrolysers the focus is on the cell stack, Opex, balance of plant (BoP), power electronics and gas conditions (temperature, impurities, bubble management). In an offshore environment the key parameters are: hydrogen output pressure, electrical efficiency, load range, footprint and current density. Together this gives an indication of the type of test facility innovation programmes that is needed.

An interesting and valid innovation challenge score table that could be used for the design of innovation programmes at (offshore) test facilities is given below in table 2 (Catapult (2020)[2]).

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[2] For instance: Catapult (2020), *Offshore wind and hydrogen, solving the integration challenge*; and: IRENA (2020), *Green hydrogen cost reduction*

[3] See for instance: pag. 59-62 and summarised pag. 65-66 in: IRENA (2020), *Green hydrogen cost reduction*; pag. 28-30 in: Catapult (2020), *Offshore wind and hydrogen, solving the integration challenge*

Innovation challenge score table								
Technology (here only PEM)	**Cost reduction**	**Durability**	**Demand response**	**Technical risk**	**Market value**	**Case for intervention**	**Health & safety impact**	**Total challenge score**
Anodes degradation	2	3	2	3	2	1	0	13
Stable catalyst support	2	3	3	2	1	1	0	12
Improved catalyst design	2	2	2	1	2	1	0	10
Alternative catalysts	2	2	2	1	2	2	0	11
Bipolar plates	1	1	3	1	2	3	0	11
Improved bubble removal	2	3	1	2	2	1	0	11
MEA structure modelling	2	1	2	1	1	1	0	8
Advanced coating	1	3	1	3	2	1	0	11
High volume manufacturing	3	0	1	2	3	2	1	12
Large scale cell systems	3	1	1	2	3	3	0	13
Thermal management	1	3	2	2	2	2	1	13
Advanced membrane materials	3	3	2	1	2	3	0	14
Standardization for testing new catalytic materials and their performance	2	3	3	2	2	3	2	17
Water purification	2	1	0	2	2	1	1	9
Component integration	1	3	2	3	1	2	1	13
Cross cutting technology								
Large scale cell systems	3	1	2	2	2	2	0	12
Data sharing	2	1	2	3	2	1	1	12
Advanced materials research	2	2	3	1	2	1	0	11
Advanced manufacturing	3	1	0	2	2	2	1	11
Test protocols harmonisation	2	1	2	2	1	2	2	12
Power electronics	2	2	2	1	2	1	1	11
Gas conditioning	2	1	1	2	3	3	2	14

Table 2 – From Annex A in: Catapult (2020)[2] *[Score range: 1 is low; except Technical risk 1 is high risk]*

Moving on to other core systems, important are the seawater lift and seawater desalination. Both are proven technologies. But noticeable different from existing applications is that the inflow (in volume) needs to be synchronised with the electrical input (from the wind turbine) and the water inflow into the electrolyser. Also the (high) level of water purification is different. The brine discharge, where allowed under environmental conditions, may need to be considered as well. All can or should be integrated in test facility innovation programmes.

Offshore hydrogen export compression is dependent on the delta between pressure output of the electrolyser and the required inlet pressure of the pipeline, given the allowed mass flow rate and needed exit pressure at the landside. In interviews are mentioned primary two type of compressors, the more suitable centrifugal compression and the reciprocating one. Research in this area is ongoing with a focus on the seals, suction pressure and compressor power. Also here is the harsh offshore environment an additional factor to test and demonstrate the viability, preferably at an offshore test facility.

Offshore hydrogen pipelines, both static and flexible, have a proven track record and are commercially widely available for land-based application. Offshore are hydrogen pipelines not yet mature. Regular inspection and higher maintenance costs in an offshore setting will be needed, not only to monitor more closely the diffusion leaks and embrittlement effects but also to remove accumulated condensates. Again also here suitable innovation programmes can be designed at offshore test facilities.

In addition to these technology and materials innovation needs, support actions also need to be addressed. In almost all interviews are the following issues placed high on the agenda.

There is a need for a common innovation programme at (offshore) test facilities to accelerate the learnings transnationally and across sectors and technologies. Mentioned was the aim to de-risk and establish cross-border standardisation, with the ambition to have a similar learning curve as in the wind turbine development and in the solar PV scale-up. Also was mentioned that the global competition is a strong motivator to accelerate across borders.

Furthermore was mentioned that strengthening the supply chain is key to meet the high hydrogen ambitions. An example is the Electrolyser Summit Joint Declaration[4] of May 2022 where the European Commission and 20 industry representatives committed themselves to increase the manufactory capacity.

