

AN OVERVIEW OF THE OFFSHORE HYDROGEN VALUE CHAIN

Subsea Engineering
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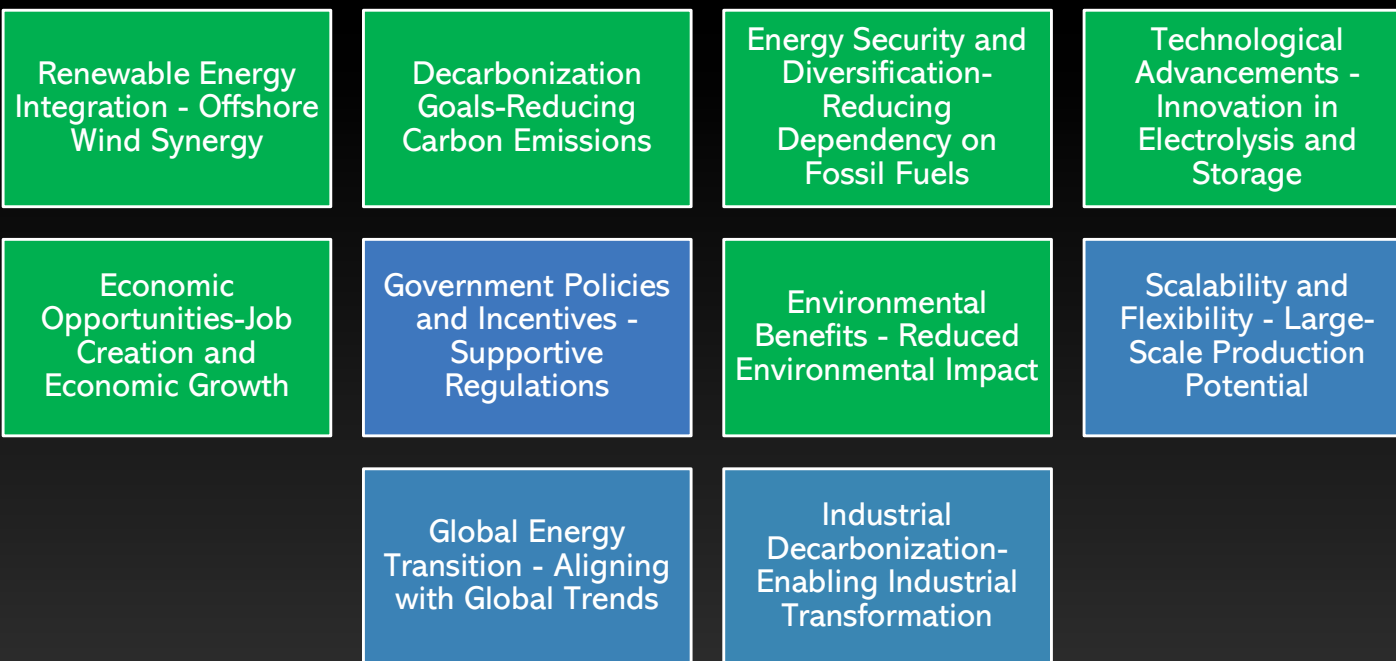
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AGENDA

1. Why is Offshore Hydrogen Important
2. Offshore Hydrogen Value Chain
3. Offshore Hydrogen - Economics
4. Offshore Hydrogen – Key Technologies
5. Offshore Hydrogen – Regulatory landscape
6. Technology Readiness
7. Risks and Opportunities
8. Value Engineering
9. Conclusions
10. Q & A

Why is Offshore Hydrogen Important ?



