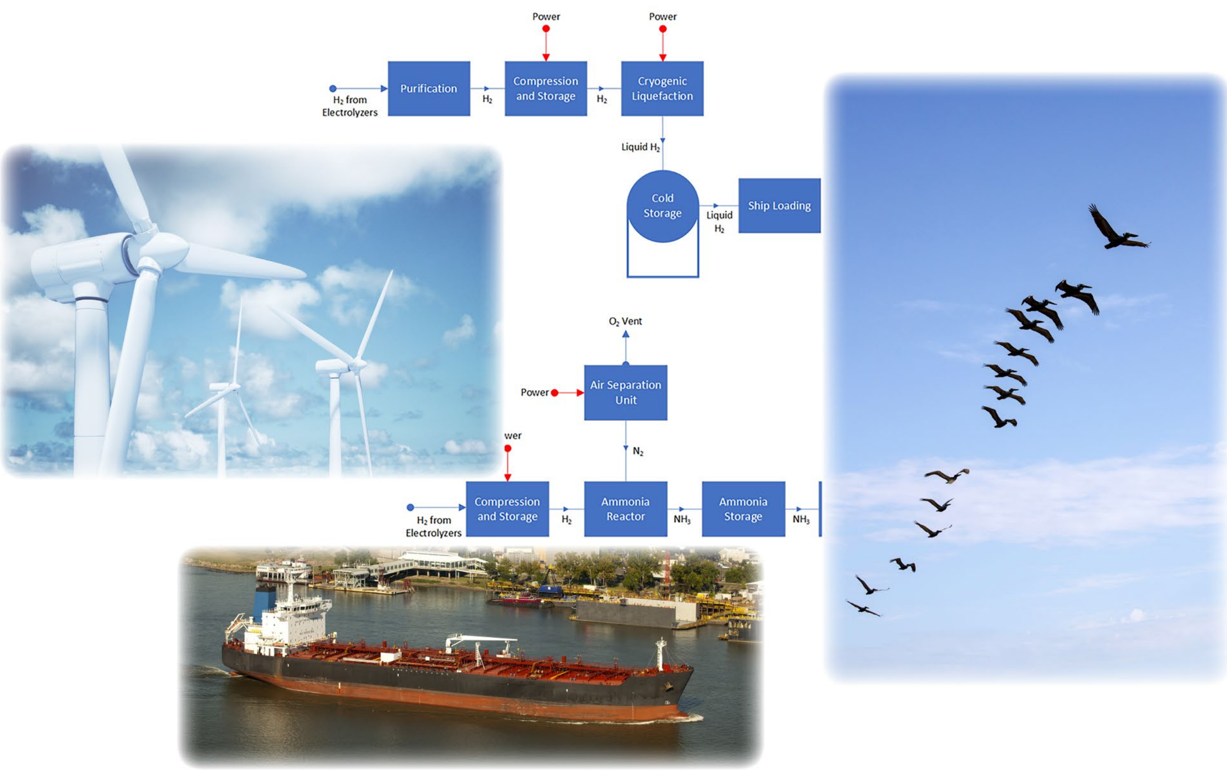
OCS Study
BOEM 2022-xxx

Assessment of BOEM's Role in Reviewing Hydrogen Production as a Complement to Offshore Wind



U.S. Department of the Interior
Bureau of Ocean Energy Management
4500 Woodland Road, Sterling, VA 20166

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Assessment of BOEM's Role in Reviewing Hydrogen Production as a Complement to Offshore Wind

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ABOUT THE COVER

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List of Abbreviations and Acronyms

°C	degrees Celsius
AC	alternating current
AEAU	Alternative Energy and Alternate Use (NEPA)
AEM	Anion Exchange Membrane
API	American Petroleum Institute
ASME	American Society of Mechanical Engineers
ASU	air separation unit
BEIS	(Department of) Business, Energy, and Industrial Strategy (UK)
BOEM	Bureau of Ocean Energy Management (US)
BSEE	Bureau of Safety and Environmental Enforcement (US)
CAPEX	capital expenditure
CFR	Code of Federal Regulations (US)
CO2	carbon dioxide
COP	Construction and Operations Plan
CPH2	Clean Power Hydrogen
CRADA	cooperative research and development agreement
Cu	copper
CZMA	Coastal Zone Management Act (US)
DC	direct current
DOE	Department of Energy (US)
DOLPHYN	Deepwater Offshore Local Production of HYdrogeN
EA	Environmental Assessment
EERE	Office of Energy Efficiency and Renewable Energy (US DOE)
EIS	Environmental Impact Statement
EMF	electro-magnetic field
EPACT	US Energy Policy Act of 2005
ESA	Endangered Species Act (US)
GAP	Gap Assessment Plan
FEED	front-end engineering and design
FR	Final Rule
GW	gigawatt
H	hydrogen (element)
H_2	hydrogen (molecule)
H_2-OSW	Hydrogen Production from Offshore Wind Energy
HFTO	Hydrogen and Fuel Cell Technologies Office (US DOE)
HHV	high heating value
HVDC	high voltage direct current
HySCORE	Hydrogen Storage Characterization and Optimization Effort (US DOE NREL)
IEA	International Energy Agency

IEC	International Electrotechnical Commission
ITM	ITM Power Inc.
Ir	iridium
kg	kilogram
KOH	potassium hydroxide
kW	kilowatt
kWh	kilowatt hour
l	liter
LNG	liquified natural gas
LOHC	liquid organic hydrogen carrier
LHV	low heating value
MCH	methylcyclohexane
mJ	millijoule
MMPA	Marine Mammal Protection Act (US)
Mn	magnesium
MOA	Memorandum of Agreement
MW	megawatt
N_2	nitrogen (molecule)
NEPA	National Environmental Policy Act
NFPA	National Fire Protection Association
NGO	nongovernmental organization
Ni	nickel
nm	nautical mile
NOAA	National Oceanographic and Atmospheric Administration
NREL	National Renewable Energy Laboratory
NTL	Notice to Lessees (US BOEM)
O	oxygen (element)
O_2	oxygen (molecule)
OCS	outer continental shelf
OCSLA	Outer Continental Shelf Lands Act (US)
OEM	original equipment manufacturer
OH	hydroxyl (ion)
ONRR	Office of Natural Resources Revenue (US)
OSHA	Occupational Safety and Health Administration (US)
OSW	offshore wind
OYSTER	Offshore hYdrogen from Shoreside wind Turbine integrated electrolyzER
PEM	polymer electrolyte membrane or proton exchange membrane
psi	pounds per square inch
PSM	Process Safety Management (OSHA)
PSU	Penn State University
PSV	pressure safety valve
Pt	Platinum

RD&D	research, development, and deployment
Rh	Rhodium
ROD	Record of Decision
ROW	Right of Way
Ru	Ruthenium
RUE	Right of Use and Easement
SALCOS	Salzgitter Low CO2 Steelmaking
SAP	Site Assessment Plan
SIS	safety instrumented system
SMR	steam methane reforming
SOEC	solid oxide electrolyte cell
SwRI	Southwest Research Institute
TRL	Technical Reports Library (US)
UC	University of California
UK	United Kingdom (of Great Britain and Northern Ireland)
US	United States (of America)

Executive Summary

The hydrogen molecule (H_2) is an emerging energy vector that can be used as a clean-burning fuel and can be produced from both conventional and renewable energy sources. Green hydrogen produced by splitting water into hydrogen and oxygen molecules (electrolysis) using renewable energy creates an opportunity to transport, store, and use carbon-free energy in industrial, transportation and other sectors traditionally powered by liquid and gaseous hydrocarbon fuels. Offshore wind (OSW) power on the Outer Continental Shelf (OCS) is a significant renewable resource that can support utility-scale green hydrogen production in the United States (US), with active development off the northeast US, permitting underway stretching south to the Carolina coast, and planned lease sales for the Gulf of Mexico as US west coast. US federal policy supports continued expansion of OSW in support of the transition toward renewables and reduction of greenhouse gas (GHG) emissions while enhancing national energy security. H_2 production, storage, and distribution technologies are rapidly evolving, and regulatory frameworks for managing relevant aspects of H_2 production from offshore wind energy (H_2-OSW) will need to anticipate emerging H_2-OSW implementations throughout US coastal waters. While hydrogen production technology has already evolved to a point where it can be sited complement to offshore wind projects, research and development to improve safety, efficiency, and commercial readiness of such coupling are still in early stages.

The US Bureau of Ocean Energy Management (BOEM) is responsible for managing energy and mineral resources on the US OCS. BOEM regulatory oversight derives primarily from the Outer Continental Shelf Lands Act (OCSLA), along with its Energy Policy Act (2005) Amendment to OCSLA covering renewable energy development. This *Assessment of BOEM's Role in Reviewing Hydrogen Production as a Complement to Offshore Wind* provides BOEM with necessary background, technical analysis, and recommendations to update existing regulatory guidance for offshore wind development on the OCS, and to identify existing gaps in technical review expertise required for administering H_2-OSW permitting and for safety enforcement under BSEE. Active engagement with BOEM personnel for discussion and feedback was a critical aspect driving this assessment, designed to maximize the long-term value of this assessment for supporting BOEM's role in this emerging US energy sector. Final interpretations regarding BOEM's role, research avenues and partnering opportunities, stakeholder engagement, bolstering subject matter expertise, and adaptations and updates to existing BOEM regulatory guidance will be undertaken by BOEM, supported by findings in this assessment report.

While technical implementations of H_2-OSW are evolving rapidly in response to research advances and diverse business cases, the general process to produce H_2 involves steps common across implementations. Seawater intake for desalination/demineralization provides the process water for electrolysis, which splits water molecules into hydrogen and oxygen, with brine discharge as a byproduct. Power conditioning adapts electricity produced from OSW for stable and safe operation of electrolyzers and includes backup/stand-by electricity storage to provide consistent supply. There are currently four primary electrolyzer types available for use in H_2-OSW: 1) the alkaline electrolyzer, which is the most mature technology at scale; 2) the Polymer Electrolyte Membrane or Proton Exchange Membrane (PEM), which is a more recent technology currently in development for deployment at scale; 3) the Solid Oxide Electrolyte Cell (SOEC), which is a developing technology; and 4) the emerging Anion Exchange Membrane (AEM) technology. Hybrid systems could potentially be considered to combine cost and flexibility characteristics in a multi-unit system. Improvements to reliability and lifespan are expected to be key factors for selecting suitable electrolyzer technology for H_2-OSW project development. Adapting electrolyzer technology for maritime use (marinization) will need to consider specific regional conditions and will be important for H_2-OSW feasibility.

H_2-OSW will require large volumes of water both for H_2 production and for cooling. Resulting environmental impacts include seawater intake, as well as discharge of brine from process water and discharge of cooling water at elevated temperatures. Depending on design specifications, discharges from roughly 1 to 2 gallons of brine per kg of H_2 produced are expected, where brine characteristics will vary with technology. Discharge impacts may be concentrated around a central H_2 production platform or distributed across an OSW development where electrolyzers are installed with individual wind turbine generators (WTG). The largest cooling load is for the electrolysis step; while other parts of the process and other utilities will also require cooling as will any downstream process such as hydrogen compression, liquefaction, and hydrogen conversion into other forms. Closed-loop systems currently in development (subsea cooling) may offer options for reduction of cooling water discharge.

H_2 as an energy vector offers versatility in terms of storage and transportation but includes potential hazards. H_2 may be stored and transported as compressed gas, as liquid hydrogen, as green ammonia, through liquid-organic hydrogen carriers (LOHC), or using metal hydrides. Each option may offer advantages in storage distance, commercial readiness, and energy requirement depending upon implementation (e.g., liquid hydrogen would be most likely for vessel/tanker transport, while compressed gas is more suitable for pipeline transport). Of the multiple storage and transport options that exist, some conditioning and H_2 compression will be required for most options. Currently compressed gas and liquified hydrogen are most proven and market-ready, though advantages for long range transport may favor ammonia or LOHC for certain implementations. H_2-OSW facilities may also serve as refueling stations for both deep ocean and coastal vessels, as there are limited options for decarbonizing marine transport and electrification is generally impractical for long-distance shipping.

Multiple business cases may drive H_2-OSW implementation. OSW energy could be used for onshore production of H_2, which would fall outside of BOEM jurisdiction, while in other cases H_2 could be produced offshore and transported to market via pipeline as compressed gas, or via vessel as either liquid hydrogen or as green ammonia. Business cases may depend heavily on regional environmental and economic conditions, and global energy market demands, with the Pacific Region currently closest to market readiness. Strategic pairing of OSW and electrolyzer technologies can be optimized in multiple ways to balance electric and H_2 energy for different market and energy grid demand scenarios.

Initiatives in the public and private sectors are actively promoting wider H_2 use at greater volumes and reduced cost with increased safety. Goals include greater US energy reliability, and global competitive influence by 2030 while addressing US and global net-zero carbon and other climate change policies and objectives. Research and development supporting new technologies broadening H_2 implementation across market sectors, with deployment at scale, are a central focus of these initiatives. Current studies run the spectrum from large-scale H_2 production to consumer-end implementation. These efforts in concert drive accelerated development of production and delivery as well as market readiness in the US, developing the US hydrogen economy as a whole. In general, federal and state initiatives tend to support H_2 production, storage, and delivery more than private sector efforts, which is more application driven. The US Department of Energy (DOE) is the lead federal agency, with multiple programs and partnering opportunities, and coordination among agencies. The pace of these initiatives suggests the combined roles of BOEM and BSEE for permitting, regulation, and oversight of H_2-OSW may increase rapidly in both scope and scale within the next 8 years, potentially necessitating anticipatory and/or adaptive responses.

The extent and timing of research efforts in the US, with an explicit emphasis on interagency/inter-entity collaboration, seem to offer the means to best leverage BOEM/BSEE research funding toward co-development of technological approaches and regulatory guidance focused on H_2-OSW. BSEE may leverage its Technology Assessment Program, interagency collaboration, and the stakeholder engagement process to help focus and promote RD&D efforts addressing specific aspects of H_2 production, storage, transport, and safety most relevant for H_2-OSW.

Some aspects of H_2-OSW do not readily fit into BOEM's existing technical review and permitting framework/guidance, and BOEM will need sufficient breadth of expertise and flexibility to review and regulate hydrogen production across variable and evolving business cases and scenarios. In general, it is recommended that BOEM consider development of a framework for allowing both current and future offshore wind lessees option for H_2-OSW activities as a complement to their offshore wind development plans. This framework should include programmatic environmental impact statement (EIS) re-examination and potential update. 30 Code of Federal Regulations (CFR) Part 585 is sufficiently broad to facilitate incorporating H_2-OSW, where multiple existing subparts are applicable and/or adaptable, potentially with modifications in certain areas including operating fees and payments, Site Assessment Plans (SAP), and Construction and Operations Plans (COP). Required NEPA analysis for H_2-OSW leasing would need to consider impacts on technology testing and site characterization; construction, operations and decommissioning; and mitigation measures. Multiple avenues already exist for H_2-OSW leasing, both for existing and future OSW developments, where rent payments and operating fees would need to be assessed for H_2 production. Outside of BOEM jurisdiction, development and refinement of relevant regulations and statutes among other federal agencies is likely to continue throughout the next decade as H_2 increases as a proportion of the US energy marketplace and as emerging technologies, implementations, and lessons learned require.

Hydrogen facilities require safety procedures similar to those required on oil and gas platforms that handle natural gas, with leak potential, gas pressurization, and flammability as chief safety concerns. Most of the safety issues with H_2-OSW have parallels in existing oil and gas offshore operations, but some concerns will be unique to hydrogen or different than the equivalent oil and gas process. These include hydrogen impacts to steel (coupled with marine corrosion), best practices for conditioning, storage and transport of H_2, and toxicity of ammonia in the event of a leak. BOEM/BSEE may wish to adapt the US Occupational Safety and Health Administration (OSHA) Process Safety Management (PSM) standard for H_2-OSW as a tool for regulation and safety enforcement for H_2-OSW, as this is considered safety best practice.

Emerging projects in Europe offer some early lessons for potential H_2-OSW in the US. Perhaps most relevant is the benefit of starting with multi-stakeholder consortia representing all aspects of the H_2-OSW value chain from the outset to establish a credible/viable project and enhance understanding of how specific projects will fit into a complex US renewables landscape. Another early lesson is that the decision whether to generate hydrogen onshore or offshore is highly project-specific and predicated in part on stakeholder feedback, and project scale has been shown to have critical impact on economic viability of offshore production. Existing demonstration and development projects from Europe offer examples for adaptation to circumstances in the US and come with a breadth of implementation strategies.

1 Introduction

The hydrogen molecule (H_2) is an emerging energy vector that can be used as a clean-burning fuel and can be produced from both conventional and renewable energy sources. Green hydrogen produced by splitting water into hydrogen and oxygen molecules (electrolysis) using renewable energy creates an opportunity to transport, store, and use carbon-free energy in industrial, transportation and other sectors traditionally powered by liquid and gaseous hydrocarbon fuels. As an energy-yielding, exothermic reaction, hydrogen combustion adds oxygen to reverse the splitting process to produce water vapor ($2H_2 + O_2 \rightarrow 2H_2O$). Hydrogen can also be electrochemically converted to electricity in fuel cells eliminating emissions generating in the combustion process. Water provides an abundant and global resource for renewable H_2 production when paired with renewable energy and electrolysis. A robust H_2 energy sector is a US federal priority supporting national energy security, resilience, and independence, and contributing to climate and environmental policy goals. Existing federal support, primarily under the Department of Energy (DOE), drives research, development, and deployment (RD&D) of green hydrogen energy.

OSW power on the OCS is a significant renewable resource that can support utility-scale green hydrogen production in the US. Under the purview of BOEM, OSW development continues to expand rapidly in US waters, with active leasing, permitting, and development off the coast of the northeast US, and with wind energy area (WEA) analyses and leasing in an active planning phase for the Gulf of Mexico and the US west coast. As with H_2 energy, US federal policy supports continued expansion of OSW in support of the transition toward renewables and reduction of GHG emissions while enhancing national energy security. Electricity from OSW is expected to offer an increasingly available and cost-effective energy resource for H_2 production. Critically, hydrogen enables energy storage capacity to synchronize wind energy resource availability with demand.

While hydrogen production technology has evolved to a point where it can be sited as a complement to offshore wind projects, research and development for improved technologies and process flows to improve safety, efficiency and commercial readiness are still in are in early stages but are progressing rapidly. The existing US regulatory framework has yet to fully mature for managing this novel resource and will need to co-develop with H_2-OSW projects which are expected see significant deployment over the next 8 years leading to 2030. Onshore H_2 generation using OSW energy is also expected, but would occur outside of BOEM's regulatory jurisdiction, and is therefore not considered in this report.

1.1 Who is the Bureau of Ocean Energy Management

BOEM, in the US Department of Interior (DOI), is responsible for managing energy and mineral resources on the US OCS. The bureau draws its statutory mandate from the Outer Continental Shelf Lands Act (OCSLA) which gives the Secretary of Interior responsibility and policy guidance for managing almost 2.5 billion acres of OCS, nearly equal the size of the nation's land acreage. The Energy Policy Act of 2005 amended OCSLA to authorize DOI to manage renewable energy development on the OCS. Authority was delegated to BOEM to establish and implement a new regulatory framework for renewable energy resources including OSW power. In 2009, BOEM finalized regulations to issue leases, easements, and rights of way to allow renewable energy development on the OCS. Subsequently, BOEM has issued multiple offshore wind leases and authorized siting and development of two utility-scale offshore wind projects.

1.2 Purpose of this Document

This *Assessment of BOEM's Role in Reviewing Hydrogen Production as a Complement to Offshore Wind* is specifically framed and purposed to help inform and drive initial updates to regulatory guidance and internal enhancement of subject matter expertise to be undertaken by BOEM in anticipation of permitting requests for H_2-OSW development in US waters. Report contents include feedback and consideration from open discussions between the authors and other subject matter experts along with BOEM / Bureau of Safety and Environmental Enforcement (BSEE) personnel during a pair of planned workshops in April and May 2022. Discussions, professional opinions, and interpretations from BOEM/BSEE helped refine the understanding of gaps in BOEM's existing expertise for reviewing, permitting, and enforcing safety for H_2-OSW projects within BOEM's jurisdiction on the US OCS.

The *Assessment of BOEM's Role in Reviewing Hydrogen Production as a Complement to Offshore Wind* provides BOEM with necessary background, technical analysis, and recommendations to update existing regulatory guidance for offshore development on the OCS, and to identify existing gaps in technical review expertise required for administering H_2-OSW permitting and for safety enforcement under BSEE. The technical components of H_2-OSW and its process flow, marketable byproducts, and initial business cases are discussed in Section 2. Section 3 provides a discussion of the state of RD&D efforts in the US, focused on H_2 energy and an outline of the current trajectory of technological advancement relevant for H_2-OSW. Section 4 provides an analysis of the existing regulatory framework and identifies permitting implications and necessary adjustments to existing OSW regulations to accommodate construction, operation, and decommissioning requirements for a range of possible H_2-OSW implementations. Current experience in Europe, which is ahead of the US in H_2-OSW research, demonstration, and deployment, is leveraged in Section 5 to provide broader context to anticipate challenges to future H_2-OSW in the US. Section 6 describes potential relationships between BOEM, other US federal agencies, academia, nongovernmental organizations (NGOs), and industry to gather stakeholder feedback and guide further RD&D in promotion of H_2-OSW development and its US regulatory framework.

In this assessment, we recommend updates to permitting and regulatory guidance, including amendments for existing leases, integrating H_2-OSW in the existing OSW stakeholder engagement process and fully incorporating H_2-OSW on the OCS as an option in future leases. We also include recommendations for the environmental assessment requirements and provide suggestions to repurpose some of the existing regulatory frameworks including OCS oil and natural gas to address potential regulatory gaps. The assessment also includes recommendations for technology development and additional research to further understand potential environmental impacts and design mitigation measures. Active engagement with BOEM, sharing findings and progressively incorporating feedback, was a critical aspect driving this assessment. Focused workshops fostering open discussion and idea development are a centerpiece of this open dialogue and engagement, maximizing the long-term value of this assessment for supporting BOEM's role in this important emerging US energy sector. Final interpretations regarding BOEM's role, research avenues and partnering opportunities, stakeholder engagement, needs for subject matter expertise, and any adaptations and updates to existing BOEM regulatory guidance will be undertaken by BOEM, supported by findings in this assessment report.

2 Technical H_2-OSW Implementation Review

This section provides a technical overview of the systems associated with production and distribution of hydrogen in an offshore environment to suitable end users. It covers the major process blocks along with the options for distribution and different use cases.

Renewable energy available from wind or solar sources is typically converted into electricity that is directly exported to the regional electrical grid for immediate used by electricity consumers. When generation capacity exceeds demand, then energy production is traditionally curtailed by taking generation offline. Battery storage is already in use to enable this excess energy to be stored over a short period of time. Hydrogen production and storage provides an alternate means of allowing this excess energy to be stored and transported to meet demand for use elsewhere.