A third and final support policy area that was mentioned in many interviews was the urgent need for cross-border regulation and common certification- and standardisation norms. The need for national alignment to provide clarity and legal certainty are necessary to scale-up and to develop a common market. This includes not only technical standards and certification, but also harmonisation of tendering and permitting

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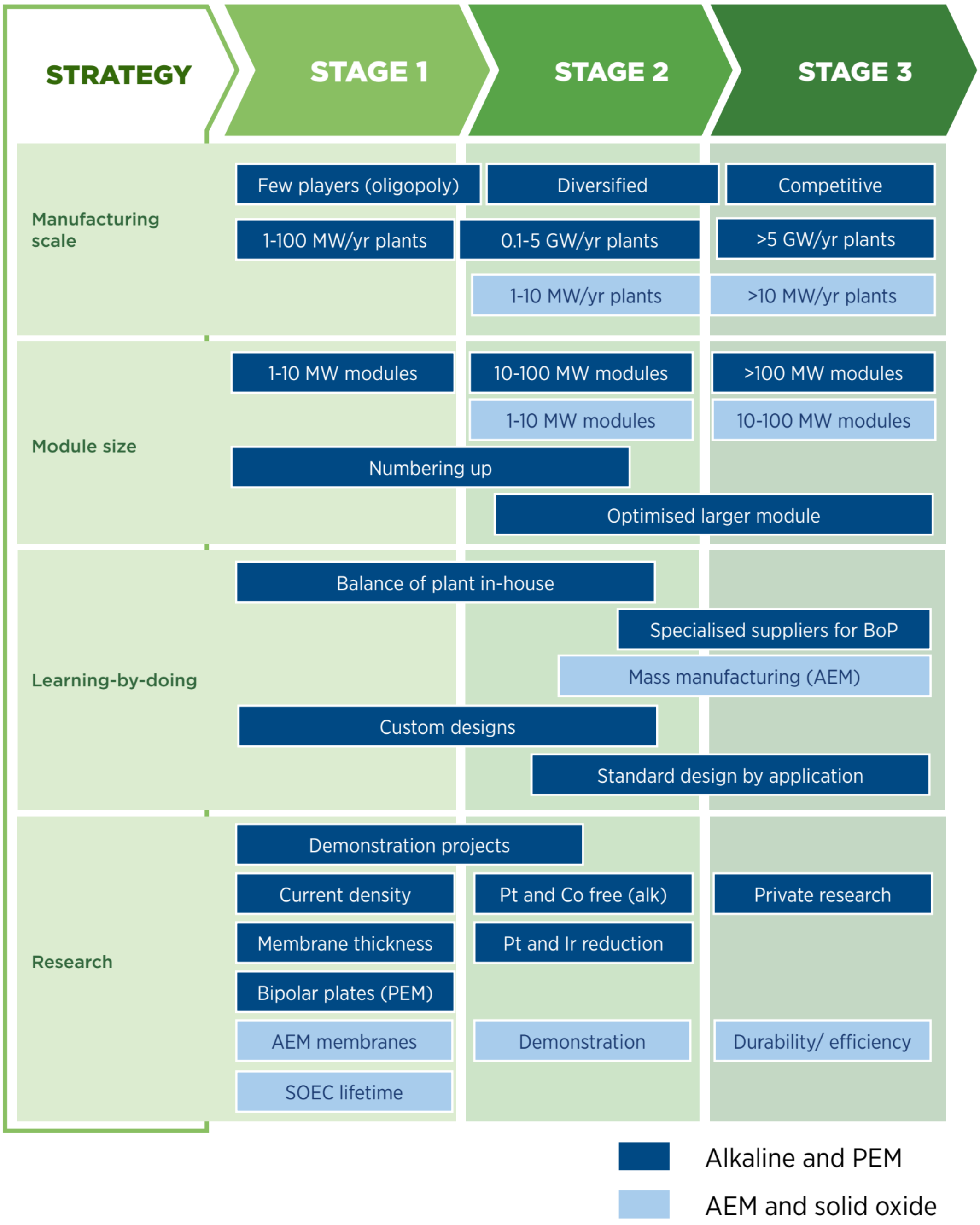
[4] Link: https://ec.europa.eu/docsroom/documents/50014/attachments/1/translations/en/renditions/native

processes, simplifying state aid rules and allowing exceptions for research and testing facilities.

An valuable overview that brings the various market and technology drivers together is shown in the below graph 1. This is just to illustrate how the green hydrogen sector could develop and how a similar graph could be designed for offshore wind and offshore hydrogen and where the test and innovation programmes may fit in.



Graph 1 – Inspirational illustration. Source: IRENA (2020), Green hydrogen cost reduction

[Stage 1: market establishment; Stage 2: scale up and improving design; Stage 3: global market. For full clarification, see pag. 86-91.]

Conclusion

In this Work Package 4 it was challenging to collect sufficient and relevant data due to various reasons, not in the least due to the still early stage of this cross-section between offshore wind energy and offshore hydrogen production. *Offshore* test facilities in the green hydrogen sector are still in a scoping phase.

Overall can be concluded that green hydrogen demand will increase and that with the ongoing developments in green hydrogen, the need for offshore test facilities will become more pronounced and more specified. Various sources in the North Sea region (and beyond) have started to identify innovation programmes, some with already specified priorities and others with still broader innovation pathways.

- The current state of affairs is that scoping the role of offshore test facilities in the green hydrogen-wind arena is in an initial stage.
- The need for alignment with onshore test facilities is evident. (Referred can be to the several national support policies.)

In terms of specific support policies regarding offshore test facilities, there are three clear areas identified:

1. Need for common innovation programmes at (offshore) test facilities to accelerate the learnings across borders (transnational) and across sectors and technologies.
2. Need to strengthen the supply chain in order to meet the high green hydrogen ambitions.
3. Urgent need for cross-border regulation, common certification and standardisation norms.