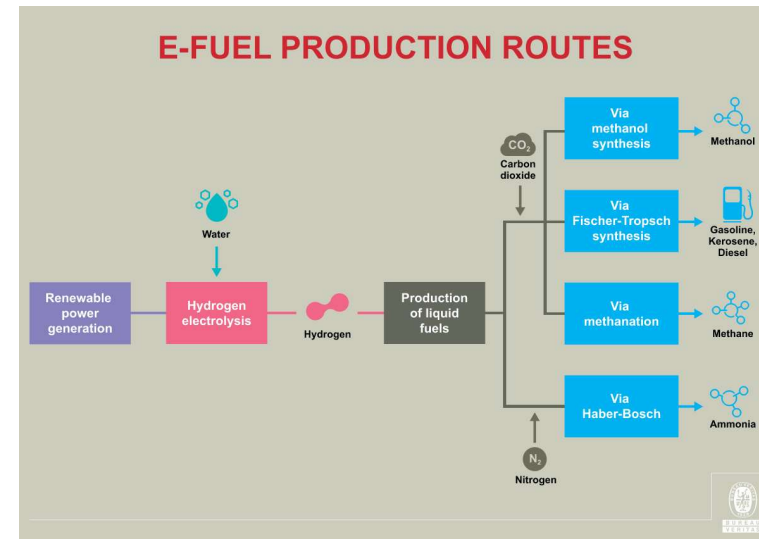
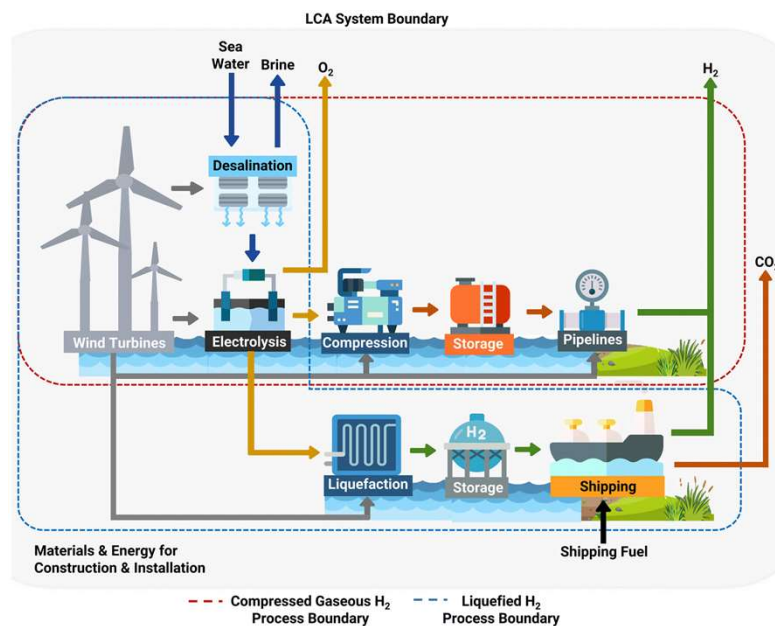
An aerial photograph of an offshore oil rig in the middle of a vast blue ocean under a clear sky. The rig is a complex of metal structures, including a tall derrick and various platforms, supported by several legs in the water.

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WHAT IS THE OFFSHORE HYDROGEN VALUE CHAIN?

- Offshore Wind Farms
- Hydrogen Production
- Hydrogen Storage
- Hydrogen Transport
- End Uses
- Integration & Power
- Regulatory



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LCOH Comparisons (Illustrative)

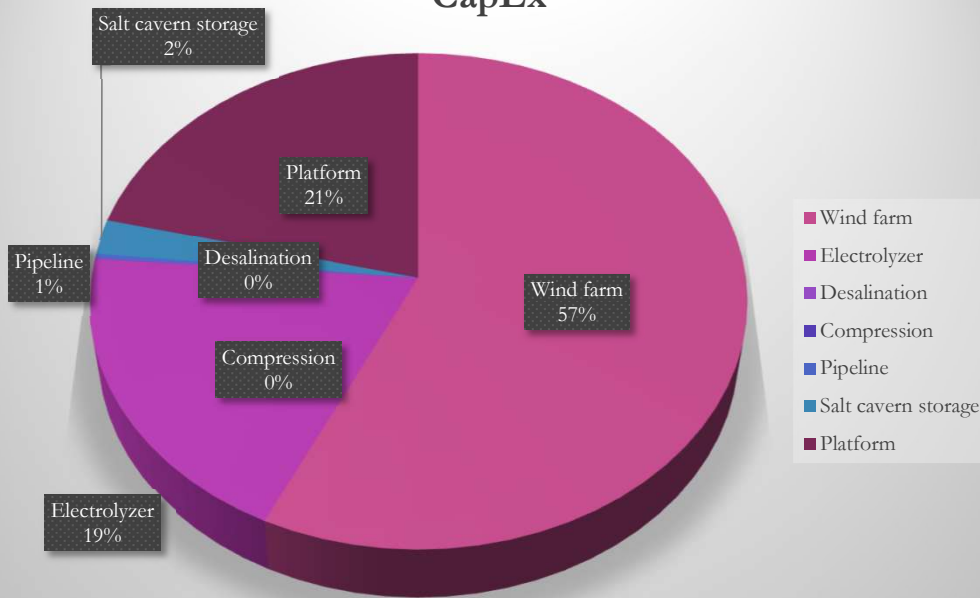
- \$2/Kg is the value that all developers aspire for.
- The table shows where we are with wind/PV coupled hydrogen compared to SMR+CCUS
- Offshore has a lot of catching up to do
- Opportunities and risk management options exist