The term “energy vector” is used to describe an “energy storage product” that enables the storage of energy at one location, followed by transportation, and use of that energy in another location and time. Hydrogen is one such energy carrier that can be generated by converting energy from a range of low carbon or renewable energy resources. Renewable ocean energy devices including wave, tidal, and ocean thermal energy convertors are all capable of generating storable and distributable forms of energy. These forms of storable energy can range from electricity (batteries), chemical (ammonia, hydrogen and others), heat and potential energy. However, in the context of this study, offshore wind is currently considered a mature renewable energy technology in the marine environment. Existing regulations inherently assume electricity generated by wind turbines is exported via high voltage cabling. However, more general language would enable renewable energy technologies to produce a wider range of energy storage products.

H_2-OSW represents an opportunity to diversify energy storage products using offshore renewable energy resources. A generic H_2-OSW system could include the following primary components, some of which may be concept-specific.

- Wind Turbine Generator
- Power Conditioning
- Cooling System
- Desalination/Seawater Lift
- Electrolyzer
- H_2 Gas Conditioning
- Compression
- Risers and gathering manifold
- H_2 Compression
- Storage for Compressed H_2
- Export transmission
- Stand-by power

A block/process flow diagram (Figure 2-1) shows how key functional components tie together serving H_2-OSW production.

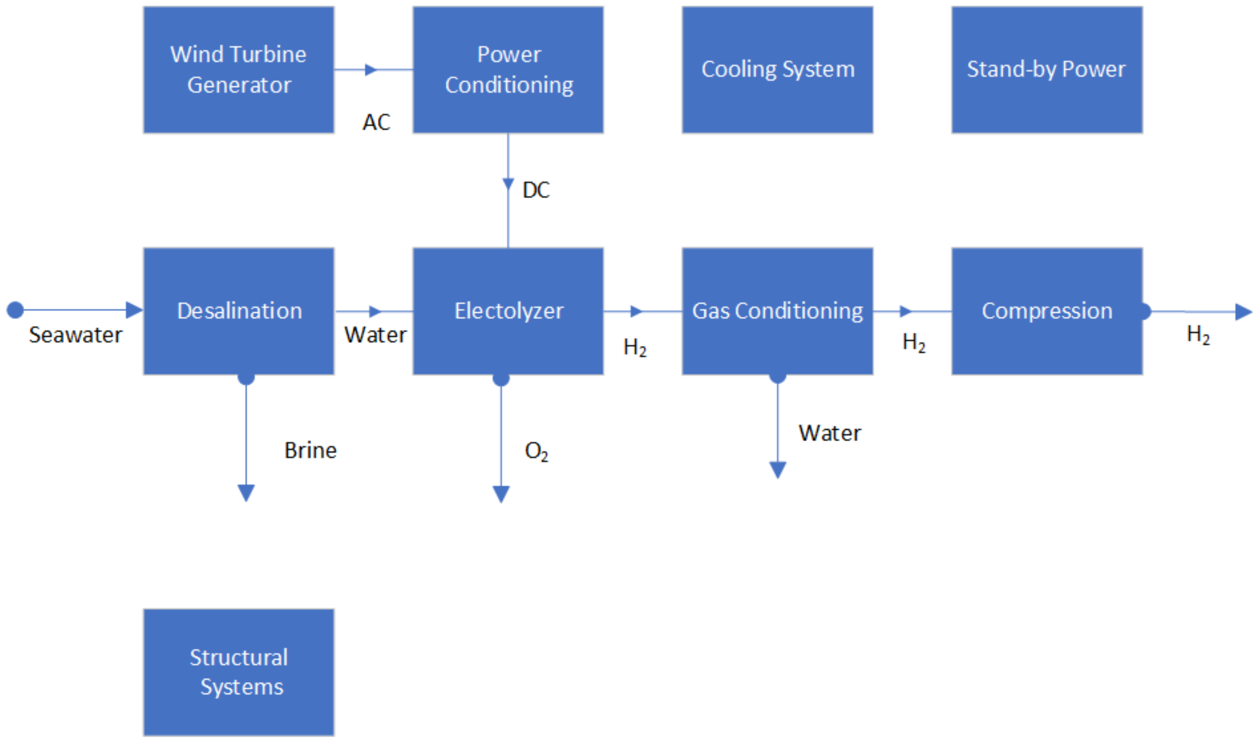

Figure 2-1. General process flow for key functions of H_2-OSW
Source: AECOM 2022

The storage of hydrogen introduces potential hazards associated with flammable gases and pressurized systems. Collection of oxygen as a byproduct introduces similar considerations. The loads associate with storage vessels and the need to provide adequate separation zone will influence on the structural design.

This study does not discuss OSW technology because this is already included in BOEM's existing regulatory framework; however, the OSW electrical generator configuration should be carefully considered to evaluate whether there are design solutions that can take advantage of the electrolyzer's requirement for direct current (DC) power. In all cases, special power conditioning systems will be required.

This study focuses on differences in hydrogen production technologies; therefore, common offshore characteristics such as substructure, mooring and anchoring, and inter-array cabling are not discussed.

Opportunities for offshore hydrogen production exist for both piled and floating wind turbine configurations, and at this stage of development of the H_2-OSW sector it is not evident whether there are inherent advantages to either; however, it may be that the details associated with top-sides, substructure, mooring, and manifolding may be more significant that the electrolyzer itself.

2.1 Power Conditioning

2.1.1 Power Electronics

Electrolyzers use DC to power the electrolysis stacks, while the balance of plant equipment in a renewable energy facility will use alternating current (AC) power. In conventional packaged electrolyzer equipment, the AC grid supplies are rectified to produce the necessary DC power.

The requirements of the electrolyzer may influence the optimum configuration for an H_2-OSW system compared to a conventional OSW system and should be reviewed early in the design phase.

2.1.2 Energy Storage System and Backup Power

Note that while renewable energy sources are intermittent by nature, a number of the platform systems will require constant energy supplies for safe operation including yaw control, platform stabilization, weather protection of systems, control, communication, and critical safety functions.

Operational and maintenance systems will need to ensure adequate automatic control and maintenance capability. This may include battery energy storage, standby generation, and temporary connection of external (ship borne) supplies. One option for standby generation is to use the hydrogen stored on site to generate power via a hydrogen fuel cell. This is an alternate method of energy storage compared to the use of batteries and may be a practical solution for H_2-OSW applications. Batteries and hydrogen fuel cells are both able to supply power without emissions and are unlikely to introduce any new regulatory concerns.

Specific operation schemes will be required to ensure safe, reliable long-term operation. Operating protocols within operation schemes will need to be regularly reviewed and will be dependent on multiple internal and external operating parameters, including wind resources, storage capacity, electricity system capacity, weather, market conditions, among others. Operating protocol review and standardization will need to account for the uniqueness of H_2-OSW configurations. For example, backup power and energy storage design should consider both safety and operational criticality as well as economics factors to help develop the system, in context of the uniqueness of the deployed equipment for offshore use.

2.2 Electrolyzers

Electrolysis uses electrochemical processes to dissociate water into its constituent hydrogen and oxygen molecules; the equipment used in this process are electrolyzers. Electrolyzers include balance of plant systems that use water at an appropriate, design-specific purity (e.g., from on-site desalination and demineralization; Section 2.3.1) and provides direct current (from the wind turbine) to an electrolyzer stack or stacks. Each stack contains a number of identical electrolyzer cells. The system also conditions and—in certain cases—compresses the products to meet the appropriate pressure, temperature, and purity specifications. The system also manages the heat generated during the process. Note that much of the energy not directly resulting in producing hydrogen molecules is lost in the form of heat.

There are four main types of commercially available electrolyzer: the alkaline electrolyzer, which is the most mature technology at scale; the Polymer Electrolyte Membrane or Proton Exchange Membrane (PEM), which is a more recent technology currently in development for deployment at scale; the Solid Oxide Electrolyte Cell (SOEC), which is a developing technology; and the emerging Anion Exchange Membrane (AEM) technology. These electrolyzers are principally characterized by the type of electrolyte and membrane they use. The technologies are further described below (with more detail available in the literature [IRENA 2020]). It is important to note also that there is current research and development into new technologies that promise lower cost and higher efficiencies.

Descriptions and ranking the four predominant technologies are shown in Figure 2-2.

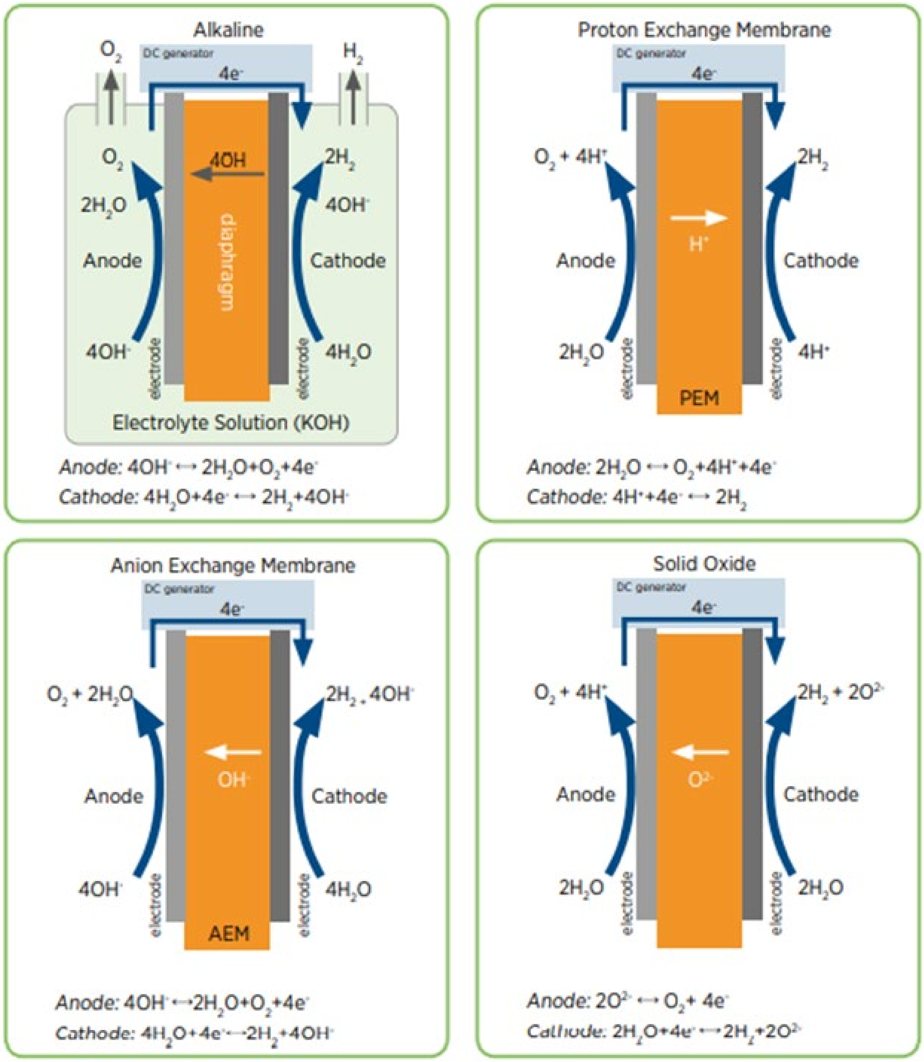

Figure 2-2. Four electrolyzer types by timeline (upper left to lower right)
Source: IRENA 2020

The recent International Energy Agency (IEA) Hydrogen Projects Database[1] includes over 800 electrolysis projects, over half of which are using dedicated renewables sources with roughly 60 referencing offshore wind as their energy source. While most of these references are not specific as to the electrolysis technology, three projects specifically cite alkaline technology, totaling approximately 5,000 Nm^3H_2/h These include:

- Ørsted's 2 MW H2RES offshore wind-to-hydrogen demonstrator in **Denmark** using an onshore electrolyzer
- DJEWELS 20MW Phase 1 demonstration project to produce industrial hydrogen in the **Netherlands** aimed at e-fuel production; this project is referenced as an OSW project, but does not make specific reference to an offshore farm

[1] https://www.iea.org/data-and-statistics/data-product/hydrogen-projects-database

- Gas Natural's 300 kW installation at the Sotavento wind farm in **Spain**; this project is referenced as an OSW project, but appears to be onshore

The five projects that cite PEM technology, totaling approximately 43,000 Nm^3H_2/h include:

- The Gigastack project links offshore wind to a 100 MW onshore electrolyzer facility producing green hydrogen for a refinery in the **UK**
- Refhyne 2 is a projected extension of the current 10 MW Refhyne project to 100 MW with a view to replacing grey hydrogen from a steam methane reforming (SMR) process for Shell's Rhineland Refinery facility in **Germany**
- H2Mare is a 14 MW project in **Germany** to establish a new turbine concept integrating the electrolyzer into an offshore wind turbine for direct conversion of energy into green hydrogen
- Port of Immingham is a 20 MW scheme aimed at developing the opportunity to substitute hydrogen for fossil fuels in a port facility in maritime and cargo handling sectors in the **UK**; this project is referenced as an OSW project, but does not make specific reference to an offshore farm
- Siemens Gamesa 400kW electrolyzer producing hydrogen for mobility in Brande, **Denmark**; this project is referenced as an OSW project, but appears to be onshore

The approximately 50 OSW projects with undefined technology account for an estimated 7,800,000 Nm^3H_2/h capacity. It should be noted that the majority of these projects will be conventional offshore generation with onshore electrolyzers for green hydrogen production. A list of website references to these projects is provided in the IEA Hydrogen Projects Database.

2.2.1 Polymer Electrolyte Membrane, Proton Exchange Membrane

2.2.1.1 High Level Technology Description

In PEM electrolysis, a charged hydrogen ion (proton) that passes through a solid polymer in place of the electrolyte to segregate the hydrogen and oxygen products. The polymer is conductive to positively charged ions but resistive to negatively charged ions, which enables a differential pressure between the hydrogen and oxygen streams.

The proton exchange membrane and the need for catalysts and high-grade materials contribute to a higher cost when compared to the alkaline electrolyzer (Section 2.2.2).

2.2.1.2 Applicability

PEM technology dates from the mid-1960s where it was originally applied in life support systems at small-scale. PEM avoided some of the limitations of industrial scale alkaline installations that relied on the use of platinum group metals and sensitive membrane materials; as a consequence, they were both relatively expensive and had a shorter operating life.

PEM hydrolyzers have the development potential to operate at high pressures; their rapid response time and operating range makes them an attractive proposition for local hydrogen production or grid services.

They are currently less widely deployed at scale; however, a number of Original Equipment Manufacturers (OEMs) are developing this technology in containerized and modular products.

2.2.2 Alkaline

2.2.2.1 High-Level Technology Description

Alkaline electrolyzers consist of a series of positive and negative electrodes (anodes and cathodes) that pass current through a liquid alkaline electrolyte solution, typically a 20 to 30% solution of potassium hydroxide in water. The charged electrodes are separated by a semi-permeable diaphragm that allows water and charged hydroxide ions to pass but separates hydrogen and oxygen gasses to prevent mixing. In general, oxygen and hydrogen are produced at a similar pressure.

The requirement for an electrolyte circuit increases the complexity of the balance of plant systems. However, the resulting size penalty is less significant as scale increases and is offset by the simplicity of the stack design and material costs.

2.2.2.2 Applicability

Alkaline electrolysis has been used since the early twentieth century, especially in the production of hydrogen and chlorine. Because of its use of more readily available materials it tends to have lower capital costs, and while it may have a lower turndown ratio in terms of minimum load and a slower response time, it is a mature and commercialized technology with several OEMs producing containerized equipment.

2.2.3 Solid Oxide Electrolyte Cell

2.2.3.1 High Level Technology Description

SOEC electrolyzer operates at very high temperatures; therefore, the electrolysis process separates hydrogen and oxygen from steam as opposed to liquid water. Although operating at high temperatures, the overall electricity demand of the electrolyzer is reduced because some of the energy required to separate the water is provided through the heat. The use of relatively cheap nickel electrodes can also be implemented, removing the need for precious metals. Another benefit of this technology is the potential for reversibility and operating the technology as a fuel cell, producing electricity from the combination of hydrogen and oxygen.

As an example, Sunfire has achieved successful demonstration of its 225 kW Sunfire-HyLink SOEC in 2021 as part of the EU-funded MultiPLHY project. During testing, the electrolyzer reached an efficiency of 84% based on the Lower Heating Value (LHV) of hydrogen, and power consumption was as low as 40 kWh/kgH_2 (Sunfire 2021). By comparison, standard alkaline and PEM electrolyzers consume between 50 and 83 kWh/kgH_2, a summary is provided in Table 2-1. Haldor Topsoe are also developing an SOEC product and have recently invested in a manufacturing facility with an annual capacity of 500 MW, which is expected to be operational by 2023.

2.2.3.2 Applicability

SOECs are less developed compared to alkaline or PEM technologies and have yet to be commercialized. They offer the potential of high efficiency and low cost and have a number of interesting integration opportunities. However, their requirement for steam as the operating fluid and current material durability under their high temperatures does not make them a likely candidate for offshore use in the short term beyond potential small-scale demonstrators or trials. Current fleet lead units have typically operated under constant power and well controlled conditions that do not correspond well to the offshore environment.

2.2.4 Anion Exchange Membrane

2.2.4.1 High Level Technology Description

AEM is the most recently developed electrolyzer technology with few product developers. It combines features from alkaline and PEM technologies and—in principle—facilitates a higher operating pressure with lower cost materials. However, the conductivity of the anions compared to the protons means that generation rates are lower requiring thinner membranes or higher electrode charge densities.

AEM electrolyzers share a number of similarities with PEM electrolyzers, (i.e., having a membrane that also serves as a solid electrolyte). This provides benefits over alkaline electrolysis systems by avoiding the use of corrosive electrolytes. The AEM electrolyzer also has an advantage over PEM electrolyzers by using a transitional metal electrocatalyst (CeO_2-La_2O) rather than the platinum-based catalyst materials used in PEM electrolyzer. As an example, Germany-based Enapter are a market leader in AEM electrolyzers. They are currently in the process of developing a kW-scale AEM electrolyzer "core" with a view to producing a MW scale system by using 420 of these smaller cores.

2.2.4.2 Applicability

The AEM electrolyzer shares a number of similar characteristics to the PEM. Although it is not yet developed at a suitable scale, it is likely that it may be used as a comparative technology to PEM or alkaline technologies in offshore demonstrators. Current durability is believed to be low with little information available.

2.2.5 Comparison of Electrolyzer Technologies

The industrially mature technologies are alkaline and proton exchange membrane; SOEC and AEM are developing and not yet widely commercialized. Alkaline benefits from lower cost base at present. However, both are amenable to future technological improvement and supply chain cost reductions, and hybrid systems could potentially be considered to combine cost and flexibility characteristics in a multi-unit system. The PEM electrolyzer is significantly more compact at small scale because of the impact of the balance of plant for alkaline technology; however, this difference is less significant at a larger scale.

The PEM technology offers a faster dynamic response than the alkaline electrolyzer. However, research by the National Renewable Energy Laboratory (NREL) suggests this difference is marginal in terms of wind and solar applications. A summary of the main characteristics comparing these technologies is provided in Table 2-1.

Table 2-1. Standard characteristics of alkaline and PEM electrolyzers

Electrolyzer Technology	Components	Exchange Particles	Operating Temperature (ºC)	Operating Pressure (bar)	Development Stage
Alkaline Water Electrolysis	– Potassium hydroxide (KOH) solution electrolyte – Nickel coated stainless steel electrodes – Zirconium oxide separator	Hydroxyl ion (OH-)	70-90	1-30	Commercial, most mature
Proton Exchange Membrane (PEM)	– Perfluorosulfonic (PFSA) acid membrane – Iridium oxide electrode (oxygen side) – Platinum nanoparticles on carbon black electrode (hydrogen side)	Proton (H+)	50-80	<70	Commercial
Anion Exchange Membrane (AEM)	– Divinylbenzene polymer support with KOH or sodium hydrocarbonate electrolyte – High surface area nickel electrode	Hydroxyl ion (OH-)	40-60	<35	Early stage, laboratory testing
Solid Oxide Electrolysis (SOEC)	– Yttria-stabilized Zirconia (YSZ) – Perovskite-type (e.g., LSCF, LSM) electrode (oxygen side) – Nickel or YSZ (hydrogen side)	Oxide (O2-)	700-850	1	(TRL 4 – 5)

Source: AECOM 2022

As mentioned in the summary above, AEM and SOEC electrolyzers are considered as emerging technologies because they are still in the early stage of development and not currently commercially available.

More detail of the specific alkaline and PEM technologies is provided in Table 2-2.

Table 2-2. Standard characteristics of alkaline and PEM electrolyzer

Characteristic	Alkaline	PEM
Feed	20 – 40 wt.% KOH solution	Pure water
Electrocatalyst	Ni, Cu, Mn, W, Ru	Pt, Ir, Ru, Rh
Separator	ZrO_2 with polysulfone polymer (Zirfon®)	Sulfonated tetrafluoroethylene-based polymer (Nafion®)
Cell temperature (°C)	60-80	50-80
Cell pressure (bara)	< 30	< 70
Production capacity (kgH_2/day)	Up to 70,000	Up to 50,000
Maximum realized size (MW)	10	10
Efficiency (based on LHV)	52 - 69%	60 - 77%
Load range (% of nominal load)	10 – 110%	20 – 100%, up to 160%
Response time	1 – 10 min	1 sec – 5 min
Electricity consumption (kWh/kgH_2)	50-78	50-83
Current density (mA/cm^2)	300-500	1000-3000
Lifetime (1000 h)	60	50-80

Characteristic	Alkaline	PEM
CAPEX for stack ($/kW)	270	400
Hydrogen cost ($/kg$H_2$)	2.6-6.9	3.5-7.5

Source: AECOM 2022

2.2.6 Potential Advances in Electrolyzer Technology and How They May Affect BOEM Guidance

Reliability—particularly in early systems—will be a key determinant for technology selection given the likelihood of normally unmanned installation and the cost and challenges in maintaining equipment offshore. The membrane is often considered to be a life limiting component; therefore, some OEMs are investigating membraneless technologies. One example is Clean Power Hydrogen Ltd. (CPH_2), who are currently developing a membrane-free electrolyzer technology based on an alkaline cycle.

With the exception of the SOEC technology that requires external steam supply, the detailed technology of the electrolyzer is not thought to be significant in terms of interfaces. General improvements in terms of cost, efficiency, and reliability will all have a positive impact on the implementation of H_2-OSW schema.