Location	Hydrogen Type	LCOH Range (\$/Kg)
Onshore	Blue	\$1.5-\$3.5
Onshore	Green	\$3-\$6
Offshore	Green	\$5-\$9

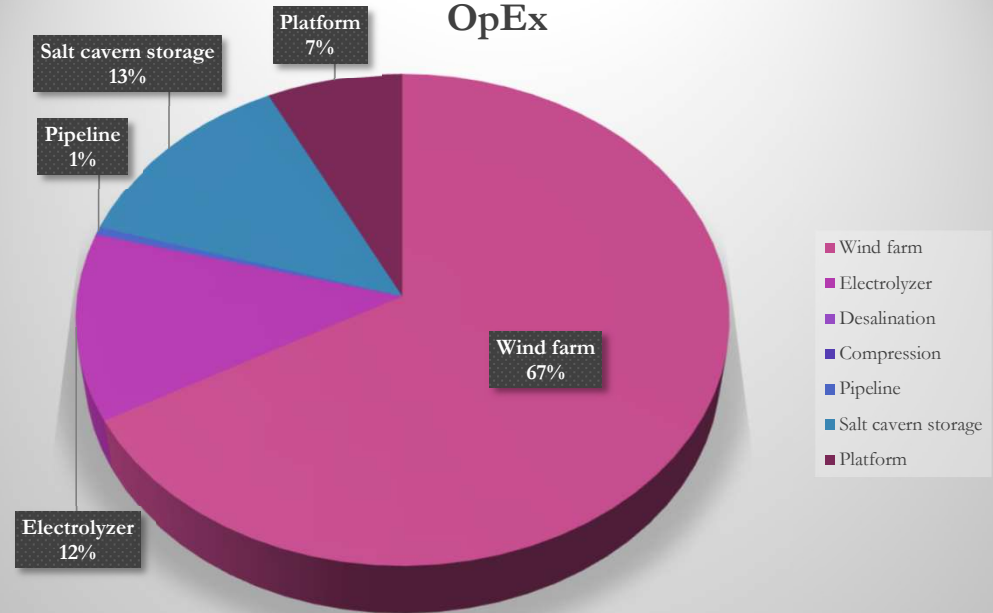
$$\text{LCOH} = (\text{Investment} + \text{Maintenance} + \text{Operational} - \text{Revenue}) / \text{Hydrogen output}$$

Typical Cost Distribution (Illustrative)

CapEx



OpEx

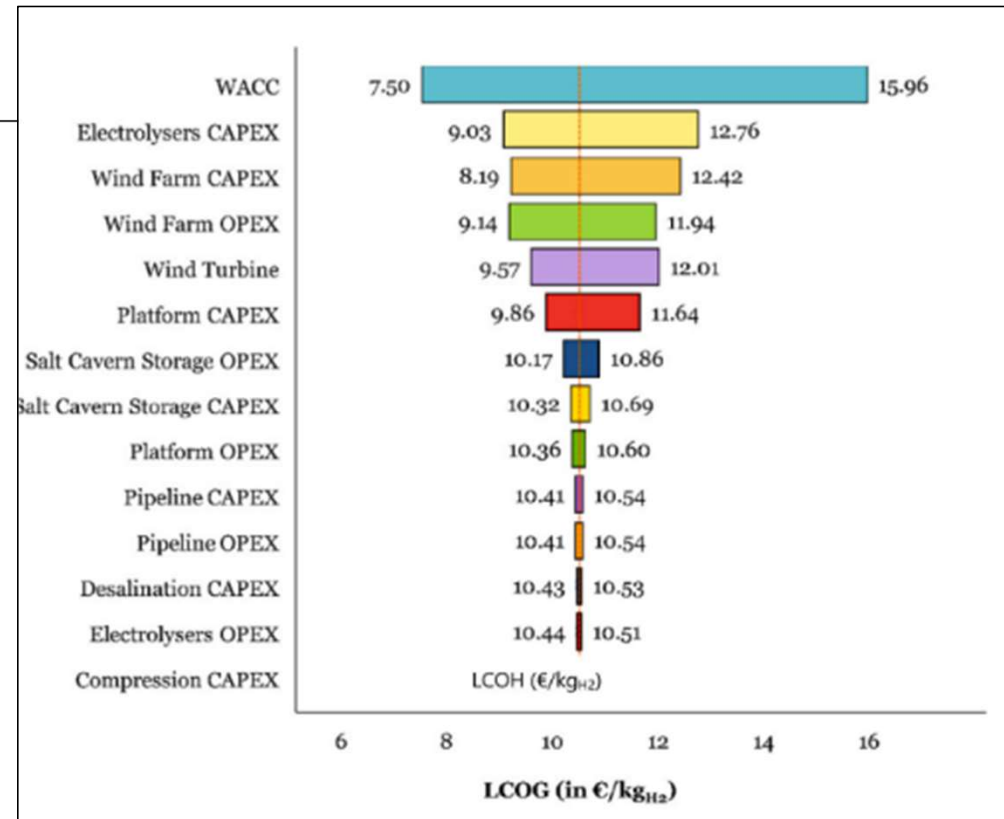


Offshore Hydrogen Economics Sensitivities

□ The numbers and graphs shown here are only illustrative in nature. The actual levelized cost of hydrogen varies with location, geography and other factors

□ Key points to note in this tornado chart

- The weighted average cost of capital (WACC) can swing the cost of hydrogen generated significantly- up to two times
- Other factors like electrolyzer, wind farm CapEx also are significant contributors.
- Also note that most of the uncertainty contributes towards the increase of levelized cost of hydrogen
- Provides inputs for area concentration in value engineering



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Offshore Electrolysis Technology

❑ Modular Offshore Electrolyzers:

- ❑ **Development:** New electrolyzer designs are being developed specifically for offshore environments. These modular systems can be deployed on offshore platforms or integrated directly into wind turbine structures.
- ❑ **Advantages:** Modular electrolyzers can be scaled up more easily and can be adapted to different sizes of wind farms. They also reduce the need for extensive infrastructure by being closer to the source of electricity.

❑ High-Efficiency Electrolysis:

- ❑ **Development:** Advanced electrolysis technologies, such as Proton Exchange Membrane (PEM) and Solid Oxide Electrolysis Cells (SOECs), are being optimized for offshore use. These technologies are being designed to operate more efficiently under variable power inputs typical of wind energy.
- ❑ Sea Water Electrolysis is an attractive albeit immature technology
- ❑ **Advantages:** Higher efficiency in electrolysis reduces the overall energy consumption and increases the hydrogen yield, making the process more cost-effective.

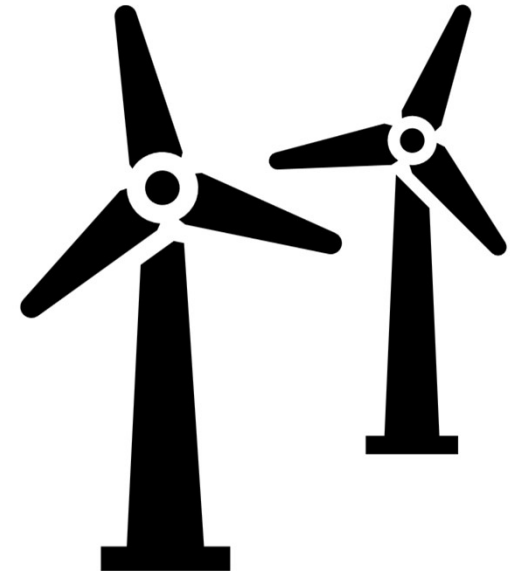
Floating Wind Turbines with Integrated Hydrogen Production