The current expected lifespan of a commercial electrolyzer is 6 to 9 years. An H_2-OSW installation is therefore likely to change out or perform a major overhaul of the electrolyzers at least once, possibly multiple times, during the lifetime of the platform. The electrolyzer packages are likely to be modularized and replacing the electrolyzers will simply involving swapping old modules for new ones.

The electrolyzer replacement could require a revision to the Construction and Operations Plan (COP), although this is unlikely. Advances in electrolyzer technology may improve electrical efficiency. This would allow future electrolyzer modules to produce more hydrogen for the same wind turbine rating. However, increasing hydrogen production would also require upgrades to other equipment to handle higher throughput. Upstream of the electrolyzers, a larger desalination plant would be required. Downstream hydrogen conditioning, compression, and transportation would also require upgrades. It is more likely that operators will continue producing the same amount of hydrogen following an electrolyzer change out.

2.2.7 Marinization

Developing a system capable of operation in a maritime environment (marinization) requires special consideration in permitting, design and operation. Specific, regional offshore environments may require unique design considerations and operation protocols to ensure compatibility with the application. Currently, electrolyzer technology has focuses on onshore applications. OEM technology is developing rapidly, however specialized designs may be required for marine environment. Marinization will be an important consideration for a number of reasons. There is ongoing research into material capability, remote monitoring, and predictive condition monitoring.

The dynamic environment of a floating platform also requires consideration the specification of equipment and layout to allow for inclination on sumps and seals.

Offshore oil and gas platforms provide an experience base that can help inform H_2-OSW marinization best practices.

2.3 Water Use

Water use is an important consideration for environmental impacts for two reasons: 1) Hydrogen production requires large volumes of high purity water. Current technology requires a desalination unit, which will discharge significant volumes of brine. 2) H_2-OSW will also require significant process cooling, which will result in the discharge of cooling water at elevated temperatures. Both issues are discussed in detail in this section and are considered as part of existing offshore regulations in Section 4.1.2.

The overall quantity of water used will depend on the detailed design configuration, noting that cooling water flows in once-through systems may result in flows which are significantly higher than that used to produce hydrogen. The water usage should be assessed in context of NPDES permits 40 CFR Parts 122 & 125 ($\geq$ 2 million gallons/day) and the Clean Water Act Section 316(b) requirements for use of best technology standards to reduce impingement and entrainment of aquatic organisms (further discussion is provided in Section 4.1.2 Regulatory Review).

2.3.1 Water for Electrolyzers

Current electrolyzer technology requires high-purity water. Current MW scale onshore H_2 installations require a low level of potable water treatment to achieve acceptable purity, generally using an integrated water treatment package. However, the use of seawater as a raw water source will require a desalination plant. On land, bulk desalination can be achieved by thermal means as part of a combined water and power plant or using reverse osmosis (RO).

Because water electrolysis requires about 9 liters of demineralized water to produce 1 kilogram of hydrogen (and 8 kilograms of oxygen), the issues of water stress are already recognized. A number of projects are seeing the potential benefits of a coastal location due to the availability of seawater. Using reverse osmosis for desalination requires an energy demand of between 3 to 4 kWh per cubic meter of water (IEA 2019), or 0.03-0.04 kWh/kg H_2, which represents a relatively small energy demand compared the subsequent electrolysis and compression demands. A typical block flow diagram for a seawater reverse osmosis plant is shown in Figure 2-3.

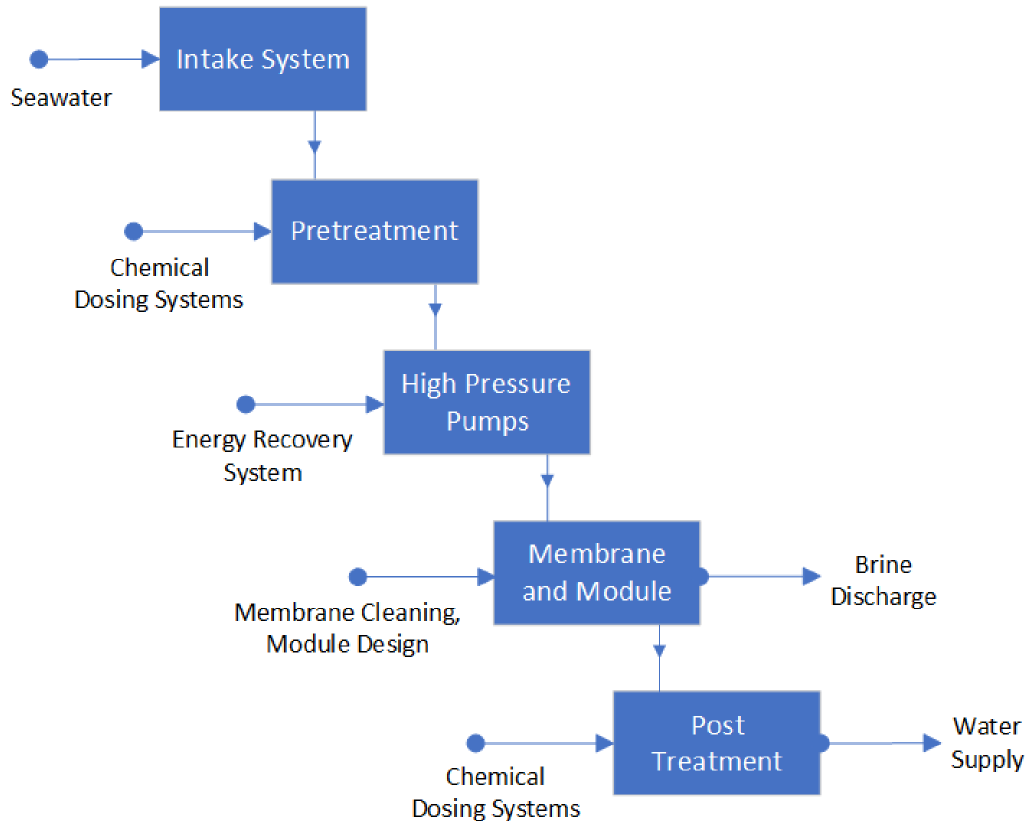

Figure 2-3. General Seawater Reverse-Osmosis Process Flow
Source: Adapted from V.G Guide Desalination and Water Treatment 36 (2011) 239-260.

A simple desalination plant will involve an intake system and screens followed by a pretreatment system to remove bulk contaminants using chemical processes. Pretreatment is followed by a high-pressure pump system ahead of the reverse osmosis membrane system. Large scale units often include a pressure recovery or energy recovery system to reduce the process energy requirement and the overall production costs for the water. Domestic potable water will often include additional chemical dosing systems that may be less relevant to the process water requirements for the electrolyzer. Note the PEM and Alkaline electrolyzers may require different levels of water quality.

Depending on the design and specification and the process yield, a reverse osmosis plant requires 14 to 18 liters of raw water for every 10 liters of demineralized process water. This type of technology has been well developed for the offshore oil and gas environment. A 10 MW turbine size will require approximately 1 metric ton per hour of demineralized water on average.

The comparison between the water consumption metrics on a per kilogram hydrogen basis scaled to a 10 MW wind turbine scale and then to a 4 GW wind farm is provided in Table 2-3. The scaled numbers are for an average hydrogen production rate consistent with the literature published on the Dolphyn H_2-OSW project planned in the UK North Sea[2].

[2] https://ermdolphyn.erm.com/

Table 2-3. Water Consumption Metrics for H_2-OSW

Scale	per kgH_2	10 MW	4 GW
Raw water	18-14 liters	1.3-1.6 m3/hr	500-650 m3/hr
Process Water	10 liters	~ 1 m3/hr	365 m3/hr
Brine	4-8 liters	0.4-0.7 m3/hr	146-292 m3/hr
Energy Consumption for RO Plant	0.03-0.04 kWh	3-4 kW	1.1-1.5 MW

Source: AECOM 2022

2.3.2 Brine Discharges

Depending on the design and specification and the process yield, a reverse osmosis plant requires 14 to 18 liters of raw seawater for every 10 liters of process water, and therefore discharges between 4 to 8 liters of brine per kg of H_2 produced.

Sea water reverse osmosis is a well-established technology in the offshore oil and gas industry and the design of the intakes, process plant and brine steam management will follow this practice.

The brine characteristics will depend on the detailed process used and the system design will be an optimization balancing the cost, energy system requirements, and discharge limits.

2.3.3 R&D status of Future Electrolyzer Technology

Current electrolyzer technologies are not suitable for direct use of seawater with the risk of corrosion and chlorine production. However, because of the potential process simplification, there is ongoing research into both freshwater and seawater as direct inputs to avoid both the desalination and de-ionization steps.

2.3.4 Cooling Water

In general terms, system inefficiency expresses itself as heat. While certain processes require specific temperatures, it is important to manage temperature in order to achieve equipment reliability.

Heat is generated in the power conversion and conditioning equipment; in the water treatment process; in the electrolysis process itself; and in the gas conditioning and compression.

The largest cooling load is for the electrolysis step; the other parts of the process and other utilities will also require cooling as will any downstream process such as hydrogen compression, liquefaction, and hydrogen conversion into other forms. Therefore, a dedicated cooling system will be required, which may rely on exchange with the surrounding seawater or with a radiator system with the ambient air or a combination of both.

Representative cooling duties and cooling water flow rates for different processes are provided in Table 2-4. The representative numbers are for a once-through open loop cooling system. Calculations assume a cooling water temperature rise of 5 degrees Celsius (°C) and hydrogen production rates consistent with the Dolphyn H_2-OSW project.

Table 2-4. Cooling Water Uses and Flow Rates

Scale	per kgH_2	10 MW	4 GW
Compression	0.6 kWh	55 kW	22 MW
Compressor Cooling	0.5 kWh	47 kW	19 MW
Compressor Cooling Water Flow Rate	0.09 m^3	8 m^3/hr	3286 m^3/hr
Electrolyzer Cooling	33 kWh	3 MW	1200 MW

Scale	per kgH_2	10 MW	4 GW
Electrolyzer Cooling Water Flow Rate	5.8 m^3	528 m^3/hr	211,000 m^3/hr

Source: AECOM 2022

The availability of abundant seawater at relatively low temperatures provides the likely cooling medium. The cooling water discharge will be at an elevated temperature, which will need to be controlled. Smaller cooling duties may be handled with air cooling with due consideration to ambient air and exhaust temperate and avoidance of thermal mixing.

Cooling technology is well established from existing offshore oil and gas experience. However, cooling demands for the electrolyzers are very high, which may result in higher volumes of cooling water discharge than typically seen at oil and gas platforms. A closed loop cooling system that rejects waste heat to ambient air would eliminate the need to discharge cooling water at elevated temperatures. However, the air coolers needed for a closed loop system require a significant amount of space on the platform, and the space requirements can be prohibitively expensive.

A third option for cooling is a relatively new technology known as subsea cooling. This is a closed loop system that pumps warm water (cooling water or process water) to a subsea heat exchanger. Ocean water flows over the outside of the heat exchanger tubes via natural currents cooling the water in the closed loop system. Early adopters in the oil and gas industry have demonstrated this technology, but H_2-OSW would potentially be able to use the technology on a much larger scale. This would be a potential area for future research.

Many of the electrolyzer packaged systems may have been developed for onshore use with minimum reliance on other supplies. However, there are significant opportunities for heat integration and waste heat recovery in order to improve overall system efficiency.

2.4 H_2 Storage and Transport

A key feature differentiating the production of electrical energy and the production of energy products is the ability to store energy in the energy products. However, this has potential hazards, and the storage and segregation of products becomes an important consideration when comparing offshore electrical generation with direct transmission to offshore hydrogen production.

Regardless of the type of storage and transport used, some conditioning will be required and compression is also needed for most options.

2.4.1 Conditioning and Purification

Conditioning and purification requirements will vary depending on the electrolyzer technology selected, the method of transportation, and the end user purity specifications. At a minimum, dehydration will almost certainly be required, although the water specification may vary. The cryogenic temperatures needed for liquefaction require a much lower water content than a pipeline gas.

An electrolyzer system will typically output very pure hydrogen (i.e., greater than 99.5%) with moisture and oxygen being the most probable impurities. Oxygen removal is typically achieved with an oxidation catalyst that converts oxygen back into water upstream of a dehydration process. Adopting drier and removal technologies can result in purities of greater than 99.999% being achieved.

Purity requirements vary depending on how the hydrogen will be used. If the hydrogen will be combusted for thermal fuel uses, high purity is not required. This would apply to hydrogen blended into a natural gas system or hydrogen used solely to feed fired heaters and/or combustion gas turbines. Hydrogen fuel cells have very stringent purity specifications and chemical-grade hydrogen is somewhere in between.

2.4.2 Compression

Hydrogen has a low molecular mass and as a result compression or liquefaction is required to make storage and transportation viable.

The typical output pressure of hydrogen production technologies is generally less than 30 bar, but it is required at much higher pressures by the end users. Hydrogen pipeline transmission networks operate at pressures up to 80 bar and refueling stations require pressures of 350 or 700 bar (US DRIVE 2013). Hydrogen liquefaction processes use staged compression and expansion steps as part of an integrated refrigeration system.

Therefore, a compression stage is needed to boost the pressure up to these elevated pressures. This can be achieved through conventional compressors, but the selection is restricted due to the small molecule size of the hydrogen with positive displacement (reciprocating) compressors being favored (especially for high pressures). Issues for other types of compressors are:

- Centrifugal compressors need to operate at high tip speeds
- Axial compressors have significant inter-stage leakage
- Rotary compressors require tight tolerances to prevent significant leakage

Ionic compressors are also available that can achieve high pressures (greater than 700 bar). These operate like reciprocating compressors using ionic fluids rather than pistons. As a result, they remove two sources of failure as they do not require either bearings or seals.

2.4.3 Compressed Gas Storage and Transport

The simplest method to store H_2 is to compress the gas and store in pressure vessels. Conventional carbon steel pressure vessels (also called bullets) are typically designed to store compressed hydrogen gas at pressures up to 250 to 300 barg. Specialized composite carbon fiber vessels can be designed to store hydrogen at pressures of 350 to 700 barg.

Most business cases will require some compressed hydrogen storage. Potential reasons to install compressed gas storage include:

- Short-term storage for usage on the platform(s)
- Fuel storage to refuel ships
- Buffer storage upstream of a pipeline to shore
- Buffer storage upstream of a liquefaction unit
- Buffer storage upstream of a conversion unit (green ammonia or other liquid organic hydrogen carrier [LOHC])
- Storage to supply ships transporting compressed hydrogen to end users

Hydrogen liquefaction and conversion processes operate best at continuous, steady-state conditions. Because power generation is variable, hydrogen production is also variable, making some gas buffer storage desirable upstream of additional processing.

Supplying hydrogen to ships transporting compressed gas would require the largest volumes of gas storage. However, this is not a likely business case because transporting hydrogen by ship is more likely to be via liquid H_2, ammonia, or another LOHC.

Buffer storage requirements for pipeline supply will depend on the pipeline operating philosophy. It is feasible to operate a pipeline with very little buffer storage, but the flow into the pipeline will vary with power/hydrogen production resulting in variable pressure and flow rates at the onshore receiving facility. If a steady supply of hydrogen is required, a larger capacity of buffer storage will be needed.

Possible uses for hydrogen as a fuel source on the platform(s) include fuel cells for power generation (a possible alternative to battery storage), combustion turbines, and fired heaters for process or comfort heat. These processes may include NO_x/N_2O emissions for combustion occurring on site, with potential regulatory implications (Section 4.6.4.1).

Another option to store large volumes of compressed hydrogen is to use geological storage, such as an underground salt cavern. This is a more economical method to store very large volumes of hydrogen, but it requires suitable geology near the H_2-OSW installation. This storage method is common in the natural gas industry; however, there are very few hydrogen applications to date.

2.4.4 Liquid Hydrogen

Liquid hydrogen is four times as dense as gaseous hydrogen at 500 barg, which makes the transportation step more efficient than compressed gas transportation. However, liquefaction is an energy-intensive process. Hydrogen has a boiling point of -253°C, which is colder than any other element except helium. Liquid hydrogen is odorless and transparent, and its density is one-fourteenth the density of water.

The liquefaction process is a multistage process that uses a series of compression and expansion loops. The process requires significant pre-cooling steps. Conventional hydrogen liquefaction plants use liquid nitrogen in the pre-cooling stage. Newer design concepts use different refrigerants, including methane, neon, and helium, to provide incremental improvements to energy efficiency.

The liquefaction process also requires a catalyzed reaction bed. A hydrogen molecule can exist in two electron orbital spin states: ortho and para. At ambient temperatures, the ortho to para ratio is approximately 3:1. Liquified hydrogen needs to be nearly 100% parahydrogen because orthohydrogen at very low temperatures will naturally convert to parahydrogen, which releases heat causing the liquid hydrogen to vaporize. Ortho/para conversion catalyst beds are installed in the liquefaction process to convert hydrogen to the para form. A significant percentage of the refrigeration energy required is consumed by the ortho/para conversion.

Current small-scale liquefaction plants require 12 to 15 kWh of electricity per kg of hydrogen. Future large-scale plants target 8 to 10 kWh/kg or less (US DRIVE 2013). In other words, current liquid hydrogen processes consume the energy equivalent of 25 to 35% of the energy contained in the hydrogen with future targets reducing that number to 18% (IEA, 2019).

Liquified H_2 is stored in specialized double-walled storage vessels with vacuum insulation. The storage vessels are likely to be spherical, although smaller applications sometimes use a cylindrical “bullet” pressure vessel. The liquified H_2 would be transported from the platform to end markets via specialized ships with storage spheres resulting in significant ship traffic at the platform.

2.4.5 Green Ammonia

Green ammonia production reacts hydrogen from the electrolyzer with nitrogen to form ammonia, which can then be shipped more easily than hydrogen. A modest amount of pressure and/or refrigeration is sufficient to liquify and ship ammonia.

Ammonia can be transported via pipeline, ships, barges, or railcars onshore. There is an existing ammonia market that uses all these transportation methods, primarily to serve the fertilizer industry. Most ammonia produced today uses a natural gas process that results in high CO_2 emissions.

Ammonia is a flammable gas at ambient conditions. It is also corrosive to the skin, eyes, and lungs. Spills of ammonia would be toxic to marine life. Required safety procedures would be analogous to those used on crude oil production platforms. Procedures to safely handle ammonia are well established because it has been in commercial use for decades.

Green ammonia is a developing industry that could become a global market. Saudi Arabia's NEOM project has announced plans to export large volumes of green ammonia, and Australian projects anticipate exporting green ammonia to Japan.

Ammonia production also requires a source of nitrogen. If the end users of the green ammonia process are cracking the ammonia to generate H_2 and N_2, then the end users may recycle the N_2 back to the H_2-OSW platform. Another option is for the platform to install a cryogenic air separation unit (ASU), although there is a significant energy demand for this process.

Converting hydrogen to ammonia requires the energy equivalent of 7 to 18% of the energy contained in the hydrogen. If the ammonia needs to be reconverted back to high-purity hydrogen at the end user, a similar amount of reconversion energy is needed (IEA 2019).

Ships may transport ammonia from the platform to local or global end markets. Ammonia could also be transported to shore via subsea pipeline.

2.4.6 Liquid Organic Hydrogen Carriers

Making an LOHC involves reacting an organic chemical with hydrogen to make the "carrier." At the end use destination, the carrier is converted back to the original chemical, liberating the hydrogen. The carriers are transported as liquids without the need for cooling. The carrier molecules in an LOHC are not used up in the process and need to be shipped back to their place of origin.

One of the most common examples currently under consideration is methylcyclohexane (MCH)/toluene. When MCH is converted to toluene, it releases three molecules of H_2 per molecule of MCH.

Other LOHCs under research include dibenzyltoluene and methanol/formic acid.

LOHCs are flammable liquids and some (including toluene) are also toxic. These liquids require careful handling. Required safety procedures would be analogous to those used on crude oil production platforms. Many of the proposed LOHCs are components found in crude oil.

There are energy penalties associated with the LOHC conversion and reconversion processes. The energy required is equivalent to 35 to 40% of the hydrogen itself (IEA 2019). The high energy penalty makes LOHCs a less likely business case unless the hydrogen must be transported a long distance.

Ships may transport LOHCs from the platform to local or global end markets. LOHCs could also be transported to shore via subsea pipeline.

2.4.7 Metal Hydrides

Metal hydrides are solid materials that adsorb and desorb hydrogen, storing the hydrogen in a solid state. These materials are in early stages of development, but they could potentially enable high density storage at atmospheric pressure.

Current research and development efforts focus primarily on stationary applications. The weight of metal hydrides makes them less practical for long distance transportation, although future projects may elect to use metal hydrides for storage for use on the platform(s).

One advantage to metal hydrides is safety versus compressed gas storage. They operate at much lower pressure and release hydrogen much more slowly than pressurize gas cylinders in the event of a vessel rupture.

2.4.8 Comparison of Transportation Options

A high-level summary of the relative advantages and disadvantages of each transportation option is provided in Table 2-5.

Table 2-5. Transportation options

Transportation Method	Distance	Energy Requirement	Commercial Readiness
Compressed Gas	Short	Low	High—Proven Technology
Pipeline	Short to Mid	Low	High—Proven Technology
Liquid Hydrogen	Short to Mid	High	High—Proven Technology
Ammonia	Long Range	High	High
LOHC	Long Range	Very High	Mid
Metal Hydride	Short to Long Range	Mid to High	Low

Source: AECOM 2022

2.5 Marketable Byproducts

Hydrogen can be considered as an energy vector by which energy generated from the offshore renewables is captured for later use. There are other process byproducts that may have a commercial value, such as oxygen, purified water, concentrated brine, and heat energy.

2.5.1 Oxygen

For every ton of hydrogen produced, the electrolysis process generates eight tons of oxygen. Hydrogen plants that are small scale and/or in remote locations are most likely to simply vent the oxygen byproduct to the atmosphere. However, large-scale hydrogen plants may choose to sell the O_2.

Oxygen can be generated anywhere using an ASU. Industrial processes that require large volumes of oxygen typically install an ASU on site. An ASU is expensive both in terms of capital cost and energy consumption. Selling oxygen as a byproduct of hydrogen production is viable only if the transportation costs from the platform to the end user are less than the costs of a local ASU.

For a 4 GW example facility, the electrolyzers would generate 7,000 tons/day of oxygen.

2.5.2 Other Byproducts

Beneficial use of waste heat remains a significant opportunity as demonstrated by the development of combined cycle plant power generation and the development of combined heat and power installations in the industry. Availability of heat off-takers may be limited offshore; however, the general trends from emerging onshore electrolyzer projects are relevant.

The electrolysis of brine is the primary method to produce sodium hydroxide (NaOH) at industrial scale. A green hydrogen plant could brine electrolysis to generate an additional byproduct, but the NaOH would likely be much cheaper to install onshore. The process also generates chlorine gas as a byproduct, which would be much easier to handle and sell in an onshore facility.

Other opportunities for brine reuse include extraction of minerals and metals concentrated in the process. However, brine reuse at large scale is not currently a subject beyond laboratory or pilot plant scale. Nonetheless, management of this waste stream or transition to a zero liquid discharge basis are for consideration.

Desalinated water is another potential marketable byproduct. In areas that are water stressed (e.g., California), an H_2-OSW facility may opt to oversize the desalination unit and transport desalinated water to shore for local use. Transportation would most likely be via subsea pipeline.

2.6 Business Cases

This section documents some of the more likely business cases for H_2-OSW. In any potential business case, the costs associated with green hydrogen need to be weighed against the market value. Once green hydrogen is generated, potential uses include industrial processes, electricity generation, energy storage, building heat, and transportation fuel. Different end uses have different merits in terms of the decarbonization benefit and the value of the fuel they displace.

The economic assessment of H_2-OSW deployment is beyond the scope of this report. Business cases presented here are simply the more likely scenarios that could move forward.

2.6.1 Likely Business Cases

One of the likely business cases—particularly for OSW installations nearshore—would be to export power to an onshore hydrogen production facility. However, there are also likely scenarios involving offshore production.

All the likely business cases involving offshore hydrogen production will impact the local environment with water intake and discharge. Seawater is needed for cooling water and for input to the desalination plant. Water discharge will include cooling water return at elevated temperature and brine discharge from desalination.

Project business cases should consider the potential carbon intensity and emissions benefits of the energy products arising from a given project. This may also include the seasonal benefits of hydrogen generation for storage and the impact of displacing fossil fuels in the associated end market.

The project business cases should also consider regional differences with respect to deployment of H_2-OSW projects. Initially, the projects are likely to involve deployment of fixed bottom turbines in regions such as the US east coast and the Gulf of Mexico, followed by the implementation of floating offshore wind technology, as the technology matures, on the US west coast and Hawaii.

Other impacts specific to each business case are provided below.

2.6.1.1 Subsea Pipeline

Conventional OSW facilities are connected to shore via AC or high voltage direct current (HVDC) cables. The transmission system selection includes consideration of the distance of transmission, levels of system loss and the project economics. In this configuration, onshore generation of hydrogen represents an alternative use of the electrical energy produced by the wind farm. Where the impact of system losses and capital and operational and maintenance costs are favorable, it may be advantageous to produce hydrogen local to the generation source and transfer the hydrogen to shore via pipeline. Review of current projects in Section 5 of this report suggests that this is not a straightforward assessment and that the appropriate solution needs to be considered on a case-by-case basis.

In this business case (Figure 2-4), the offshore platform is situated relatively close to an onshore hydrogen market. Hydrogen from the electrolyzer is dehydrated and compressed to 70 to 100 barg. Some compressed gas hydrogen storage may be included to ensure a consistent flow of hydrogen to the pipeline. The subsea pipeline transports the hydrogen to shore where it supplies local or regional markets.

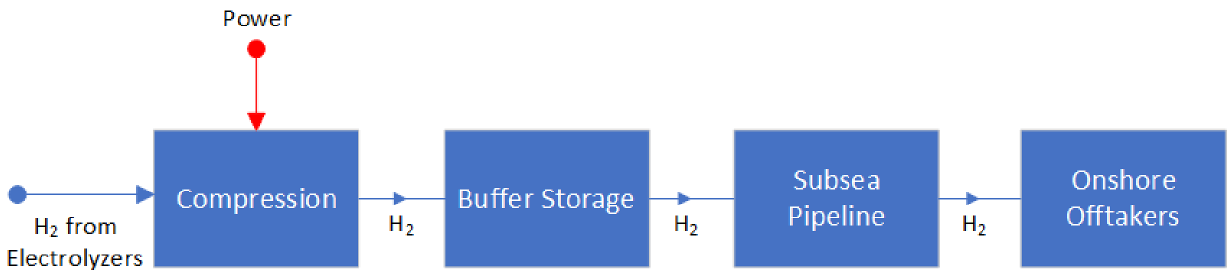

Figure 2-4. Process flow hypothetical business case near onshore H_2 market
Source: AECOM 2022

A parallel O_2 pipeline may be installed if there is a local demand for industrial-scale O_2 volumes. This case minimizes the amount of space needed on the platform(s) for the hydrogen facility.

One of the primary impacts to nearshore and onshore areas would be the construction of the subsea pipeline and the onshore facilities that connect to the pipeline. Onshore facilities could include a connection to an end user, a compressor station, or just a connection to an onshore pipeline network.

Comparison between pipeline and electrical cabling will consider the physical operation and maintenance envelope and provision of adequate width corridors around these transmission / distribution systems. Cable and pipeline protection systems and the ability to maintain and repair infrastructure will need to be considered especially in early projects.

For the 4 GW example facility, this option would require 22 MW of power to compress to typical pipeline pressure and would require 3,300 cubic meters per hour of cooling water assuming a 5°C temperature rise for the cooling water.

2.6.1.2 Hydrogen Liquefaction

A second business case is to liquify the H_2 and transport it via ship to regional users. While liquid H_2 is not yet a significant portion of the hydrogen market, it is seen as a likely part of a large-scale hydrogen economy in a similar way that cryogenic techniques have been developed to transport liquified natural gas (LNG) by sea. The general configuration of this case is shown in Figure 2-5.

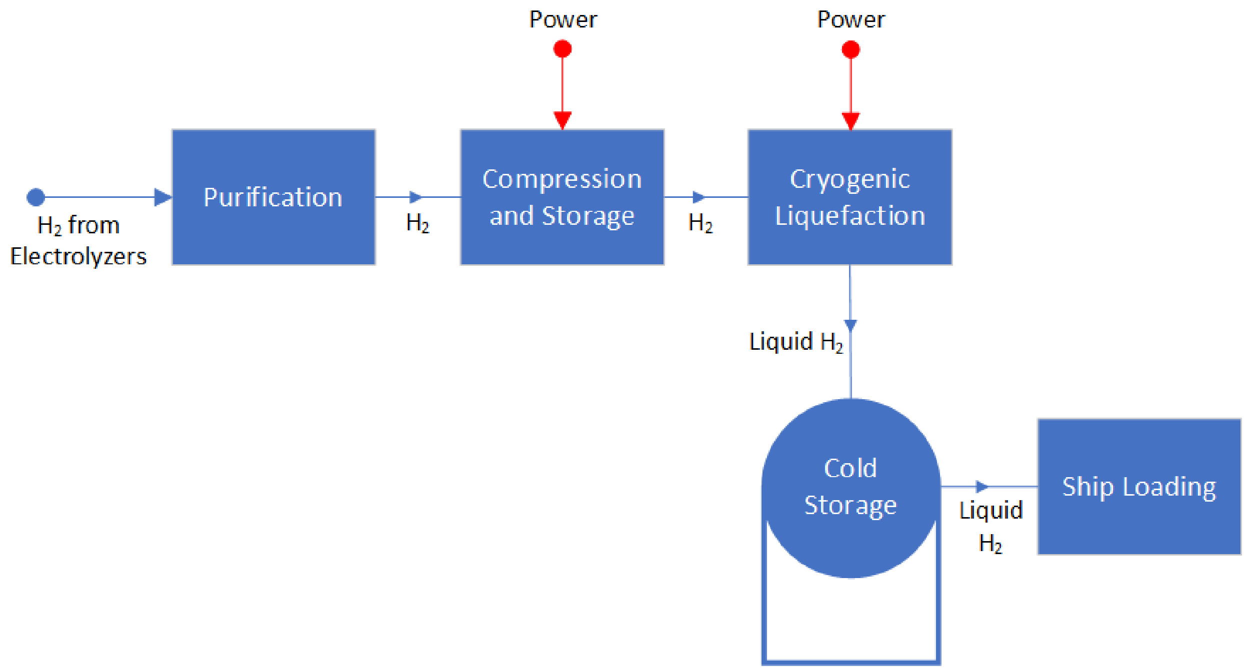

Figure 2-5. Liquid hydrogen block flow diagram
Source: AECOM 2022

In this scenario, hydrogen from the electrolyzer would be purified (dehydrated), possibly compressed, and likely stored in buffer vessels. The liquification process works best at constant steady-state conditions, and the buffer storage will make it easier to operate. Liquified H_2 would be stored in specialized double-walled storage vessels with vacuum insulation. The storage vessels are likely to be spherical, although smaller applications sometimes use a cylindrical "bullet" pressure vessel.

Some liquid hydrogen will boil off in the storage vessels due to heat ingress. The boil off hydrogen may be recompressed and recycled to the inlet of the liquefaction process. Liquid hydrogen will be transferred from storage to specialized hydrogen ships that have spheric storage tanks, similar to current LNG ships. Hydrogen boil-off on the ships may limit the transportation time and distance. Ships may contain onboard refrigeration systems to reliquefy any H_2 that boils off during transit, which would increase the delivery range.

A primary impact to nearshore and onshore areas will be a significant amount of vessel traffic. All the hydrogen produced will be transported by ship. Because liquid hydrogen is well suited for short- to mid-range transportation, most of the vessel traffic is likely to be between the platform and docks in the same region as the platform.

For the 4 GW example facility, next generation hydrogen liquefaction plants would consume 260 to 370 MW of power, which represents 6 to 9% of the total power output from the wind turbines.

2.6.1.3 Green Ammonia Production

A third business case is the production of green ammonia at the H_2-OSW facility. Green ammonia is more energy dense than liquid H_2 and is easier to transport. A modest amount of pressure and/or refrigeration is sufficient to liquify and ship ammonia.

In this scenario, hydrogen from the electrolyzer would be purified (dehydrated), compressed, and likely stored in buffer vessels. The ammonia production process works best at constant steady-state conditions, and the buffer storage will make it easier to operate. The general configuration of this case is shown in Figure 2-6.

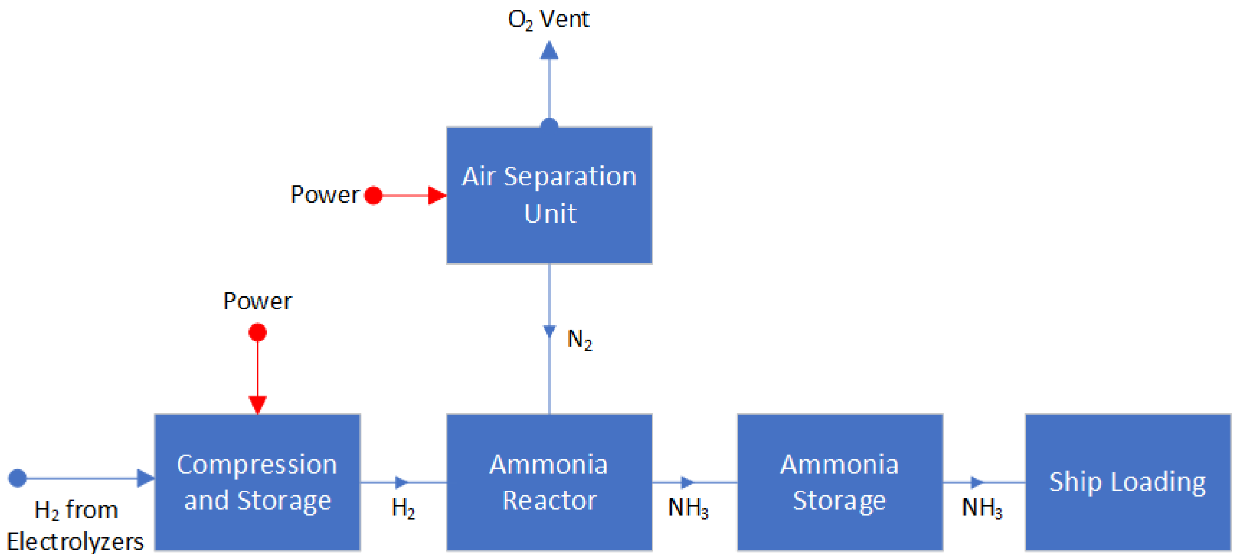

Figure 2-6. Green ammonia block flow diagram
Source: AECOM 2022

Ammonia production also requires a source of nitrogen. If the end users of the green ammonia process are cracking the ammonia to generate H_2 and N_2, then the end users may recycle the N_2 back to the H_2-OSW platform. Another option is for the platform to install a cryogenic ASU, although there is a significant energy demand for this process.

Ammonia can be economically transported long distances. The green ammonia business case enables the H_2-OSW facility to transport and sell ammonia on the global market.

The green ammonia can be transported from the platform via subsea pipeline or ship. The more likely business case would transport ammonia via ship as the primary motivation for using ammonia is to facilitate long-distance transportation. This business case will have a significant amount of vessel traffic, although the vessels may connect to global markets instead of regional markets.

2.6.2 Sizing to Maximize Generation

From the point of view of simple energy efficiency, where feasible, renewable generation directly interconnected to the grid, microgrid, or energy consumer might seem to be the logical choice to supply electrical demand because this avoids both the inefficiency of producing hydrogen, the inefficiency of converting hydrogen back into electrical energy or motive power, and the associated additional costs. However, in more practical terms, the difference in the electrical generation capacity of a renewable source and the market demand for that energy will have implications for the value and amount of electricity produced. Furthermore, the rating of the OSW and the electrolyzer can be matched in a number of ways to maximize and fully use the wind energy at the site.

Traditionally, OSW has been operated to maximize generation with curtailment of the wind generated energy when grid demand is low and lower cost energy or committed energy sources are available. As installed solar and wind energy resources increase and without adequate demand for the electric generation during the low system demand periods, generated renewable energy will continue to be subject to increased curtailment pressure.

Existing grid connected schemes allow a level of flexibility where the developer can choose to sell electricity to the grid, generate hydrogen, or even import electricity if appropriate to suit their operational hydrogen generation profile and business model. As described in Section 5.2, a number of current schemes involve conversion of a percentage of electrical output into hydrogen, which will lead to a higher level of wind-generated energy use balanced with increased operation of the electrolysis plant. The scope to operate such a hybrid configuration may be limited if the windfarm is connected to the electrolyzer either by cable or by pipeline. Dual systems do not appear to be discussed; however, in theory this is not an either/or situation, especially where phased buildouts are likely.

The optimum sizing and configuration of H_2-OSW is therefore more complex than simply maximizing generation, which may be a suitable simplification for OSW. This is because there are more variables associated with hydrogen production to achieve an optimum business case based on reducing the cost of hydrogen to a competitive level and there will be a desire to maximize the capacity factor of the high capital cost electrolyzer. Some level of battery storage may also be involved in this optimization; however, this will involve a high capital cost subsystem.

2.6.3 Refueling Vessels

H_2-OSW facilities may also serve as refueling stations for both deep ocean and coastal vessels. Currently, there are limited options for decarbonizing marine transport. Electrification is impractical for long-distance shipping due to the size and weight of the batteries. Biodiesel may be an option for some vessels, but land availability limits the potential production rates of biodiesel. Green hydrogen is one of the more promising options to decarbonize marine transportation. Green ammonia is also an option. Either fuel could potentially be dispensed from an offshore platform. Using the platform as a refueling station will increase vessel traffic in the area.

2.6.4 Energy Islands with Blue Hydrogen

Although outside the scope of this report, another potential business case that may warrant further research is the use of wind energy in the production of blue hydrogen. The most common type of conventional hydrogen production is steam methane reforming, which uses natural gas and steam as inputs and generates significant CO_2 emissions. If the CO_2 is captured and sequestered, the resulting product is called “blue hydrogen.”

This idea would co-locate natural gas production, steam methane reforming, and wind turbines on an offshore “energy island.” Electricity from the wind turbines would power compressors and other electrical equipment required in the CO_2 capture process. One of the challenges would be to balance the intermittent wind power with the hydrogen production process, which typically operates at continuous steady state conditions.

3 US Offshore H_2 Initiatives

US initiatives in both the public and private sectors are actively promoting wider H_2 use at greater volumes and reduced cost with increased safety toward greater US energy independence, reliability, and global competitive influence by 2030 while addressing US and global net-zero carbon and other climate change policies and goals. Research and development supporting new technologies broadening H_2 implementation across market sectors, with deployment at scale, are a central focus of these initiatives. Research efforts run the spectrum from large-scale H_2 production to consumer-end implementation. These efforts in concert drive accelerated development of production and delivery as well as market readiness in the US, serving to develop the US hydrogen economy as a whole.

These advances suggest the combined roles of BOEM and BSEE for permitting, regulation, and oversight of H_2-OSW may increase rapidly in both scope and scale within the next 8 years. In particular, flexible and responsive updates to assessments of safety, socioeconomic, and environmental impacts for H_2-OSW as new technologies and shifting market forces will be critical for efficient regulation and oversight, as safety advances are offset by increased volume and diversity of development projects. The proportion of subject matter expertise needed within the agencies may progressively shift with accelerating innovation, while a regulatory and oversight framework that is scoped for rapid adaptability to accommodate new technologies will facilitate BOEM and BSEE's capacity to fulfill their mission.

An overview of the most prominent US initiatives currently underway that are driving current research and development and are rapidly evolving, presented in context of policy and technological goals, is provided below.

3.1 US Federal Agency Efforts

3.1.1 US Department of Energy Hydrogen Program and Hydrogen Shot Funding

DOE is the central entity actively engaged in promoting green/renewable energy technologies and implementations toward greater US energy independence and affordability, while supporting net-zero carbon emissions goals and other long-range policies addressing global climate change. Green H_2 development is a significant area of focus for DOE within this framework. The DOE Hydrogen Program[3], led by the Hydrogen and Fuel Cell Technologies Office[4] (HFTO) in the Office of Energy Efficiency and Renewable Energy[5] (EERE), *conducts research and development in hydrogen production, delivery, infrastructure, storage, fuel cells, and multiple end uses across transportation, industrial, and stationary power applications. The program also includes activities in technology validation, manufacturing, analysis, systems development and integration, safety, codes and standards, education, and workforce development* (DOE 2022).

DOE maintains a Hydrogen Program Plan (DOE 2020) as a strategic planning document for accelerating RD&D of hydrogen and related technologies in the US which is periodically updated to expand on previous goals considering recent developments. The plan and the initiatives and policies pursued therein

[3] https://www.hydrogen.energy.gov

[4] https://www.energy.gov/eere/fuelcells/hydrogen-and-fuel-cell-technologies-office

[5] https://www.energy.gov/eere/office-energy-efficiency-renewable-energy

are originally derived from the US Energy Policy Act of 2005 (EPACT), under Title VIII – Hydrogen. Its stated purposes under Section 802 are:

1. To enable and promote comprehensive development, demonstration, and commercialization of H_2 and fuel cells with industry
2. Make critical public investments in building strong links to private industry, universities, and National Labs to expand innovation and industrial growth
3. Build a mature H_2 economy for fuel diversity in the US
4. Decrease the dependency foreign oil and emissions and enhance energy security
5. Create, strengthen, and protect a sustainable national energy economy

Hydrogen Program Plan strategies are predicated on existing and emerging demands for H_2 energy as shown in Figure 3-1. These illustrate the diversity of perceived uses from flagship energy systems to consumer-end private vehicles, while suggesting the possible breadth of scope and scale of US H_2 implementation by 2030.

	Transportation Applications	Chemicals and Industrial Applications	Stationary and Power Generation Applications	Integrated/Hybrid Energy Systems
Existing Growing Demands	• Material-Handling Equipment • Buses • Light-Duty Vehicles	• Oil Refining • Ammonia • Methanol	• Distrubuted Generation: Primary and Backup Power	• Renewable Grid Integration (with storage and other ancillary services)
Emerging Future Demands	• Medium-and Heavy-Duty Vehicles • Rail • Maritime • Aviation • Contruction Equipment	• Steel and Cement Manufacturing • Industrial Heat • Bio/Synthetic Fuels	• Reversible Fuel Cells • Hydrogen Combustion • Long-Duration Energy Storage	• Nuclear/Hydrogen Hybrids • Gas/Coal/Hydrogen Hybrids with CCUS • Hydrogen Blending

Figure 3-1. Existing and emerging demands for hydrogen
Source: Department of Energy (DOE) Hydrogen Program Plan (2020)

The Hydrogen Program Plan defines the program's mission as research, development, and validation of transformational hydrogen and related technologies to meet the above goals. Addressing the mission involves partnering with industry; academia; US National Laboratories; other US federal and international agencies; and stakeholders. Objectives include the following:

- Overcoming technical barriers through basic and applied research and development
- Integrating, demonstrating, and validating "first-of-a-kind" hydrogen and related technologies
- Accelerating the transition of innovations and technologies to the private sector
- Addressing institutional issues including safety concerns, education and workforce development, and the development of codes and standards
- Identification, implementation, and refinement of appropriate strategies for federal programs to catalyze a sustainable market and concomitant benefits to the economy, the environment, and energy security

DOE currently views the role of H_2 within the US energy system as a highly interlinked fuel source with broadly diversified applications as shown in Figure 3-2.

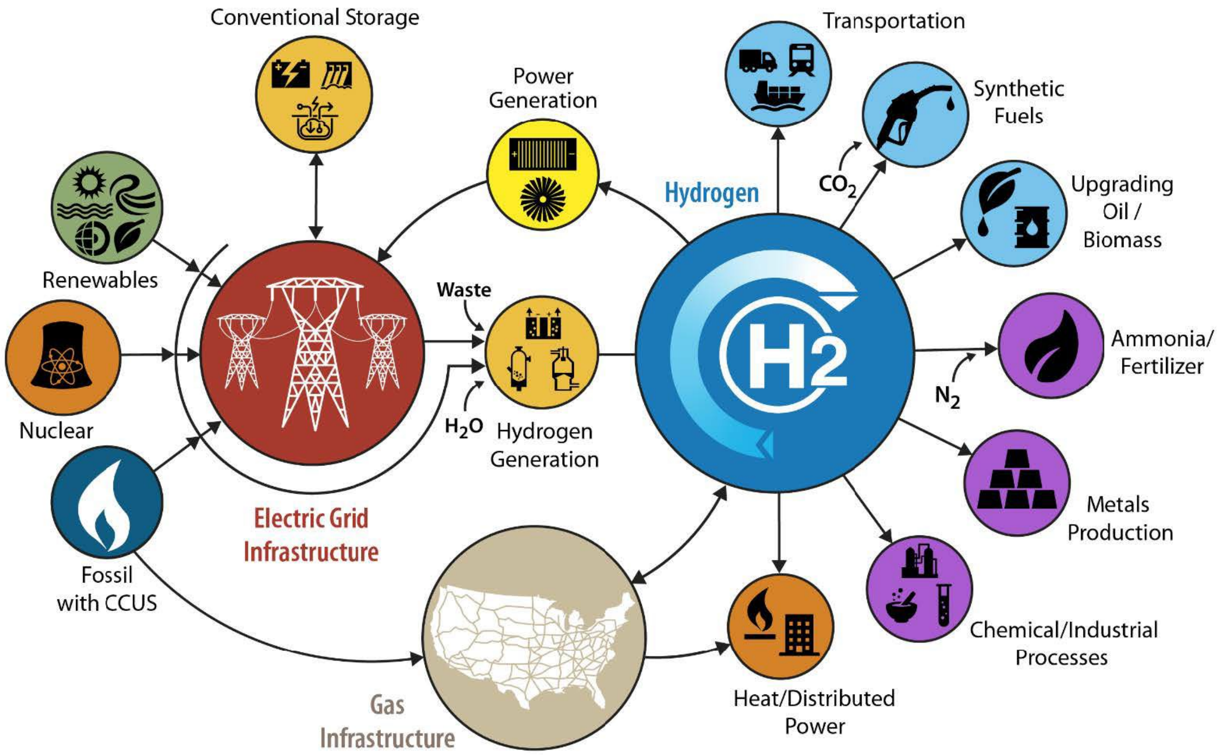

Figure 3-2. Conceptual US H_2 energy system
Source: DOE 2020: Schematic developed over 3 years of stakeholder engagement with national labs and industry; an illustrative example depicting key applications and how hydrogen may be put on par with today's electric and natural gas "grids."