❖ Floating Platforms:

- ❖ **Development:** Floating wind turbines are being developed for deep-water areas where fixed-bottom turbines are not feasible. These platforms can now incorporate hydrogen production facilities, allowing for the generation and conversion of electricity to hydrogen directly on-site.
- ❖ **Advantages:** This integration reduces the need for expensive subsea cables and complex grid connections. It also enables the exploitation of high-wind areas far offshore, increasing the potential for large-scale hydrogen production.

❖ Dynamic Cable and Mooring Systems:

- ❖ **Development:** New designs for dynamic cables and mooring systems are being developed to support the dual functions of floating wind turbines and hydrogen production units.
- ❖ **Advantages:** These systems are designed to withstand the stresses of deep-sea environments while ensuring stable operations of both the wind turbines and hydrogen production equipment.



Advanced Hydrogen Storage Solutions

Cryo-Compressed Hydrogen

Subsea Hydrogen Storage:

- **Development:** Research is underway on subsea hydrogen storage solutions, including high-pressure storage vessels and the use of geological formations such as salt caverns beneath the seabed.
- **Advantages:** Subsea storage can reduce the footprint and visual impact of storage facilities. It also offers the potential for large-scale storage that can buffer the variability of wind energy and support a steady hydrogen supply.

Ammonia and Liquid Organic Hydrogen Carriers (LOHCs):

- **Development:** Hydrogen is being increasingly stored and transported in the form of ammonia or liquid organic hydrogen carriers, which are more stable and less energy-intensive to transport over long distances.
- **Advantages:** These carriers simplify the logistics of hydrogen transport from offshore sites to onshore facilities and can be easily converted back into hydrogen at the point of use.



Offshore Hydrogen Transportation Innovations



Subsea Hydrogen Pipelines:

Development: Specialized subsea pipelines designed to transport pure hydrogen from offshore production sites to onshore facilities are under development. These pipelines are engineered to handle the specific challenges of hydrogen, such as its small molecular size and high diffusivity.

Advantages: Direct hydrogen pipelines reduce the need for electrical grid connections and allow for efficient long-distance transport of hydrogen.



Hydrogen Shipping:

Development: New shipping technologies are being developed for the transport of liquid hydrogen or hydrogen carriers like ammonia. These include specialized cryogenic tankers and ammonia carriers.

Advantages: These innovations enable the export of hydrogen from offshore wind-rich regions to global markets, supporting international trade in green hydrogen.

Digital and Hybrid Energy Systems

•Smart Grid Integration:

- Improved grid integration reduces curtailment of wind energy, ensures the efficient use of electricity for hydrogen production, and balances supply with demand.

•Predictive Maintenance and AI

- Predictive maintenance reduces downtime and operational costs by identifying potential issues before they lead to failures. AI also helps in optimizing the production process, ensuring maximum efficiency.

•Hybrid Wind-Hydrogen Systems:

- Hybrid systems reduce the variability of energy inputs, improving the consistency of hydrogen production and reducing reliance on backup power sources.

•Energy Storage Integration:

- **Advantages:** Energy storage can store excess electricity during periods of high wind and release it when wind speeds are low, ensuring continuous hydrogen production.

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Regulatory Environment-Snapshot



Offshore Wind Farm Permitting and Environmental Compliance

Site Leasing and Permitting:
Marine Spatial Planning:
Environmental Impact Assessments (EIA):
Stakeholder Consultation:
Marine and Navigational Safety:
Maritime Safety Regulations:
Collision Risk Assessment:



Hydrogen Production

Electrolysis and Chemical Safety:
Electrolysis Plant Permitting:
Emissions and Waste Management:



Hydrogen Storage

Storage Facility Permitting:
Safety Regulations:
Environmental Permits:



Hydrogen Transportation

Pipeline and Shipping Regulations:
Hydrogen Pipelines:
Shipping of Hydrogen or Ammonia
Cross-Border and International Regulations:
Export/Import Regulations:
Transboundary Environmental Impact Assessments:



Grid Connection and Energy Integration

Grid Connection Permits:
Connection Agreements:
Grid Capacity Assessments:
Energy Market Regulations:
Renewable Energy Certificates:
Hydrogen Certification: 6.
Occupational Health and Safety



Worker Safety Regulations:

Offshore Safety Protocols:
Training and Certification:



Regulatory Coordination and Harmonization

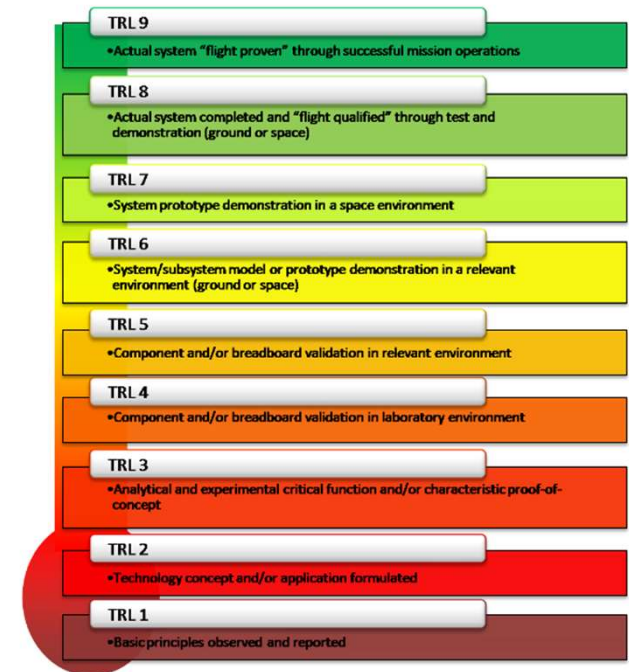
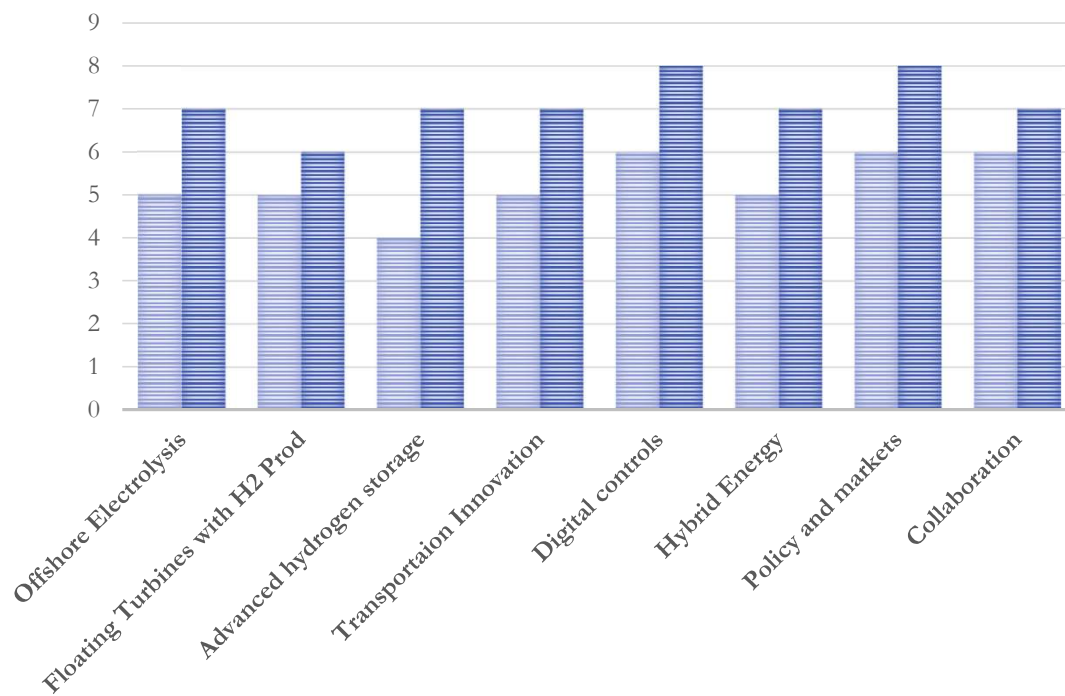
Harmonization of Standards:

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Technology Readiness Levels (TRL)



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Offshore Hydrogen

Top 4 Risks (Authors opinion)



Technical Risks: Reliability and Durability of Offshore Electrolysis Technology

Impact: Reduced system reliability could lead to significant operational disruptions, increased maintenance costs, and lower overall efficiency in hydrogen production.