The Hydrogen Program subdivides its RD&D support into five technology focus areas:

1. Hydrogen Production
2. Hydrogen Delivery
3. Hydrogen Storage
4. Conversion
5. Applications

Of these, major developments in the first three focus areas will have the greatest impact on BOEM's regulatory role for H_2-OSW, where developers are likely to continually adopt new approaches as technological advances become market-ready leading up to 2030. While the nature of technological advances will shift with emerging innovations, some existing research initiatives—largely coordinated and funded through DOE—that illustrate the current thrust of technological focus are provided in the following sections. These are included within DOE's four primary areas of funding support: 1) DOE National Laboratories and Field Offices; 2) universities, institutes and nonprofits; 3) industry; and 4) state and local government.

3.1.1.1 Hydrogen Shot Initiative and Funding

"Hydrogen Shot" is the first implementation of DOE's Energy Earthshots Initiative and was launched on June 7, 2021 with a goal of supporting research and development toward a "1-1-1" goal, where market costs for green hydrogen would drop 80% from current levels to $1.00 per 1 kilogram of hydrogen within one decade. The Energy Earthshots Initiative is designed to help achieve net-zero carbon emissions by the year 2050 through development and promotion of dependable, clean, and renewable energy solutions with broader implementation and lowered costs within the coming decade. Hydrogen Shot offers a framework for gathering expert and stakeholder input to identify the most promising of diverse H_2 development pathways, and to help drive and refine Hydrogen Program research funding priorities in context of quantifiable end goals.

While US industries are beginning to incorporate green hydrogen as part of net-zero commitments, current costs (roughly $5.00 per kilogram of H_2) are prohibitive for many potential implementations of H_2 energy, limit the range of market sectors where H_2 could be competitive, and inhibit deployment of H_2 at scale. Specific goals include benchmarks of creating 700,000 new US jobs and generating $140 billion in revenues while reducing GHG emissions by 16%, 2030. *Hydrogen Shot would catalyze innovation in any hydrogen pathway with potential for meeting the targets—such as renewables, nuclear, and thermal conversion—providing incentives to diverse regions across the country* [6]. The current commitment for DOE-funded research informed by the Hydrogen Shot Initiative is $400 million for fiscal year (FY) 2022, increased from $285 million in FY 2021.

3.1.1.2 H2@Scale

H2@Scale is DOE's initiative for implementing funding in support of Hydrogen Shot's 1-1-1 goal through grants and partnerships, frequently through cooperative research and development agreements (CRADA) among US National Laboratories and public, private, or nonprofit partners. CRADA opportunities under H2@Scale may be a viable pathway for leveraging existing BSEE Technology Assessment Program (TAP) and BOEM Environmental Studies Program funds targeting H_2-OSW research (Section 6.2).

3.1.1.3 NREL Hydrogen and Fuel Cells Research

DOE's NREL is a primary DOE entity conducting research under H2@Scale. NREL's current H_2 focus is on hydrogen production and delivery and hydrogen storage technologies. NREL is currently engaged in development of electrolysis approaches optimized for OSW in order to lower costs while improving performance and maintenance profiles, with a current focus on PEM electrolysis. While PEM electrolysis advances would facilitate H_2-OSW, NREL is also committed to diversified hydrogen production, with research expanding beyond electrolysis-driven production through use of biological water splitting, fermentation, biomass conversion, and photoelectrochemical and solar thermal water splitting. While these production alternatives may play a prominent future role, they are more suited to smaller-scale production and are not anticipated to outpace or eclipse electrolysis for readiness or applicability by 2030.

NREL's Hydrogen Storage Characterization and Optimization Effort (HySCORE) research is focused on alternatives to compressed gas or liquified hydrogen storage options. These include analyses of various fuel cell materials including carbon and platinum for improved practical capacity as hydrogen-sorbent storage vectors. While promising, these alternatives are more focused on user-end / fuel cell applications

[6] https://www.energy.gov/eere/fuelcells/hydrogen-shot

and are not anticipated to outpace or eclipse compressed gas and liquified options for upstream H_2 storage by 2030.

3.2 Industry/Private Sector Efforts

Industry and private sector H_2 research is primarily application-driven, to include fuel cell and fueling station topics. Notable recent efforts include Airbus's commitment to developing a green-hydrogen based commercial aircraft for entry into service by 2035, as well as the SpaceX initiative to use green-hydrogen for commercial space travel. In the electric power sector, there is significant interest to repurpose natural gas combined cycle power plants to use green hydrogen. Depending on the model, natural gas turbines will either operate 100% on hydrogen or on a blended composition of natural gas and hydrogen. Hydrogen has lower energy density than natural gas which translates into a nonlinear relationship between volumetric hydrogen content and carbon intensity of a hybrid turbine. A relatively high ratio of hydrogen is required (in excess of 90% blend) to achieve significant CO2 emissions (around 80%). Long-haul heavy duty-transportation is another sector where green hydrogen holds the promise of decarbonization though challenges including upfront cost and lack of refueling infrastructure would have to be overcome to ensure greater adoption.

3.3 Nongovernmental Organization and Academic Efforts

In the US, academic and NGO H_2 research spans large-scale production to consumer-end implementation, with institutions generally emphasizing characteristics of their constituencies. For example, California universities have fully developed programs examining socioeconomics of H_2 implementation (Stanford) and hydrogen fuel cell research for vehicle applications (UC Davis), while the Universities of Wyoming and North Dakota have extensive programs to help their energy sectors best engage large-scale hydrogen production, storage and distribution. Generally, academic research is more heavily weighted toward the application-end, though certain programs are more inclusive. The University of Central Florida has three focus areas: fuel cells, solar powered H_2 production, and H_2 storage and purification. Penn State University (PSU) maintains one of the most diversified portfolios of H_2 research of US universities, including high-level policy and economic research, H_2 production, storage, and use, with a more national to global view of H_2 research. PSU maintains multiple collaborative relationships with US National Laboratories and other public and private partners in pursuing these objectives.

The Southwest Research Institute (SwRI) in Texas operates as an NGO serving government and industry with energy-related research. Like PSU, their hydrogen energy research areas take a more holistic view and span all phases of the hydrogen economy (Figure 3-3), including safety advances. Funding streams include H2@Scale resources for cooperative research with DOE.

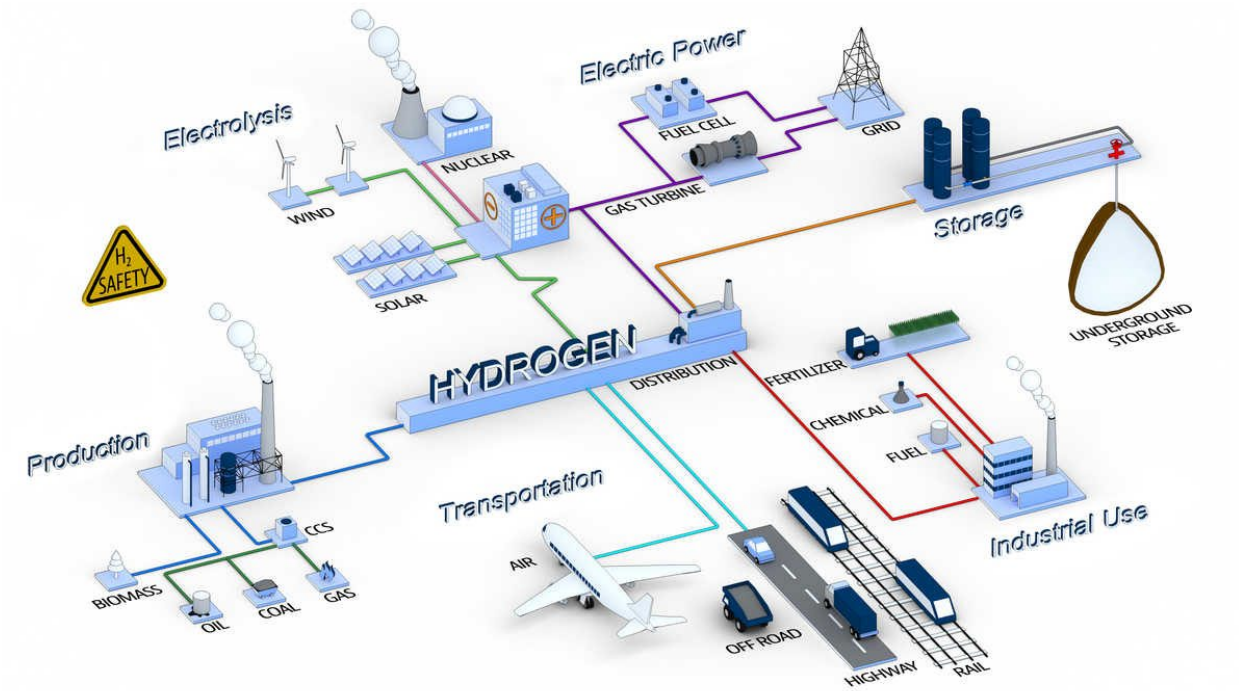

Figure 3-3. SwRI's hydrogen energy research spanning multiple industries and applications
Source: SwRI 2022

4 Gap Analysis—BOEM's Regulatory and Technical Reviewer Role

The following gap analysis is focused on aspects of H_2-OSW that do not readily fit into BOEM's existing technical review and permitting framework/guidance. BOEM will need sufficient breadth of expertise and flexibility to review and regulate hydrogen production across variable and evolving scenarios. The following key areas are considered in this analysis of BOEM's regulatory authority and permitting role: H_2-OSW Programmatic Framework; H_2-OSW Leasing; Financial Assurance; Rent Payments and Operating Fees; H_2-OSW Guidance for Lessees; and H_2-OSW Safety.

4.1 H_2-OSW Programmatic Framework

The 2005 Energy Policy Act amended the Outer Continental Shelf Lands Act (OCSLA) to grant the Department of Interior authority for managing renewable energy and alternate uses on the OCS. In 2007, the *Final Programmatic Environmental Impact Statement for Alternative Energy Development and Production and Alternate Use of Facilities on the Outer Continental Shelf* (Final Programmatic EIS) was completed in accordance with the National Environmental Policy Act (NEPA) to assess the impacts of establishing an Alternative Energy and Alternate Use (AEAU) Program.

As part of this analysis, it is recommended that BOEM consider development of a framework for allowing current and future offshore wind lessees the option for H_2-OSW activities as a complement to their offshore wind development plans. The required considerations for this framework are described in the following sections.

4.1.1 Final Programmatic EIS Review

The 2007 Final Programmatic EIS analyzed the potential impacts for creating an AEAU Program to issue leases, easements, or rights-of-way (ROWs) for alternative energy and for the alternate use of existing OCS facilities for energy and marine related uses anticipated within a 5- to 7-year timeframe. The alternate use of existing OCS facilities is not directly relevant to this H_2-OSW Assessment (Section 4.1.2); therefore, the details of this analysis within the Final Programmatic EIS are not discussed further. The near-term offshore alternative energy technologies anticipated to be proposed for research, demonstration, or commercial use during the 2007-2014 timeframe included wind, wave, and ocean current. The analysis included the identification of impacts associated with technology testing, site characterization, construction, operation, and decommissioning of the selected technologies, as well as an assessment of potential mitigation measures. The impacts were assessed on the following resources in the geographic areas determined to be suitable for the technologies.

- Ocean surface and sediments
- Air quality
- Ocean currents and movements
- Water quality
- Acoustic environment
- Hazardous materials and waste management
- Electromagnetic field (EMF)
- Marine mammals
- Marine and coastal birds
- Terrestrial Biota
- Fish resources and essential fish habitat
- Sea turtles
- Coastal habitats
- Seafloor habitats
- Areas of special concern
- Military use areas
- Transportation
- Socioeconomic resources
- Cultural resources
- Land use and existing infrastructure
- Visual resources
- Tourism and recreation
- Fisheries
- Nonroutine conditions

Alternatives considered in the NEPA analysis were as follows:

- Proposed Action: the establishment of the Alternative Energy and Alternate Use Program on the OCS through rulemaking
- Case-by-Case Alternative: consider individual project proposals for alternative energy or alternate use on a case-by-case basis but not issuing formal regulations
- No Action Alternative: not approve leases, easements, or ROW for any alternative energy facility on the federal OCS or alternate use of existing offshore facilities
- Preferred Alternative: a combination of the proposed action and the case-by-case alternative

In the Record of Decision (ROD) issued in December 2007, the agency selected the Preferred Alternative because it facilitated expedited approvals while a comprehensive program was designed. In support of the ROD, an Environmental Assessment for a Proposed Rule began in 2008 and resulted in the issuance of the *Renewable Energy and Alternate Uses of Existing Facilities on the Outer Continental Shelf Final Rule* (Final Rule) in April 2009, discussed in Section 4.1.2.

4.1.1.1 Hydrogen Implications

As part of the Final Programmatic EIS, the production of hydrogen was classified as unlikely to be economically viable within the assessed timeframe and was therefore not analyzed. However, the document states that if the outlook for hydrogen changes then the agency will revisit the issue. As technology has developed since 2007, this H_2-OSW Assessment is a part of BOEM's effort to revisit hydrogen production on the OCS, particularly as an element of offshore wind energy development. Prior to authorizing H_2-OSW activities, BOEM will need to carry out an assessment for associated leasing and site characterization activities. As in the Final Programmatic EIS, the hydrogen assessment would consider the impacts of H_2-OSW activities expected to occur within a specified timeframe and would be carried out in compliance with NEPA. Considerations for this NEPA review are described in Section 4.1.3.

4.1.2 Regulatory Review

The Final Rule, with an effective date of June 29, 2009, provided the regulatory basis for the comprehensive program envisioned in the Final Programmatic EIS. As such, it establishes procedures for leases, ROW grants, and Right of Use and Easement (RUE) grants for renewable energy production on the OCS and RUEs for the alternate use of OCS facilities for energy or marine-related purposes. In addition, it establishes the obligations for parties that undertake activities as part of a lease or grant and ensures that activities are conducted in a safe and environmentally sound manner. The Federal Register notice for the Final Rule includes background information on the rulemaking process and a discussion providing additional context for each section of the regulations.

In alignment with the Final Programmatic EIS, the Final Rule anticipated wind, wave, and ocean current technologies in the near-term, acknowledging that hydrogen production and other technologies could be proposed in the future. Per the Federal Register Notice, the Final Rule was specifically designed to facilitate "a broad spectrum of renewable energy development, without specific requirements for each type of energy production" and to facilitate updates "to include energy-resource-specific provisions and incorporate by reference appropriate documents" as the program matures. Accordingly, this review concludes that the existing regulations in 30 Code of Federal Regulations (CFR) Part 585 are comprehensive, yet sufficiently broad to facilitate the flexibility to adjust for emerging technologies.

Amendments to the Final Rule were approved as follows:

- **2010 Renewable Energy Alternate Uses of Existing Facilities on the Outer Continental Shelf—Acquire a Lease Noncompetitively**
    - This rule change addresses inconsistencies in the process for issuing noncompetitive leases and an unsolicited request for a lease by removing a redundant notice in the Federal Register to determine if competitive interest exists.
- **2014 Timing Requirements for the Submission of a Site Assessment Plan (SAP) or General Activities Plan (GAP) for a Renewable Energy Project on the OCS**
    - This rule included many minor corrections to the text of the Final Rule in addition to the change establishing that leases and grants will have a preliminary term of 12 months in which a lessee or grantee must submit a SAP or a GAP. This is an extension from the Final Rule requirements of 6 months for competitive leases and grants and 60 days for noncompetitive leases and grants.

Under BOEM's leasing authority for renewable energy activities on the OCS (Energy Policy Act of 2005; Title 30 of the CFR Part 585) more than 20 leases have been awarded since the issuance of the Final Rule. In preparing this section, a review of 30 CFR Part 585 and supporting BOEM documents were completed, with specific sections noted below to highlight applicability to hydrogen activities and identify gaps in covering the unique aspects of hydrogen production, as discussed in Section 2.

4.1.2.1 30 CFR Part 585 Subpart A: General Provisions

The General Provisions in Subpart A discuss the authority granted under OCSLA, the purpose for the regulations, BOEM's responsibilities, a lessee's responsibilities, general information on qualifications for lessees and includes relevant definitions. The addition of hydrogen to an offshore wind lease is adequately covered within the regulations in this subpart and it is not anticipated that any updates or modifications will be required. Specific considerations of how hydrogen fits into Subpart A are as follows.

§ 585.112 Definitions

- **Alternate use and alternate use RUE**—these definitions are specific to the use of an existing facility for activities not covered under this subchapter or other applicable law. Note that this does not apply to hydrogen activities as hydrogen is authorized by this subchapter (although additional NEPA analysis will be required).
- **Best available and safest technology**—this definition is not dependent on any specific technology type and refers to those "technologies that BOEM determines to be economically feasible wherever failure of equipment would have a significant effect on safety, health, or the environment." The definition is applicable to all technology options that could be authorized under this part; specific discussion of potential H_2 failures that could have a significant effect on safety and health are discussed in Section 5.
- **Commercial activities—**this definition provides for a broad range of technology options by including "all activities associated with the generation, storage, or transmission of electricity **or other energy product** from a renewable energy project on the OCS, and for which such electricity or other energy product is intended for distribution, sale, or other commercial use" (emphasis added).
- **Commercial lease**—this covers a lease issued under this part that will facilitate commercial activities and would cover hydrogen production.

- **Commercial operations**—similar to *commercial activities* above, this definition includes "electricity **or other energy product** for commercial use, sale, or distribution on a commercial lease" (emphasis added).
- **Facility**—this definition provides flexibility by encompassing "***any structures; devices; appurtenances****; gathering, transmission, and distribution cables;* ***pipelines; and permanently moored vessels.*** *Any group of OCS installations interconnected with walkways, or any group of installations that includes a central or primary installation with one or more satellite or secondary installations, is a single facility*" (emphasis added). As discussed in Section 2, H_2-OSW could include co-located electrolyzers on individual turbines, co-located electrolyzers on offshore substations or added structures to house the electrolyzers; all these options fit within the definition of a facility. The definition also includes the statement "BOEM may decide that the complexity of the installations justifies their classification as separate facilities." Based on the research carried out for this document, it is not anticipated that addition of hydrogen to an offshore wind facility would add the level of complexity required to trigger this classification. However, BOEM may consider providing clarification on what elements may create the need for a separate facility and how that might impact the permitting process as this is not stipulated in the current regulations.
- **Limited lease**—this definition allows activities supporting the production of energy but those that "do not result in the production of electricity or other energy products for sale, distribution, or other commercial use exceeding a limit specified in the lease." It is possible that BOEM could issue a request for nominations or receive an unsolicited request for a limited lease for technology testing of hydrogen activities.
    - This could be recommended for RR&D funding and represents a key topic for consideration with industry stakeholder (Section 6)
- **Project easement**—this definition provides flexibility for an easement to include a hydrogen pipeline or hydrogen-related support structures by stating "you are entitled as part of the lease for the purpose of installing, gathering, transmission, and distribution cables, **pipelines, and appurtenances** on the OCS as necessary for the full enjoyment of the lease."
- **Renewable Energy**—this definition is broad to allow for technological advancements or additional sources of renewable energy by stating "resources include, but are not limited to, wind, solar, and ocean waves, tides, and current." As discussed above, during development of the regulations hydrogen activities were anticipated to be proposed on the OCS.
- **Site assessment activities**—this definition is broad to allow for various survey activities or technology testing required for any type of renewable energy.

§ 585.115 Documents Incorporated by Reference

- Includes an American Petroleum Institute (API) document - *API RP 2A-WSD, Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms - Working Stress Design.*

§ 585.116 Requests for Information on the State of the Offshore Renewable Energy Industry

- Per this section, BOEM can issue a request for information related to the hydrogen industry and interest in H_2-OSW as a follow-up to this H_2-OSW Assessment. Discussion of additional recommended outreach activities is provided in Section 6.

4.1.2.2 30 CFR Part 585 Subpart B: Issuance of OCS Renewable Energy Leases

The General Lease Information in Subpart B discusses the rights granted with a lease, pre-leasing consultations and areas considered for leasing. The addition of hydrogen to an offshore wind lease is adequately covered within the regulations in this section and it is not anticipated that any updates or modifications will be required. Specific considerations of how hydrogen fits into this section of Subpart B are as follows.

§ 585.200 What rights are granted with a lease issued under this part?

- The lease allows all types of commercial activities (definition includes "transmission of electricity or other energy product" as discussed above) and "other limited activities that support, result from, or relate to the production of energy from a renewable energy source."
- The lease allows one or more project easements without further competition per section (b); easements could be used to bring hydrogen to shore.

§ 585.202 What types of leases will BOEM issue?

- This section permits co-located offshore wind and hydrogen production because it states "BOEM may issue leases on the OCS for the assessment and production of renewable energy and may authorize a combination of specific activities. We may issue commercial leases or limited leases". Hydrogen activities could be proposed within a commercial lease or limited lease. Additional discussion of leasing options for H_2-OSW is provided in Section 4.2.

§ 585.204 What areas are available for leasing consideration?

- BOEM allows leases in "any appropriately platted area of the OCS, as provided in § 585.205, for a renewable energy lease, except any area within the exterior boundaries of any unit of the National Park System, National Wildlife Refuge System, National Marine Sanctuary System, or any National Monument."
- Within the broad geographic constraints of BOEM's leasing areas, offshore wind has its own limitations based on parameters such as water depths, foundation types, and distance from shore; the addition of hydrogen is not expected to add further location constraints. Alternatively, a pipeline carrying hydrogen is not subject to losses with added distance, as with electric transmission lines, and would alleviate this concern for offshore wind projects located further from shore (Section 4.1.3).

In discussions related to this H_2-OSW Assessment, BOEM has indicated that the Pacific Region will be the initial priority for these activities, due in part to a perceived market readiness among West Coast states for introduction and expansion of a H_2 economy.

The Competitive Lease Process in Subpart B discusses initiation of competitive lease issuance, the Call for Information and Nominations, the Area Identification process and the contents of Proposed and Final Sale Notices. The addition of hydrogen to an offshore wind lease is adequately covered within the regulations in this section and it is not anticipated that any updates or modifications will be required. Specific considerations of how hydrogen fits into this section are as follows.

§ 585.211 What is the process for competitive issuance of leases?

- The competitive lease process includes a Call for Information and Nominations (Call), Area Identification to determine areas to be assessed in an environmental analysis, the Proposed Sale

Notice and the Final Sale Notice. The process is applicable to all renewable energy sources that may be proposed on the OCS.

§ 585.213 What must I submit in response to a Request for Interest or a Call for Information and Nominations?

- Subsection (b) requires a description of objectives and the facilities proposed to achieve the objectives; this may be the first indication to BOEM that a potential lessee is interested in pursuing H_2-OSW activities. The benefit would be for BOEM to know that H_2-OSW is being considered before it receives a SAP or COP associated with these activities.

§ 585.214 What will BOEM do with information from the Requests for Information or Calls for Information and Nominations?

- Under this section, BOEM indicates that information will be used to "identify the lease area, develop options for the environmental analysis and leasing provisions (stipulations, payments, terms, and conditions); and prepare appropriate documentation to satisfy applicable federal requirements, such as NEPA, CZMA, the ESA, and the MMPA." In the event that hydrogen is proposed, BOEM can include any relevant H_2-OSW provisions into the site characterization EA and the lease stipulations. However, BOEM should consider including hydrogen as an option during all future leasing activities for offshore wind (additional details are provided in Section 4.5).

§ 585.216 What information will BOEM publish in the Proposed Sale Notice and Final Sale Notice?

- The Proposed Sale Notice (PSN) and Final Sale Notice (FSN) introduce the proposed and final terms and conditions for a lease sale, respectively.

The Competitive Lease Award Process in Subpart B discusses auction formats, bidding systems and steps after a bid is accepted. The addition of hydrogen to an offshore wind lease is adequately covered within the regulations in this section and it is not anticipated that any updates or modifications will be required. Section 4.2 includes additional discussion of H_2-OSW leasing.

The Noncompetitive Lease Award Process in Subpart B discusses unsolicited lease requests, BOEM's actions once receiving an unsolicited lease request and the process for acquiring a noncompetitive lease after a Request for information or a Call. The addition of hydrogen to an offshore wind lease is adequately covered within the regulations in this subpart and it is not anticipated that any updates or modifications will be required.

The Commercial and Limited Lease Terms in Subpart B discusses the timing for leases, extensions and research activities allowed. The addition of hydrogen to an offshore wind lease is adequately covered within the regulations in this subpart and it is not anticipated that any updates or modifications will be required. Specific considerations of how hydrogen fits into this section are as follows.

§ 585.235 If I have a commercial lease, how long will my lease remain in effect?

- The operations term for a commercial lease is 25 years, though the regulations do allow for renewals. An offshore wind project is expected to have a lifecycle of 25-35 years and could potentially be re-powered after that point. The lifecycle of hydrogen storage and handling elements of an H_2-OSW project will match that of the offshore wind turbines, though the electrolyzers have a shorter lifecycle and will likely need to be replaced every six to nine years.

§ 585.236 If I have a limited lease, how long will my lease remain in effect?

- As stated in the definitions above, activities on a limited lease could include technology testing of H_2-OSW or other hydrogen activities. The terms of the limited lease discussed in this section (12-month preliminary term and 5-year operations term) are suitable for hydrogen research or testing.

§ 585.238 Are there any other renewable energy research activities that will be allowed on the OCS?

- Leases, rights-of-way (ROW) grants and rights-of-use and easement (RUE) grants can be issued to federal agencies or states for renewable energy research activities on the OCS. Hydrogen research, with or without an offshore wind component could be proposed under this part, though additional details are discussed under § 585.300 below.

4.1.2.3 30 CFR Part 585 Subpart C: Rights-of-Way Grants and Rights-of-Use and Easement Grants for Renewable Energy Activities

Subpart C discusses ROW grants and RUE grants – authorized activities, requirements for grant holders, obtaining grants and financial requirements. The addition of hydrogen to an offshore wind lease on the OCS is not applicable to the regulations in this subpart, though BOEM could receive proposals for hydrogen-related activities associated with other projects that could require a ROW or RUE grant.

§ 585.300 What types of activities are authorized by ROW grants and RUE grants issued under this part?

- Per (a), the "ROW grant authorizes the holder to install on the OCS cables, pipelines, and associated facilities that involve the transportation or transmission of electricity or other energy product from renewable energy projects. The Final Rule Federal Register Notice states that the ROW applies to "renewable energy not generated on a lease issued under this part", and therefore, it would not apply to an H_2-OSW project on the OCS. However, BOEM could receive an ROW request for a hydrogen pipeline associated with an offshore wind farm in state waters where the pipeline is intended to enter the OCS (similar to the Block Island Wind Farm and the Block Island Transmission System).
- Per (b), the "RUE grant authorizes the holder to construct and maintain facilities or other installations on the OCS that support the production, transportation, or transmission of electricity or other energy product from any renewable energy resource". The Final Rule Federal Register Notice states that the RUE applies to "activities on a lease or other approval not issued under this part (e.g., on a State-issued lease)" and therefore it would not apply to an H_2-OSW project on the OCS.
- Per (c), "you do not need an ROW grant or RUE grant for a project easement authorized under § 585.200(b) to serve your lease" – this section applies to H_2-OSW projects on the OCS and adequately allows for anticipated hydrogen pipeline activities.

4.1.2.4 30 CFR Part 585 Subpart D: Lease and Grant Administration

Subpart D discusses general administrative items including Noncompliance and Cessation Orders, Designation of Operator as well as the assignment, suspension, renewal, termination, relinquishment, contraction and cancellation of a lease or grant. The addition of hydrogen to an offshore wind lease on the OCS is adequately covered within the regulations in this subpart and it is not anticipated that any updates or modifications will be required.

4.1.2.5 30 CFR 585 Subpart E - Payments and Financial Assurance Requirements

The Payments section in Subpart E discusses deposits, rent and operating fees for leases. The addition of hydrogen to an offshore wind lease is adequately covered within this subpart and it is not anticipated that any updates or modifications will be required to the regulations. However, operating fees associated with H_2-OSW will require further consideration, as discussed in Section 4.5. Specific considerations of how hydrogen fits into this section are as follows.

§ 585.503 What are the rent and operating fee requirements for a commercial lease?

- Rent payments for a commercial lease are $3/acre/year (competitive), $.25/acre/year (noncompetitive) "unless otherwise established in the Final Sale Notice or lease." It is not anticipated that H_2-OSW would warrant a change in rent payments, though the regulations do allow for adjustments of the rent "to take effect during the operations term and prior to the commercial generation" per § 585.503(a)(2).
- An operating fee is required when commercial generation of electricity begins on the lease, "or on the date specified by BOEM." An H_2-OSW scenario where wind turbines power on-site hydrogen production and the hydrogen is transported to shore via pipeline would not result in commercial generation of electricity – therefore the start date for the operating fee must be set by BOEM in relation to the start of hydrogen production and delivery.

§ 585.506 What operating fees must I pay on a commercial lease?

- Operating fees are required "on your commercial lease when you begin commercial generation". This section describes the operating fee formula for projects resulting in the generation of electricity, which would not apply to hydrogen production from an H_2-OSW project. § 585.506(e) provides the flexibility to account for hydrogen production – "BOEM will establish the operating fee in the Final Sale Notice or in the lease on a case-by-case basis for: (1) Activities that do not relate to the generation of electricity (e.g., hydrogen production)". Section 4.5 discusses options for establishing operating fees for H_2-OSW.

§ 585.507 What rent payments must I pay on a project easement?

- As discussed above, a hydrogen pipeline associated with H_2-OSW on the OCS will qualify as a project easement, which will have rent of $5 per acre per year based on the size of the easement. It is not anticipated that H_2-OSW would warrant a change in rent payments for project easements, though the regulations do allow for adjustments of the rent to be specified in the Final Sale Notice or lease.

§ 585.508 What rent payments must I pay on ROW grants or RUE grants associated with renewable energy projects?

- A ROW grant would not be associated with an H_2-OSW facility on the OCS, per discussion at § 585.300 above. However, BOEM could have an opportunity to authorize a hydrogen pipeline and the existing regulations provide a framework for assessing rent payments.

The Financial Assurance Requirements for Commercial Leases section in Subpart E discusses the financial assurance associated with commercial leases and requirements for all stages of the lease. The addition of hydrogen to an offshore wind lease is adequately covered within in this subpart and it is not anticipated that any updates or modifications will be required to the regulations. Specific considerations of how hydrogen fits into this section are as follows.

§ 585.515 What financial assurance must I provide when I obtain my commercial lease?

- Before lease issuance, a $100,000 minimum lease-specific bond (or other equivalent financial assurance instrument) guaranteeing compliance with the lease terms and conditions. § 585.515(b) allows for adjustments "to reflect changes in the Consumer Price Index-All Urban Consumers (CPI-U) or a substantially equivalent index if the CPI-U is discontinued" every 5 years from the adoption of the Final Rule – it is not anticipated that H_2-OSW would have any impact on this provision.

§ 585.516 What are the financial assurance requirements for each stage of my commercial lease?

- In addition to the $100,000 lease-specific bond discussed in § 585.515, additional bonds are required as follows:
    - A supplemental bond is required before SAP approval, for an amount dependent upon the "complexity, number, and location of facilities" proposed in the SAP. Therefore, a mechanism exists in the regulations to account for any additional complexity associated with H_2-OSW site assessment activities.
    - A supplemental bond is required before COP Approval, for an amount dependent upon the "complexity, number, and location of all facilities involved in your planned activities and commercial operation" proposed in the COP. Therefore, a mechanism exists in the regulations to account for any additional complexity associated with H_2-OSW projects.
    - A decommissioning bond is required before installing facilities approved in a COP, for an amount dependent upon the anticipated decommissioning costs of the approved facilities. Therefore, a mechanism exists in the regulations to account for any additional complexity associated with H_2-OSW projects.

§ 585.517 How will BOEM determine the amounts of the supplemental and decommissioning financial assurance requirements associated with commercial leases?

- In addition to the methods described in § 585.516, supplemental and decommissioning bonds are based on "estimates of the cost to meet all accrued lease obligations" – providing a mechanism to account for any additional complexity associated with H_2-OSW projects.

The Financial Assurance for Limited Leases, ROW Grants, and RUE Grants section in Subpart E discusses the financial assurance associated with commercial leases and requirements for all stages of the lease. As discussed above, the addition of hydrogen to an offshore wind lease is not applicable to limited leases, ROW grants or RUE grants – therefore, no updates or modifications will be required in this section.

The sections within Subpart E titled Requirements for Financial Assurance Instruments and Changes in Financial Assurance cover specific mechanisms for financial assurance and are not impacted by the proposed activities on the lease – therefore, no updates or modifications will be required in this section.

The Revenue Sharing with States section in Subpart E discusses the 27 percent revenue sharing with eligible coastal states from qualified projects (per subsection 8(g) of OCSLA). Due to the proximity to shore required for revenue sharing, it is unlikely that any H_2-OSW project will qualify; however, the regulations apply adequately to any technology and will not require updates or modifications.

4.1.2.6 30 CFR 585 Subpart F: Plans and Information Requirements

The SAP sections in Subpart F discuss the information requirements, contents, and activities conducted under an approved SAP. The addition of hydrogen to an offshore wind lease is adequately covered within the regulations in this subpart and it is not anticipated that any updates or modifications will be required.

However, BOEM's guidance for and review of SAPs for H_2-OSW projects may require further consideration, as discussed in Section 4.5. Specific considerations of how hydrogen fits into Subpart F are as follows.

§ 585.605 What is a Site Assessment Plan (SAP)?

- A lessee will submit a SAP to propose and describe activities (e.g., installation of meteorological towers, meteorological buoys) for the characterization of the lease and project easement, or to test technology devices. The regulations allow for any type of site characterization activities to be proposed – however, additional NEPA requirements may apply to certain activities per § 585.611.
- Incorporating hydrogen production is not anticipated to require additional site characterization devices – any measurements needed to inform the hydrogen aspect of the project can be collected from a meteorological buoy.
- A SAP must include data from physical characterization surveys (e.g., geological and geophysical surveys or hazards surveys) and baseline environmental surveys (e.g., biological or archaeological surveys) – this requirement will not change for H_2-OSW projects.
- If a lessee proposes hydrogen technology testing devices associated with hydrogen—these could be deemed to be "complex or significant" per § 585.613(a)(1) and would be subject to 30 CFR 585 Subpart G. This requirement is the same for any site characterization facility or technology testing activity deemed to be complex and significant.

§ 585.606 What must I demonstrate in my SAP?

- A SAP must demonstrate that the lessee is "prepared to conduct the proposed site assessment activities in a manner that conforms to your responsibilities listed in § 585.105(a) and that the activities will provide the data necessary for a COP. This requirement is not technology-specific and H_2-OSW projects will fit within the parameters set forth in this part.

§ 585.610 What must I include in my SAP?

- The SAP must include project-specific details on proposed activities, technology to be used, schedule of activities, decommissioning and site clearance procedures and results of on-site surveys. These content requirements are not technology-specific and H_2-OSW projects will fit within the parameters set forth in this part.

§ 585.611 What information and certifications must I submit with my SAP to assist BOEM in complying with NEPA and other relevant laws?

- A SAP must include "detailed information to assist BOEM in complying with NEPA and other relevant laws as appropriate". A SAP covering "an area in which BOEM has not previously reviewed site assessment activities under NEPA or other applicable federal laws, must describe those resources, conditions, and activities… that could be affected by your proposed activities or that could affect the activities proposed".
- A SAP covering an area that has considered site assessment activities (through NEPA) and that proposes activities "significantly different than those previously anticipated" then BOEM may determine that additional information must be submitted to support a NEPA analysis. H_2-OSW site characterization activities are not expected to be "significantly different than those previously anticipated" for recent offshore wind site characterization EAs.

The COP sections in Subpart F discuss the information requirements, contents, and activities conducted under an approved COP. The addition of hydrogen to an offshore wind lease is adequately covered within the regulations in this subpart and it is not anticipated that any updates or modifications will be required.

However, BOEM's guidance for and review of COPs for H_2-OSW projects may require further consideration, as discussed in Section 4.5. Specific considerations of how hydrogen fits into Subpart A are as follows.

§ 585.620 What is a Construction and Operations Plan (COP)?

- A COP includes "construction, operations, and conceptual decommissioning plans under your commercial lease, including your project easement" and descriptions of all planned facilities including those located onshore. Whether an H_2-OSW project proposes hydrogen production offshore or onshore, all aspects of the hydrogen production facilities must be fully described within the COP.

§ 585.626 What must I include in my COP?

- The COP requirements are not technology-specific – the included data must adequately describe conditions in the project area and provide the information necessary to carry out the NEPA EIS. A more complex project will result in a more complex COP, but the underlying requirements per the regulations will not change.

The General Activities Plan (GAP) sections in Subpart F discuss the information requirements, contents, and activities conducted under an approved GAP for limited leases, ROW grants and RUE Grants. The addition of hydrogen to an offshore wind lease is adequately covered within the regulations for limited leases in this subpart and it is not anticipated that any updates or modifications will be required. Specific considerations of how hydrogen fits into this section are as follows.

§ 585.640 What is a General Activities Plan (GAP)?

- A GAP will describe activities on a limited lease or grant including "proposed construction, activities, and conceptual decommissioning plans for all planned facilities, including testing of technology devices and onshore and support facilities that you will construct and use for your project, including any project easements". As discussed above, limited leases could be used for H_2-OSW, but an H_2-OSW project on the OCS will not require a ROW or RUE.

§ 585.645 What must I include in my GAP?

- The GAP requirements are not technology-specific—it must include "results of geophysical and geological surveys, hazards surveys, archaeological surveys (if required), and baseline collection studies (e.g., biological)" to fully characterize the project area.

The Cable and Pipeline Deviations sections in Subpart F discuss the lessee's responsibilities in case of a deviation from a COP or GAP and includes air quality requirements. The addition of hydrogen to an offshore wind lease is adequately covered within the regulations in this section and it is not anticipated that any updates or modifications will be required. Specific considerations of how hydrogen fits into this section are as follows.

§ 585.658 Can my cable or pipeline construction deviate from my approved COP or GAP?

- Lessees "must make every effort to ensure that all cables and pipelines are constructed in a manner that minimizes deviations from the approved plan under your lease or grant"—§ 585.658 (b)-(d) discuss the implications of changes before and after construction. This requirement would apply to an electricity cable or pipeline associated with H_2-OSW the same as any other technology.

§ 585.659 What requirements must I include in my SAP, COP, or GAP regarding air quality?

- Lessees must comply with the Clean Air Act—BOEM will make air quality determinations for projects in the western Gulf of Mexico and projects located elsewhere on the OCS are subject to the Environmental Protection Agency (EPA) regulations at 40 CFR 55. This requirement is not technology-specific, though there will be specific air quality considerations for H_2-OSW as discussed in Section 4.5.

4.1.2.7 30 CFR 585 Subpart G: Facility Design, Fabrication, and Installation

The Reports and Certified Verification Agent (CVA) sections in Subpart G discuss the requirements for the Facility Design Report (FDR), the Facility Installation Report (FIR) and the role of the CVA. The addition of hydrogen to an offshore wind lease is adequately covered within these regulations and it is not anticipated that any updates or modifications will be required. Specific considerations of how hydrogen fits into this section are as follows.

§ 585.700 What reports must I submit to BOEM before installing facilities described in my approved SAP, COP, or GAP?

- An FDR and FIR are required before fabrication and installation of "facilities described in your approved COP (§ 585.632(a)) and, when required by this part, your SAP (§ 585.614(b)) or GAP (§ 585.651)". A project deemed to be "complex or significant" under a SAP or GAP will trigger this requirement. Dependent upon specific proposal, H_2-OSW activities could be deemed by BOEM to be complex and significant.

§ 585.701 What must I include in my Facility Design Report?

- The FDR requires "specific details of the design of any facilities, including cables and pipelines that are outlined in your approved SAP, COP, or GAP". The report requirements are general and designed to encompass the information needed for BOEM to review projects utilizing various technologies – the complexity of the report will be dependent upon the facilities proposed.

§ 585.702 What must I include in my Fabrication and Installation Report?

- The FIR requires a description of how "facilities will be fabricated and installed in accordance with the design criteria identified in the Facility Design Report; your approved SAP, COP, or GAP; and generally accepted industry standards and practices"—this report is not technology-specific.

§ 585.705 When must I use a Certified Verification Agent (CVA)?

- A CVA is required to certify the FDR, FIR, and any project modification reports, as well as to ensure that "facilities are designed, fabricated, and installed in conformance with accepted engineering practices." A CVA for an H_2-OSW project may require additional qualifications than those generally considered for offshore wind. BOEM will need to take this into consideration when reviewing nominations for CVAs.

4.1.2.8 30 CFR 585 Subpart H: Environmental and Safety Management, Inspections, and Facility Assessments for Activities Conducted Under SAPs, COPs and GAPs

Subpart H discusses requirements for Safety Management Systems (SMS), maintenance, equipment failure, inspections and incident reporting. The addition of hydrogen to an offshore wind lease is adequately covered within these regulations and it is not anticipated that any updates or modifications will

be required. H_2-OSW projects will include items that are not usually part of an OSW electrical generation facility and will require additional consideration with respect to safety (Section 4.6).
Specific considerations of how hydrogen fits into this section are as follows.

§ 585.810 What must I include in my Safety Management System?

- A SMS must be submitted with a COP (and may be required for activities deemed complex and significant in a SAP or GAP). Section 4.6 discusses the safety risks for H_2-OSW and hydrogen safety regulations from other agencies that could be used to support BOEM's development of H_2-OSW guidance documents.

4.1.2.9 30 CFR Part 585 Subpart I: Decommissioning

In alignment with the goals of the regulations, the general decommissioning requirements are broad and designed to cover any facility that is authorized by BOEM and proposed within a SAP, COP, or GAP. The decommissioning requirements and financial assurance (Section 4.3) are directly dependent on the facilities proposed and approved under a lease. Any additional risks or concerns associated with H_2-OSW would therefore be addressed in the project-specific decommissioning plan and decommissioning bond.

4.1.2.9.1 30 CFR 585 Subpart J: Rights of Use and Easement for Energy- and Marine-Related Activities Using Existing OCS Facilities

Per the Final Rule (FR) notice, this was designed to facilitate alternate uses of existing platforms, specifically activities that are not otherwise regulated. The example of an "existing oil and gas platform in the Gulf of Mexico as an offshore emergency rescue training facility" is used to represent a use that is not regulated. Hydrogen production is regulated under 30 CFR Part 585 and therefore would not qualify for an Alternate Use RUE. However, an installed H_2-OSW facility could qualify as an existing platform for an Alternate Use RUE in the future.

4.1.3 H_2-OSW NEPA Analysis

This H_2-OSWAssessment focuses on hydrogen activities that are co-located with offshore wind and although BOEM has authority to regulate renewable energy sources on the OCS—the only technologies assessed through NEPA for leasing are wind, wave and ocean current. Therefore, for BOEM to advance leasing for H_2-OSW activities, additional NEPA analyses will be required. Following the process for NEPA analyses of existing leases, shown in Figure 4-1, an offshore wind project with an approved COP is the subject of several NEPA processes.