Economic Risks: High Capital and Operational Costs

Impact: High upfront and ongoing costs can make offshore hydrogen production economically challenging, potentially leading to financial risks if projects do not achieve the expected return on investment (ROI).



Technical Risks: Structural Integrity of Floating Wind Turbines with Integrated Hydrogen Production

Impact: Structural failures or mechanical issues can lead to significant safety hazards, costly repairs, or even complete loss of infrastructure, severely impacting project viability and safety.



Regulatory and Market Risks: Uncertain Regulatory Landscape and Market Volatility

Impact: Regulatory changes could impose additional costs or restrictions, while market volatility could lead to uncertain revenue streams, affecting the economic stability of offshore hydrogen projects.

Offshore Hydrogen

Top 4 Opportunities (Authors opinion)



Cost Reduction through Technological Innovation

Impact: Reducing the cost of key components will make offshore hydrogen production more competitive with other energy sources, accelerating its adoption and scalability. This will also attract more investment into the sector, fostering further innovation.



Integration of Renewable Energy Systems

Impact: Hybrid systems can reduce the variability in power supply, improving the efficiency and reliability of hydrogen production. This approach maximizes the use of available renewable resources and enhances the overall energy yield from offshore installations.



Market Growth for Green Hydrogen

Impact: Growing market demand for green hydrogen will drive investments and scale-up of offshore hydrogen production, creating a positive feedback loop that further reduces costs and enhances technological development.



Regulatory Support and Policy Incentives

Impact: Proactive policy support can accelerate the development and deployment of offshore hydrogen production facilities, making them more economically viable. This will help to establish offshore hydrogen as a key component of the global energy transition, ensuring long-term sustainability and profitability.



Development of Advanced Storage Materials

High-Pressure Storage:
Cryogenic Storage:
Solid-State Storage:



Enhancing Durability and Safety of Infrastructure

Corrosion Resistance:
Hydrogen Embrittlement Prevention:



Improving Efficiency of Transportation Systems

Pipelines and Seals:
Hydrogen Carriers:



Advancing Manufacturing and Construction Techniques

Modular and Lightweight Designs:
Additive Manufacturing:

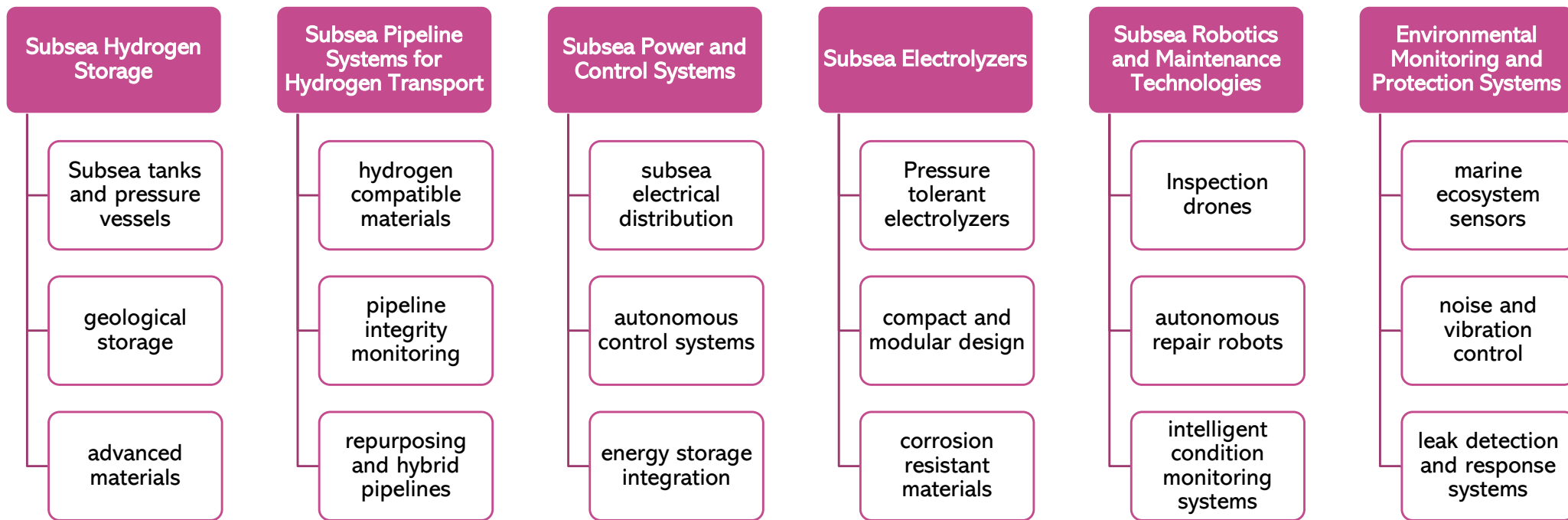


Enhancing System Integration and Performance

Smart Materials:
Sensors and Monitoring:

Materials Science plays a crucial part

Offshore Hydrogen Subsea Technology Focus



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System	Why	Impact
Turbine and Electrolyzer Design and Integration	The design, optimization, standardization and integration of wind turbines with electrolyzers - Optimizing these components can significantly reduce both capital and operational expenditures, improve energy efficiency, and enhance the reliability of the entire system.	Reduces overall project costs, increases system efficiency, and ensures higher hydrogen production output.
Storage Solutions	Innovations in storage materials and technologies can lower costs and increase storage capacity, which is crucial for balancing supply and demand.	Lowers storage costs, enhances safety, and ensures a stable hydrogen supply, which is vital for scalability.
Leveraging Existing Offshore Infrastructure	Repurpose existing offshore oil and gas infrastructure, such as pipelines and platforms, for hydrogen storage and transportation.	Repurposing existing infrastructure can significantly reduce initial capital investments and project timelines while minimizing the environmental impact associated with new construction.
Installation and Construction Efficiency	By improving the efficiency of installation and construction processes through modular designs, prefabrication, and lean practices, significant cost savings can be achieved.	Reduces Capex, shortens project timelines, and minimizes environmental impact, leading to quicker project completion and faster return on investment.
Enhancing Digitalization and Automation	Integrate advanced digital technologies and automation into the design, monitoring, and maintenance of offshore hydrogen systems.	Digitalization and automation can lead to significant cost savings through reduced labor, minimized downtime, and optimized operations, improving both Capex and Opex efficiency.
Supply Chain Optimization	A well-optimized supply chain is essential for keeping costs down and ensuring timely delivery of materials and components. By standardizing components, securing bulk purchasing agreements, and optimizing logistics, offshore projects can significantly reduce costs and avoid delays.	Reduces material costs, shortens lead times, and minimizes project delays, contributing to overall cost savings and project efficiency.
Efficient Project Management and Execution & Front-End Loading	Improve project management practices to ensure efficient execution and delivery of offshore hydrogen storage and transportation projects.	Improved project management can reduce delays, prevent cost overruns, and ensure that resources are used as efficiently as possible, leading to a lower overall cost structure.

Value Engineering Offshore Hydrogen

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Conclusions



High Potential in Renewable Energy Transition

Offshore hydrogen production, particularly through the integration of offshore wind, has strong potential

Its scalable

More consistent than onshore wind



Cost Challenges and Economies of Scale

Currently higher LCOH compared to onshore

Large scale deployment, learning curves and optimization will reduce costs



Technological Readiness and Innovation Needs

TRL in offshore hydrogen production is still in the early to mid-stages of development

Significant engineering and research is required to improve the readiness



Significant Infrastructure and Logistics Requirements

Investment in marine and offshore facilities.

Complex with high uncertainty



Environmental and Regulatory Considerations

Complex environmental and regulatory landscape

Reduction in GHG and impact on ecosystem

Q&A

Thank You