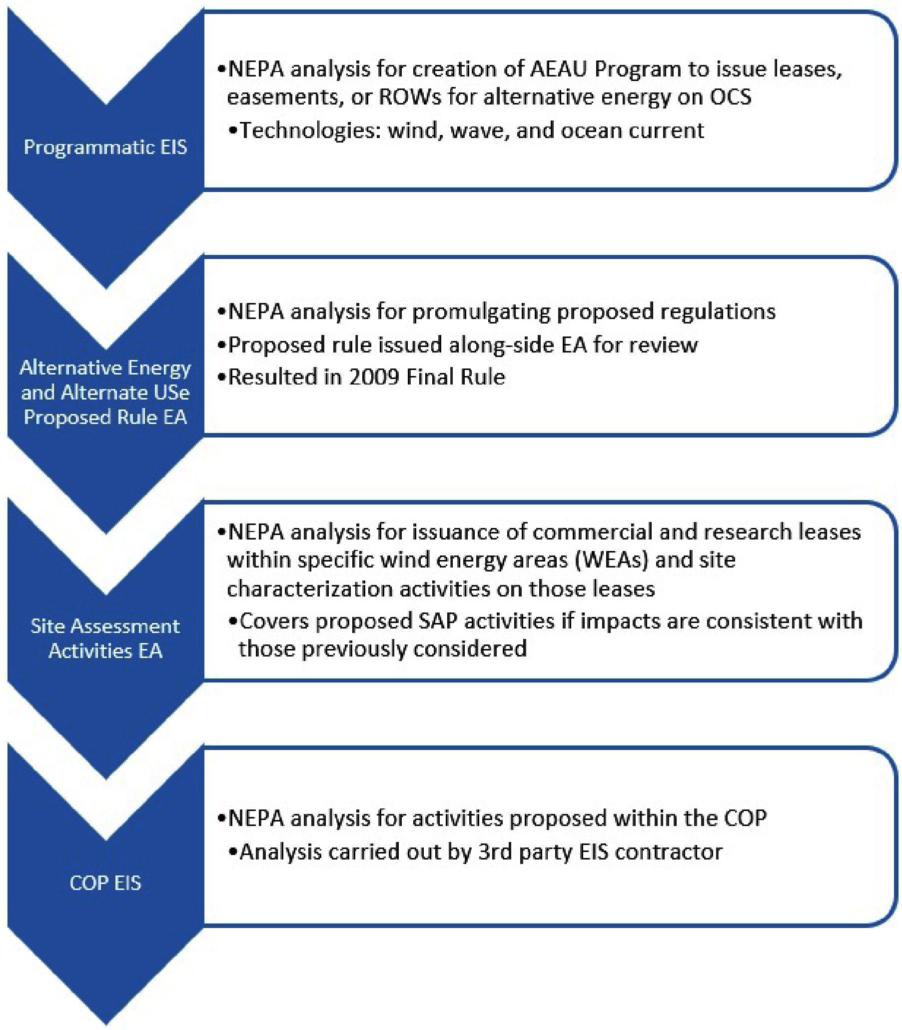

Figure 4-1. Offshore wind leasing NEPA analyses
Source: AECOM 2022

The Council on Environmental Quality (CEQ) issued updated NEPA Implementing Regulations (40 CFR 1500) in 2021. Per § 1501.1, federal agencies assess applicability of NEPA for a proposed activity or decision and make a determination in their agency NEPA procedures or on an individual basis. The 2021 NEPA Implementing Regulations state that federal agencies must revise their NEPA procedures, per § 1507.3, by September 14, 2023. The current Department of the Interior NEPA procedures are described in Department Manuals (DMs). 516 DM 15, effective on May 27, 2004, covers the Minerals Management Service. Per 15.4, the DM states that approval of offshore lease sales qualify as "major actions normally requiring an EIS"—it should be noted that this DM was written prior to the 2005 EPAct and was therefore considering oil and gas leases, not renewable energy leases. This DM does provide a precedent, along with the fact that a Programmatic EIS was prepared for leasing in 2007; however, the 2007 document covered both the establishment of the AEAU Program and the specific technologies covered. If these precedents do not automatically require an EIS, it could be possible for the addition of hydrogen as a technology option for leases to undergo an EA and receive a FONSI. However, with the near-term CEQ requirement and the longer-term prospect of moving forward on H_2-OSW leasing, it is recommended that BOEM consider the addition of leasing for hydrogen and other renewable technologies when updating NEPA DMs.

Following the structure of the Final Programmatic EIS, the NEPA analysis for H_2-OSW leasing would consider impacts on technology testing and site characterization; construction, operations and decommissioning; and mitigation measures. Because these impacts have been assessed previously for wind—the assessment will only need to focus on hydrogen technology.

4.1.4 Overview of Statutory Authority and Regulations of Other Federal Agencies

Regulations within federal regulatory space relevant for H_2 production and distribution comprise both H_2-specific guidance, as well as more general guidance applicable to natural gas or to hazardous materials. Development and refinement of relevant regulations and statutes is likely to continue throughout the next decade as H_2 increases as a proportion of the US energy marketplace and as emerging technologies, implementations, and lessons learned require. An overview of existing regulatory guidance outside of BOEM-specific requirements that are relevant for H_2-OSW are provided in the following sections.

4.1.4.1 Environmental Protection Agency (40 CFR Part 98: Subpart P)

As a green hydrogen production approach using OSW, H_2-OSW in itself would not meet threshold requirements administered through the Environmental Protection Agency (EPA), which regulates emissions and reporting requirements for greenhouse gas (GHG) emissions during the production of hydrogen. Under 40 CFR Part 98 Subpart P, GHG emissions from H_2 production at the production source, within a hydrogen production source category, is defined as facilities producing hydrogen gas to be sold as a product to other entities. While potential future hybrid implementations that include H_2-OSW with grey or blue hydrogen production might be subject to GHG reporting under Subpart P, H_2-OSW alone will not be subject to these requirements. If a development project planned to use H_2 produced on site, for example for combustion generating heat supporting other facility operations, NO_2 and N_2O might be emitted and reportable as GHG.

4.1.4.2 US Occupational Safety and Health Administration (OSHA)

Existing regulations specific to H_2 storage are covered under 40 CFR Part 1910 Subpart H for hazardous materials, administered by OSHA (§ 1910.103 Hydrogen). However, these regulations are written specifically for consumer-end implementations of hydrogen energy and would not cover offshore H_2-OSW storage. More general requirements for compressed gases are therefore applicable.

DOI issued a policy statement, effective October 18, 2019, that clarifies the role of the DOI in regulating workplace safety and health conditions on renewable energy facilities on the OCS. According to the statement, DOI is the principle federal agency for regulation and enforcement of safety and health requirements for OCS renewable energy facilities. Therefore, OSHA will have a nonregulatory role though DOI will collaborate and consult with OSHA on workplace safety and health standards. As per BOEM-BSEE Memorandum of Agreement (Dated December 22, 2020), BSEE, on behalf of BOEM is providing safety oversight and recommending related enforcement actions for OCS renewable energy facilities.

4.1.4.3 US Coast Guard

The Coast Guard regulates facilities transferring oil or hazardous material in bulk under 33 CFR 154, which could apply to hydrogen facilities; however, this specifically does not include any *"offshore facility operating under the jurisdiction of the Secretary of the Department of Interior."* In addition, under Title 46, the USCG regulates vessels and marine safety. As outlined in the 2019 policy statement described above, the DOI will continue to collaborate with the Coast Guard to share relevant safety and training information to promote safety while the USCG will maintain its regulatory and enforcement role for worker safety on vessels.

4.1.4.4 US Department of Transportation – Pipeline and Hazardous Materials Safety Administration

The Department of Transportation (DOT) regulates the transportation of hazardous materials under 49 CFR Subpart C – including specific requirements for transportation via rail, aircraft, vessel and highway – with hydrogen specifically included in the Table of Hazardous Materials and Special Provisions. The DOT also regulates pipeline safety under 49 CFR Part 192 including the "minimum safety requirements for pipeline facilities and the transportation of gas, including pipeline facilities and the transportation of gas within the limits of the OCS" though there are conditions for applicability on the OCS and hydrogen gas is not specifically mentioned.

In 2020, DOT and BSEE signed an updated Memorandum of Understanding (MOU) on OCS pipelines stating that "DOI has authority over upstream producer-operated pipelines, and DOT has authority over downstream transporter-operated pipelines."[7] The MOU clarifies the statutory and regulatory roles of each agency as well as provisions for rulemaking, consultations and inspections.

4.1.4.5 Electrical Codes

Depending on certain factors, a lessee may follow either NFPA 70 or IEC standards. If the proposed platform is considered a deep-water rig, then it is a vessel; vessels typically follow IEC standards. Shallow-water rigs are more likely to follow NFPA 70. Any onshore facilities that are included in the project scope will be required to follow NFPA 70.

NFPA 70 regulates the type of electrical equipment used by defining the area classification. This method uses the composition of the hazardous material present and the probability that it is present to determine the appropriate equipment and installations. Hydrogen is categorized as a Class 1, Group B gas. If the electrical equipment is within 5 feet of a vent or if hydrogen is normally vented to atmosphere, the electrical equipment needs to be Class 1, Division 1. If the electrical equipment is within 10 feet of a vent or leak point and hydrogen is only vented in emergencies or in the case of leakage, the electrical equipment can be Division 2.

Electrical equipment in both divisions must be hermetically sealed and non-sparking. Division 1 equipment also must be explosion proof and intrinsically safe. Hydrogen also has autoignition point of 585°C. All electrical equipment is required to have a surface temperature under 585°C to prevent an explosion.

4.2 H_2-OSW Leasing

Following a positive finding through NEPA for H_2-OSW leasing, BOEM could incorporate this option into future leasing opportunities and provide the option for existing lessees to include a hydrogen option as a lease amendment. This section provides details for how BOEM can advance these options.

4.2.1 Existing Leases

Existing OSW leases have been through the Planning and Analysis phase of the BOEM process, which includes extensive stakeholder engagement through an Intergovernmental Task Force (Task Force) and

[7] https://www.bsee.gov/sites/bsee.gov/files/mou-est-17430-doi-dot-outer-continental-shelf-pipelines-mou-2020-12-22.pdf

the preparation of an Environmental Assessment (EA). Both the Task Forces and EA analyses specifically considered the impacts of OSW leasing and associated site characterization activities, but not impacts specific to hydrogen production.

If an existing lessee proposed hydrogen production as an alternative offtake option for a planned offshore wind farm, then BOEM will address this additional activity within the lease and assessed within the required SAP and COP. Following a positive EA finding for hydrogen production leasing and site characterization activities, BOEM could provide a lease amendment, with appropriate lease stipulations, to an existing offshore wind lease allowing for these activities contingent upon an approved SAP and COP.

H_2-OSW could be incorporated into a lease as follows:

- Include H_2-OSW in Addendum A as a renewable energy resource authorized by the lease
- Include H_2-OSW in rent and operating fee calculations in Addendum B (if determined to be different from the base OSW rent/operating fee)
- Include H_2-OSW-appropriate lease stipulations, allowing for these activities contingent upon an approved SAP and COP Existing lessees could similarly opt-in for H_2-OSW activities on their current lease by executing an H_2-OSW Lease Amendment.

4.2.1.1 Competitive Interest

As part of the leasing process, BOEM determines if competitive interest exists and then based on that determination, the leasing will either move forward noncompetitively or through the competitive lease process. For existing offshore wind leases, competitive interest was sought for offshore wind activities and not hydrogen activities. Therefore, if a current OSW lessee proposes an H_2-OSW project, BOEM must determine if it wants to access competitive for the proposed activity.

4.2.2 Future Leases

The addition of hydrogen production as an offtake option for future OSW leases would require its incorporation into the Planning and Analysis phase of the BOEM process and the discussions of the Intergovernmental Task Forces. Hydrogen and offshore wind would be considered during the EA for the wind energy areas; hydrogen-specific conditions can be included in the PSN and FSN; and the auction format and operating fees can be selected based on H_2-OSW project characteristics.

4.2.2.1 Supplemental Bond

When BOEM approves a renewable energy project SAP or COP, a supplemental bond or financial assurance is required in addition to the minimum lease specific bond as specified in 30 CFR Part 585.516. The supplemental bond amount is determined based on the complexity, location, and number of facilities involved in the site assessment activities as well as the planned commercial operation. A co-sited or co-located hydrogen production facility will likely increase the complexity of a project; therefore, requirements for supplemental bonds will have to be adjusted accordingly.

4.2.2.2 Decommissioning Bond

Before BOEM allows installation of facilities approved in a SAP or a COP, it may require a decommissioning bond or other financial assurance in an amount based on anticipated decommissioning costs as discussed in 30 CFR Part 585.516. Platforms, installations, and devices for hydrogen production that are permanently or temporarily attached to the seabed could incur additional decommissioning costs. BOEM will require that these costs are covered through the decommissioning bond or similar financial assurance mechanisms.

In line with the BOEM/BSEE Memorandum of Agreement (MOA) dated December 2, 2020, BSEE will likely have a role in ensuring compliance with lease terms and relinquishment of leases. The MOA established a framework for coordination between the two bureaus for regulating OCS renewable energy activities.[8] Per the MOA, BSEE will provide support with decommissioning and site clearance plan review as well as decommissioning cost estimates, while BOEM will be responsible for issuing specific regulatory actions.

The general requirements for decommissioning of renewable and alternative energy structures, described in 30 CFR Part 585.902, requires removal of all facilities and clearing the seafloor of all obstructions within 2 years of lease termination. Pursuant to the National Fishing Enhancement Act (Public Law 98-623, Title II), the National Oceanic and Atmospheric Administration (NOAA) developed the National Artificial Reef Plan that established a reef-permitting system. The Rigs to Reef Program managed by BSEE provides a framework for the oil and gas lease holders in the Gulf of Mexico to reef the structures either in-place or at a designated location (in coordination with an approved state specific artificial reef program). Once the proposed structure and reef site have been permitted, the state and project operator negotiate the terms of an agreement for its donation to the state. In most cases, half of the cost benefits to the operator from reefing a structure is donated to the state's artificial reef program. Once the technical and financial closure for reefing the structure is achieved, the operator is released from decommission bonding requirements.

Extending the Rigs to Reef option to renewable energy leases and projects (including hydrogen facilities) will result in significant decommissioning cost savings while preserving and supporting marine life as an artificial reef. The decommissioning bond for complete removal of renewable energy generation and associated structures will still hold.

4.3 Rent Payments and Operating Fees

An assessment of the rent payments and operating fees associated with offshore wind leases would be required as part of BOEM's role with consideration of any changes required for H_2-OSW. Currently, rent payments for offshore wind are $3 per acre per year (competitive), $0.25 per acre per year (noncompetitive) and then once commercial generation of electricity begins on the lease, an operating fee is required. Per 30 CFR Part 585.516, the operating fee rate for a lease is $0.02 for each year; however, the regulations note that this may change for new technologies.

4.3.1 Overview of Existing OSW Rent Structure

An amendment to the Outer Continental Shelf Lands Act (OCSLA) under the Energy Policy Act of 2005, authorized US Department of Interior Office of Natural Resources Revenue (ONRR) to collect several types of revenues from offshore wind leasing and operation, including bonuses, rents, operating fees, and similar payments made in connection with the project or project area.

4.3.1.1 Bonus Bids

When BOEM auctions offshore wind lease areas, the winning bidder pays a bid amount (bonus bid) to the federal government. The bonus bid amount depends on the competitive interest in a lease area. Co-siting

[8] MOA between BOEM and BSEE dated Dec 2, 2020. https://www.boem.gov/sites/default/files/documents/renewable-energy/BOEM-BSEE-Renewable-Energy-MOA_0.pdf

or co-locating a hydrogen production facility with an offshore wind project is unlikely to impact the bonus bids.

4.3.1.2 Rents

Under BOEM regulations, prior to the stage when a project begins commercial operations, the lessee pays a rent of $3 per acre on commercial offshore wind leases. In addition, pursuant to 30 CFR Part 585.508, for each RUE grant that BOEM approves, a fee of $70 for each nautical mile is assessed. Additional ROW grant outside the 200-foot-wide corridor incurs an additional $5 per acre. A hydrogen pipeline can be permitted as either an RUE or an ROW grant. In both instances, the existing regulations provide a framework for assessing rent payments.

4.3.2 Operating Fees

The lessees are required to pay an operating fee on the electricity produced from an operating offshore wind facility. This fee is based on the nameplate capacity of facility, a capacity factor representing the anticipated project efficiency (accounting for generation intermittency), and the average wholesale price of electricity in the state where the transmission cable makes a landfall. The operating fee formula is specific to electricity generation from OCS renewable energy projects. OCS oil and gas regulations described in 30 CFR 560 provides an alternative framework for assessing royalties for natural gas production that can be applied to hydrogen production and transportation onshore. Oil and gas leases have a fixed royalty rate, no lower than 12.5%, applicable to the value of natural gas sold, net of certain transportation, and processing costs.[9] Similar to oil and gas leases, royalty rates for life of the project can be defined for an offshore wind lease with a proposal for hydrogen production. Producing hydrogen using offshore wind is a novel technology and the risk associated with commercial deployment are relatively undetermined. The Department of the Interior (DOI) has the authority to suspend, waive, or reduce royalties collected from oil and gas resources on the OCS. If needed, DOI can adopt this approach to grant a royalty waiver for hydrogen production, at least in the initial years.

In case an offshore wind project produces both electricity and hydrogen, the project operating fee can be calculated separately for two outputs using the formulas discussed above, based on metered production of each resource.

4.4 H_2-OSW Project Structure

4.4.1 Offshore Co-sited/Co-located Facility

Financial assurance may be required at various stages of leasing and development of a hydrogen project. The scope of financial assurance will depend on siting of a hydrogen production facility either on site, coupled, or co-located with an offshore wind project or an onshore facility that uses OSW generation to produce green H_2. The pipeline can be permitted as part of the project easement authorized under 30 CFR Part 585.200(b). The on-site electrolysis production facility for hydrogen may require additional financial assurance depending on the permitting scenario.

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[9] For example, if an operator produces and sells $1,000 of natural gas on a federal lease during a given month, application of the minimum royalty rate of 12.5% would result in $125 royalties owed to the federal government for that month's production.

In cases where H_2-OSW is permitted as a unified project, financial assurance would be covered under 30 CFR Part 585 where:

- Hydrogen is a potential renewable energy resource covered by 30 CFR Part 585
- Commercial activities: this definition provides for a broad range of technology options by including "*all activities associated with the generation, storage, or transmission of electricity or other energy product from a renewable energy project on the OCS, and for which such electricity or other energy product is intended for distribution, sale, or other commercial use*"
- § 585.516 What are the financial assurance requirements for each stage of my commercial lease?
    - In addition to the $100,000 lease-specific bond discussed in § 585.515, additional bonds are required as follows:
        - A supplemental bond is required before SAP approval, for an amount dependent upon the "complexity, number, and location of facilities" proposed in the SAP. Therefore, a mechanism exists in the regulations to account for any additional complexity associated with H_2-OSW site assessment activities.
        - A supplemental bond is required before COP approval, for an amount dependent on the "complexity, number, and location of all facilities involved in your planned activities and commercial operation" proposed in the COP. Therefore, a mechanism exists in the regulations to account for any additional complexity associated with H_2-OSW projects.
        - A decommissioning bond is required before installing facilities approved in a COP, for an amount dependent on the anticipated decommissioning costs of the approved facilities. Therefore, a mechanism exists in the regulations to account for any additional complexity associated with H_2-OSW projects.
- § 585.517 How will BOEM determine the amounts of the supplemental and decommissioning financial assurance requirements associated with commercial leases?
- In addition to the methods described in § 585.516, supplemental and decommissioning bonds are based on "estimates of the cost to meet all accrued lease obligations" providing a mechanism to account for any additional complexity associated with H_2-OSW projects.

4.4.1.1 Onshore H_2 Generation

In a scenario where hydrogen is produced at an onshore facility using offshore wind power, no additional financial assurance will be required for the hydrogen production facility. Existing financial assurance applicable for renewable and alternative energy sources discussed in 30 CFR Part 585.515 will be sufficient to cover the project. The US coastal state where the production facility is sited may require additional financial assurance.

> Before BOEM issues a commercial lease, the lessee is required to provide a minimum $100,000 lease specific bond, or another financial assurance instrument of the same amount. The minimum financial assurance bond is adjusted to the consumer price index, every 5 years.

4.5 H_2-OSW Guidance for Lessees

BOEM's guidance documents provide additional direction to lessees on the various regulations and activities anticipated to be carried out under renewable energy leases. With the addition of H_2-OSW, existing guidance documents may need to be updated and others may need to be created. This section considers areas of intersection between existing guidance documents and the necessary guidance needed for H_2-OSW technology.

4.5.1 Applicability of Existing Guidance Documents to H_2-OSW

The extensive requirements for SAPs and COPs under 30 CFR 585 cover the broad requirements for H_2-OSW, but specific aspects of the technology and potential impacts will be considered as well.

The SAP requires lessees to provide an overview of baseline conditions and outline site characterization activities, generally consisting of offshore meteorological buoys/moorings to measure site-specific conditions. Buoys for offshore wind site assessment can be equipped with a variety of measurement devices to collect data on wind speed, direction, and shear; in-air and ocean temperature; waves and currents; and bird, bat and marine mammals. Hydrogen generation on an offshore wind lease is not anticipated to create additional data needs for site characterization activities.

The COP, per 30 CFR §585.626, requires lessees to provide additional, detailed, site assessment survey results, describe proposed facilities, detail construction methodologies, and outline decommissioning procedures. A lessee may include hydrogen production as a central component of their COP, or it could be included as part of the Project Design Envelope (PDE) to allow for flexibility in offtake options. Incorporation of hydrogen production in offshore wind facilities has the potential to add novel environmental and human health risks that will need to be adequately assessed within the COP. The lessee can utilize existing COP requirements to address hydrogen production, though additional considerations will be required. The addition of hydrogen to offshore wind projects could impact priorities for micro-siting of turbines and other project related structures.

4.6 H_2-OSW Safety

4.6.1 Hydrogen Safety Hazards

Hydrogen is a flammable gas with an autoignition temperature of 585°C. Hydrogen facilities require safety procedures similar to those required on oil and gas platforms that handle natural gas. Hydrogen is lighter than air and will disperse upward if a leak occurs. It is particularly important to be aware of any potential ignition sources above areas where hydrogen will be present, especially in enclosed spaces.

Hydrogen has a wider range of flammability limits and explosion limits in air than natural gas, but it disperses rapidly in air, decreasing the probability that a leak will result in a fire. Another important difference between hydrogen and typical oil and gas operation is that hydrogen burns with a nearly invisible flame. Special infrared flame detectors are required.

Comparing hydrogen properties to more conventional fuels (e.g., natural gas and gasoline vapor) shows that hydrogen presents similar flammability hazards (Table 4-1).

Table 4-1. Fuel Comparisons

Fuel Property	Hydrogen	Gasoline Vapor	Natural Gas
Flammability Limits (in air)	4-74%	1.4-7.6%	5.3-15%
Explosion Limits (in air)	18.3-59.0%	1.1-3.3%	5.7-14%
Ignition Energy (mJ)	0.02	0.20	0.29
Flame Temperature in air (°C)	2045	2197	1875
Stoichiometric Mixture (most easily ignited in air)	29%	2%	9%

Source: https://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/h2_safety_fsheet.pdf

Like natural gas, hydrogen is a colorless odorless gas. Hydrogen detectors should be installed in indoor areas where hydrogen could potentially be present or accumulate. Unlike natural gas, hydrogen typically does not contain any odorants because the chemicals typically used to provide odor are poisonous to fuel cells.

Another safety concern with gaseous hydrogen is the potential for leaks. H_2 is a very small molecule that may leak from equipment that would safely hold heavier gases, such as natural gas. Proper selection of materials for hydrogen plant design is critical.

H_2-OSW will require handling pressurized hydrogen gas. Pressures will vary depending on the plant configuration, but some design options require very high gas pressures.

Table 4-2. Representative pressures for different hydrogen options

	Pressure (barg)
Electrolyzer	1-30
Liquefaction Plant	20
Pipeline	>70
Compressed Gas Storage	250-500
Fueling Station	350-700

Source: https://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/h2_safety_fsheet.pdf

Any vessel that operates above 15 psig (1 barg) is considered a pressure vessel and must be designed, constructed, and tested in accordance with ASME Boiler and Pressure Vessel Code, Section VIII - Unfired Pressure Vessels (Section VIII). These vessels need to be inspected before being put into service and after every 5 years or every alteration or major repair. Any stamped Section VIII vessel is required to have a pressure safety valve (PSV) or a documented relief path.

API has recommended practices for sizing PSVs and pressuring relieving systems. They are considered good engineering practices to follow.

A PSV is a safety device designed to protect a pressure vessel or system during an overpressure event. This is the first line of defense for any chemical facility. There is a PSV protecting every piece of equipment or system. This is a standard piece of equipment.

PSVs must discharge to a safe location. In some cases, PSVs can be discharged to the atmosphere. It is important to ensure that the fluids venting to atmosphere have a low enough concentration such that the resulting atmospheric conditions are not toxic or explosive. A long tail pipe with a flame arrestor might be required. Another option, the PSV can discharge to an exhaust collection system. The PSVs would be connected by a pipe network that feeds a discharge stack called a flare, which combusts the relieving fluid from the PSVs. This flare would have a pilot light, which would require a small amount of fuel like natural gas.

Because hydrogen is lighter than air and nontoxic, it may be permissible to vent the hydrogen to the atmosphere to a safe location, such as a vent stack with an outlet above any process equipment. NFPA 2 allows hydrogen PSVs to vent to atmosphere in a safe location.

A Safety Instrumented System (SIS) is designed to prevent overpressure of complex pieces of equipment like compressors. The SIS consists of an engineered set of hardware and software controls. This system would be used to shut off the compressor before the system design pressure is exceeded, therefore preventing loss of hydrogen containment. The system must follow Internal Electrotechnical Commission 61511 (IEC 61511).

Before maintenance, it is important to purge the piping and equipment. Purging involves pushing an inert gas through the system to displace the hydrogen. This provides a stable environment that is safe for welding. The hydrogen purged from the system undergoing maintenance would be routed to the flare if the plant has a flare.

The water electrolysis process generates a considerable amount of O_2 as a byproduct (8 kilograms O_2 per kilogram H_2). In H_2-OSW applications, the O_2 may be vented to the atmosphere rather than recovering it and selling it as a byproduct. O_2 must be vented to a safe location.

If the site vents the O_2, dispersion modeling is called for to ensure there is no likelihood of high concentrations of O_2 reaching any combustion processes (e.g., ship motors, fired heaters, designated smoking areas).

4.6.2 H_2-OSW Safety Areas of Focus

Most of the safety issues with H_2-OSW have parallels in existing oil and gas offshore operations, but some concerns will be unique to hydrogen or different than the equivalent oil and gas process. This section details some of the areas where additional focus is warranted. Some topics may be good areas for further research.

Proper metallurgy selection will be critical for long term process integrity. Steel components in H_2-OSW applications will face two challenges. Hydrogen on the process side can cause hydrogen embrittlement, which can cause cracks in the steel. On the outside of piping and vessels, steel will face potential marine saltwater corrosion. While both issues are well understood, there are limited existing facilities that face both issues at once. Offshore oil and gas operations typically do not deal with hydrogen. Nearly all hydrogen services are onshore. Because hydrogen is a small molecule that leaks easily, selecting the correct metallurgy at the start of a project will be crucial to ensuring safe operation over the life of the project. Marinization research will also be required for specialized components, such as electrolyzers.

Another area of focus should be establishing best practices for loading hydrogen onto ships and barges. The loading process is not an automated process and requires personnel to be present. Compressed gaseous hydrogen may be loaded onto ships either to provide fuel for the ship or to transport to shore. Current best practices cover onshore operations involving trucks, small vehicles, and stationary storage vessels. While there are similarities to transferring natural gas in offshore applications, hydrogen transfer involves unique equipment and procedures. As the H_2-OSW industry develops, operators should also share lessons learned.

Best practices for loading liquid hydrogen onto ships and barges will be just as important. The loading process requires the use of specialized vacuum jacketed piping to transfer the liquid hydrogen and to return vapor from the storage vessel head space. Oceanic shipment of liquid hydrogen is a very new process. The first ship carrying liquid hydrogen completed the first international liquid hydrogen shipment in January and February of 2022, carrying hydrogen from Australia to Japan. The ship reportedly had a fire shortly before the ship left port. An investigation as to the cause of the fire is in progress.[10]

Additional research may be required to determine if hydrogen liquefaction is feasible and safe on a floating platform. The cryogenic process to liquefy hydrogen requires careful control of liquid levels of the cryogenic hydrogen and refrigerant streams. Existing hydrogen liquefaction facilities are onshore. Floating platform operation will be more challenging. The closest comparable oil and gas process is floating liquefied natural gas (FLNG), which refers to the process of producing and liquefying natural gas on a floating platform. While LNG transport by ship is a mature technology, FLNG is a relatively new process. There are only three FLNG vessels in commercial operation to date, and one of the three reportedly had operational challenges upon initial startup.[11]

4.6.3 Safety Hazards from Specific Process Options

4.6.3.1 Cryogenic Temperatures

Hydrogen liquefaction requires cryogenic temperatures (-253°C or below). Liquid hydrogen can cause severe freeze burns if it contacts the skin. However, storage facilities typically use double-walled, vacuum-jacketed vessels with PSVs to safely store liquid hydrogen while keeping it cold. These design features minimize the likelihood for human contact. Offshore LNG facilities handle cryogenic liquids, but these types of cryogenic process are not typically found on traditional oil and gas platforms.

4.6.3.2 Oxygen Byproduct

If oxygen is sold as a byproduct, it will likely be transported as a liquid. Like hydrogen, oxygen is a cryogenic liquid with the associated concerns with freeze burns. Oxygen is also highly reactive and will rapidly accelerate any combustion process. Care must be taken to keep the oxygen byproduct away from any combustion process. Pure O_2 is not normally found on offshore oil and gas facilities.

4.6.3.3 Ammonia—Health Hazards, Flammable Liquid

Converting H_2 to green ammonia will introduce an additional set of hazards. Ammonia is transported as a liquid, but if it leaks to the atmosphere, it quickly evaporates. The resulting gas is corrosive to the skin, eyes, and lungs. Ammonia is also flammable in air. If liquid ammonia spills into seawater, it will be toxic to aquatic marine life. While ammonia introduces additional safety concerns versus hydrogen production, proper safety procedures will mirror safety procedures already employed in oil and gas operations on any platform that handles sour oil or gas.

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[10] : https://www.rechargenews.com/energy-transition/serious-incident-fire-aboard-worlds-first-hydrogen-carrier-vessel-investigated-by-australian-authorities/2-1-1195848

[11] https://www.upstreamonline.com/lng/floating-lng-sector-showing-its-strengths/2-1-1020778

4.6.3.4 Liquid Organic Hydrogen Carrier—Flammable Liquids

Other types of LOHCs will also introduce an additional set of hazards in the form of flammable liquids. Current research and development efforts are considering many different chemicals for LOHC applications, but the types of compounds being considered are either naturally occurring in crude oil or are similar to crude components. Safety procedures employed on oil platforms will be directly applicable to LOHC operations.

4.6.4 Safety Management System Requirements

4.6.4.1 Requirements per 30 CFR Part 585.810

Under current regulations 30 CFR Part 585.810, lessees are required to submit a description of their Safety Management System that includes:

1. Procedures to ensure the safety of personnel or anyone on or near facilities
2. Remote monitoring, control, and shut down capabilities
3. Emergency response procedures
4. Fire suppression equipment, if needed
5. How and when the Safety Management System will be tested
6. How it will be ensured that personnel who operate facilities are properly trained

The context of H_2-OSW includes a number of items that are not usually part of an OSW electrical generation facility including water and gas purification equipment, gas storage facilities and high-pressure compression equipment and export pipelines. These will have their specific sub-system and integrated system level hazards to be identified and mitigated.

4.6.4.2 OSHA Process Safety Management Requirements

The US Occupational Safety and Health Administration (OSHA) Process Safety Management (PSM) standard under 29 CFR 1910 Part 119 does not apply to offshore platforms, but it would apply to onshore facilities used for hydrogen production. While PSM requirements do not apply under OSHA's jurisdiction, they are considered safety best practices, are more prescriptive than the 585.810 requirements, and may be adapted by BOEM/BSEE for H_2-OSW as a tool for regulation and safety enforcement. This standard is written to address facilities with an inventory of Category 1 flammable gas over 10,000 pounds. Hydrogen is a Category 1 flammable gas, and there is a significant likelihood that many implementations of H_2-OSW production and associated storage and transport infrastructure would have more than 10,000 pounds of hydrogen on site.

PSM includes the following requirements:

1. Employees access to hazard information and elements of PSM. This would include the process hazard analysis and materials safety data sheets (MSDS) that meet 29 CFR Part 1910.1200.
2. Block flow diagram or process flow diagram
3. Information about equipment, relief design system, ventilation systems
4. Heat and material balance
5. Safety systems
6. Design codes and standards
7. Process hazard analysis with documented resolutions of recommendations, updated with every executed change and re-evaluated every 5 years
8. Written operating procedures for normal operations, temporary operations, start-up and shut down
9. Employee training

10. Pre-startup safety review
11. Program to show mechanical integrity (inspections and reporting)
12. Hot work permits
13. Management of change
14. Incident investigation
15. Emergency response
16. Compliance audits

4.6.5 Safety Organizations

The G+ Global Offshore Wind Health and Safety Organization is a global health and safety group dedicated to the offshore wind industry. Work areas include incident data reporting, good practice guidance, Safe by Design works, and learning from incidents. The group currently focuses on wind for power generation, which is an important component of the H_2-OSW process. Although based in Europe, the group includes a North American focal group.[12]

The Ocean Energy Safety Institute (OESI) is a US-based consortium of industry, national labs, nongovernmental organizations, and academia that looks at safety across all aspects of offshore energy development.[13] The OESI would be a potential backer of research related to H_2-OSW.

[12] Source: https://www.gplusoffshorewind.com/

[13] Source: https://oesi.tamu.edu/

5 Lessons Learned from Europe: Implications for BOEM's Emerging Role

Emerging projects in Europe offer some early lessons for potential H_2-OSW in the US. Perhaps most relevant is the benefit of starting with multi-stakeholder consortia representing all aspects of the value chain from the outset as an effective method to establish a credible/viable project. Such consortia are likely to include utility companies, OEMs, government agencies, energy sector analysts, and end users of the hydrogen product toward a thorough understanding of how a project will fit into a complex US renewables landscape. Another early lesson is that the decision whether to generate hydrogen onshore or offshore is highly project-specific and predicated in part on stakeholder feedback. It also appears that project scale may have critical impact on economic viability of offshore production. Sections below frame the context for existing demonstration and development projects and provide specific examples.

5.1 Existing efforts and applicability to the US

Many emerging projects in Europe involve a combination of national or regional support and partnerships between offshore project developers, technology providers, and end users. This helps foster a consistent and integrated stakeholder community. Certain projects focus on a particular end-use sector, especially where pilot projects are considered. The energy economy can be thought of as a process moving from production, storage, and transportation to use in a series of sectors such as industrial, chemical, mobility, and generation. A number of these emerging regulatory partnerships emphasize this integration from the outset in order to facilitate the necessary infrastructure, supply chains, and market readiness.

To develop H_2-OSW projects at scale, the majority of efforts are multi-stakeholder consortia including potential off-takers who may come from a variety of market sectors. This "value chain" approach has shown significant benefits in establishing credible projects addressing existing limitations in process flow efficiency and proportionality of technological readiness. Status of these projects suggests this is a transitional period with a marked learning curve for best practices and process development. Project refinements are being actively proposed to drive and demonstrate technology readiness with the capacity to deliver H_2-OSW to meet anticipated demand. In the US, H_2-OSW may involve regional differentiators driving implementation strategy where the value chain approach may be critical to successful development. Environmental conditions such as water depth and weather/storm patterns, market readiness and size, state-level onshore permitting, and other factors will likely result in a range of technical approaches and offtake strategies from the Pacific coast to the Gulf of Mexico and to the eastern seaboard, requiring integrated planning to scope viable implementations in an evolving energy economy.

5.1.1 European Commission Public-Private Partnership: Fuel Cells and Hydrogen 2 Joint Undertaking (FCH_2-JU)

The Fuel Cells and Hydrogen Joint Undertaking ceased operations in November 2021 and its role has been taken over by the Clean Hydrogen Joint Undertaking to take over its legacy portfolio and develop the European value chain for safe clean hydrogen technology. Example projects under FCH_2-JU include:

5.1.1.1 OYSTER (Offshore hYdrogen from Shoreside wind Turbine Integrated Electrolyzer)—UK[14]

The Offshore Hydrogen from Shoreside Wind Turbine Integrated Electrolyzer (OYSTER) project is sponsoring development and demonstration of a marinized electrolyzer designed for integration with offshore wind turbines. To realize the potential of offshore hydrogen production there is a need for compact electrolysis systems that can withstand harsh offshore environments and have minimal maintenance requirements while still meeting cost and performance targets that will allow production of low-cost hydrogen. This project includes Ørsted, ITM, Siemens Gamesa, and Element Energy.

5.1.1.2 HAEOLUS (Hydrogen-AEOLic energy with optimized electrolyzer Upstream of Substation)—Norway[15]

This project will involve head-to-head comparison of containerized Alkaline and PEM technologies in a remote location including development of optimized remote monitoring and prognostics. These projects illustrate a number of research themes such as marinization, technology comparison, remote monitoring, and prognostics that indicate the challenges that the hydrogen from offshore wind needs to address.

5.1.2 WindH2 Project—Germany[16]

The WindH2 project is part of the SALCOS program that is investigating integrated low carbon intensity steel production facility, which includes two projects: wind to H_2 via PEM for steel production and a separate high temperature electrolysis process using an SOEC process. The end user in this case is industrial—steel production using low carbon intensity—and is also acting as a vehicle for advanced electrolyzer technology.

5.1.3 SeaH2Land—Netherlands[17]

The SeaH2Land project is a North Sea project that is combining 2 GW offshore wind with electrical transmission to an onshore 1 GW electrolyzer facility. While this is targeted at onshore production, the outcomes will support the development of H_2-OSW and the case studies and project scoping expertise to establish the comparative economics and concept selections contrasting onshore versus offshore hydrogen production.

5.1.4 Mar de Agata—Spain[18]

This project is a 300 MW OSW development between Blue Float Energy and Sener for 20*15 MW producing roughly 910 GWh per year. It includes 66kV cable to onshore facilities. The project reference website includes a reasonable level of technical detail for floating wind installation including site plans.

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[14] https://oysterh2.eu/

[15] https://www.haeolus.eu/

[16] https://salcos.salzgitter-ag.com/en/windh2.html

[17] https://seah2land.nl/en

[18] https://www.bluefloat.com/a-300-mw-offshore-wind-farm-mar-de-agata-is-planned-in-levante-almeriense-spain/

5.1.5 Edinburgh Airport—UK[19]

This project is a partnership with Ørsted and Edinburgh Airport to power airport with H_2 produced from OSW and includes efforts to update applicable regulations. Electricity will be sourced from offshore wind farms and the renewable hydrogen will then be combined with sustainably sourced carbon to produce 250,000 tons of e-kerosene and e-methanol per year when fully scaled up. This will service the following energy demands:

- Energy requirements for the airport facilities
- Fuel for airport service vehicles
- Fuel for vehicles transporting passengers and goods to and from the airport
- Aviation fuel for aircraft with service to the airport

5.1.6 Dolphyn (Deepwater Offshore Local Production of HYdrogeN)—UK[20]

The Dolphyn project has been supported by funding from the UK Department for Business, Energy and Industrial Strategy (BEIS) Energy Innovation Programme (2016-2021) and as such forms part of an open knowledge base available to via the UK government website. The project concept encompasses production of hydrogen by electrolysis and integrates a renewable energy source, seawater desalination, and local production of hydrogen to be transported on shore via pipeline. A specific concept has been selected to suit UK market and technological drivers and this concept is being developed to Front End Engineering Design (FEED) stage under Phase 1 of the BEIS Hydrogen Supply Competition.

The concept selection considers three primary options that differ functionally in the location of the electrolysis unit. The electrolyzers can be co-located with an individual wind turbine generator, co-located with a wind turbine array, or situated onshore. This latter configuration is equivalent to the current offshore wind technology, albeit requiring some level of marinization of the electrolyzer.

The wind turbine concepts considered in the study were all floating rather than fixed platform. The study considered offshore distance up to several hundred kilometers and water depths in excess of 50 meters.

The concept selection cost model indicated that while the hydrogen production costs for offshore hydrogen production were relatively insensitive to distance, the onshore costs continued to increase with distance suggesting that at scale, and the transportation of hydrogen was more cost effective than the transmission of electricity.

The underlying design assumptions for the Dolphyn concept are around a North Sea environment both in terms of location and supply chain infrastructure. The operational locations considered for this project were deemed to be predominantly with in the design parameters for wind turbine generators of increased wind speeds in the range of 3 meters per second to greater than 25 meters per second and a temperature range from -10 to +25°C.

Offshore floating wind is a priority area, as indicated by UK and Scottish government development plans. Use of offshore hydrogen production facilitates a parallel development strategy that offers alternatives to potentially constrained electricity demand and infrastructure capacity.

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[19] https://orsted.co.uk/media/newsroom/news/2021/10/airport-mou

[20] https://ermdolphyn.erm.com/p/1

The Dolphyn concept favors the use of PEM technology. However, either technology could be applicable.

5.1.7 H2Mare—Germany[21]

H2Mare is a 14 MW project in Germany to establish a new turbine concept integrating the electrolyzer into an offshore wind turbine for direct conversion of energy into green hydrogen. This program includes **four** subprojects to address the wind turbine, the electrolyzer, additional processing to alternative vectors, and safety and environmental integration described in the follow sections:

5.1.7.1 OffgridWind

The key feature of this project is its implementation of a turbine concept distributing electrolysis directly at the OSW turbine generators, aimed at increasing efficiency.

5.1.7.2 H2Wind

Consists of the development of a PEM electrolysis system optimally adapted to the offshore environment and tuned to the wind turbine. In addition to the durability of the turbines and the challenge of processing seawater, the maximum yield of wind energy is one of the project's goals.

5.1.7.3 PtX-Wind

In contrast to pure offshore hydrogen production, the focus of this project is on conversion to more easily transportable synthetic energy carriers and fuels such as methane, methanol, and ammonia. The power-to-X products are produced via high-temperature electrolysis and CO_2 extraction from the air or sea. Direct saltwater electrolysis is also being tested.

5.1.7.4 TransferWind

TransferWind addresses the transfer of knowledge to the public as well as the exchange of expertise across projects. At the same time, it also considers safety and environmental issues as well as infrastructure requirements.

5.1.8 Atlantic Shores Proposal—US[22]

Atlantic Shores is a JV between Shell New Energies and EDF Renewables to form Atlantic Shores Offshore Wind in New Jersey with an initial contract to develop 1.5 GW of offshore wind of an available wind resource that may be as high as 2.3 to 2.4 GW. The scheme also includes a 5 to 10 MW green hydrogen plant; however, the scheme appears mostly a conventional Offshore Wind Scheme with electrical cabling to shore.

It also appears that the H_2 produced by the project will be blended into the natural gas grid to lower the carbon intensity of the home heating fuel supply.

[21] https://www.wasserstoff-leitprojekte.de/projects/h2mare

[22] https://www.atlanticshoreswind.com/

5.1.9 NorthH2—Netherlands[23]

NortH2 is a consortium made up of Equinor, Gasunie, Groningen Seaports, RWE, and Shell Netherlands planning for 4 GW of green hydrogen by 2030 between 80 and 100 kilometers off the coast in the northern region of the Netherlands.

The project currently anticipates offshore wind farms at a scale of 12 to 15 MW at a depth of roughly 35 meters. The electricity will be used to generate hydrogen onshore that will either be stored in salt caverns that are currently empty or immediately transported to the market using existing natural gas infrastructure.

As wind turbines are erected farther offshore, it becomes economic to collocate the hydrogen production. The current project calculations indicate that onshore electrolysis at Groningen province's Eemshaven "hydrogen port" is more economic. However, innovations in this field and the growing hydrogen market suggest that the costs involved in offshore electrolysis will decrease.

5.1.10 AquaVentus[24]

This project is an offshore hydrogen scheme at 2*14 MW units. In contrast to some of the other projects but in common with Dolphyn, this project considers that compared to the transport of electricity generated offshore, the hydrogen production at sea and the transport via pipeline could offer economic benefits. The pipeline could replace five high voltage direct current (HVDC) transmission systems, which would otherwise have to be built and so represents a cost-effective option for transporting large volumes of energy over long distances.

5.1.11 BIG HIT (Building Innovative Green Hydrogen systems in Isolated Territories)—Orkney Hydrogen (Surf 'n' Turf)—UK[25]

This is an overarching project that is developing a small island scheme that integrates tidal turbines and onshore wind with 500 kW of ITM Power's PEM electrolyzer technology onshore. Follow on project involves two PEM units (1 MW and 500kW scale).

5.1.12 Offshore to X—Germany[26]

The RWE-BASF project Offshore-to-X aims to accelerate the transition to a CO_2-free chemical industry by electrifying production processes that were previously based on fossil fuels and through CO_2-free hydrogen. The idea is that BASF replaces CO_2 intensive processes for basic chemical production at its Ludwigshafen site with innovative CO_2-free technologies. The green electricity needed for this will be produced by RWE and BASF in an offshore wind park to be built in the German North Sea in addition to the new installations foreseen by existing policy. With the remaining electricity, RWE will produce green hydrogen at an onshore electrolysis facility.

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[23] https://www.north2.eu/en/

[24] https://aquaventus.org/

[25] https://www.bighit.eu/

[26] https://www.rwe.com/en/press/rwe-ag/2021-05-21-BASF-and-RWE-plan-to-cooperate-on-new-technologies-for-climate-protection

5.1.13 PosHYdon—Netherlands[27]

This demonstration project seeks to integrate offshore wind and electrolysis with injection into a natural gas supply line to shore. The platform itself is an existing nearshore fully electrified unit and so provides a suitable testing platform.

[27] https://poshydon.com/en/home-en/

6 Technology Assessment Program Opportunities

US and global research initiatives advancing technology for the H_2 economy are rapidly reshaping potential implementations of potential H_2-OSW projects in the US. The extent and timing of research efforts in the US, with an explicit emphasis on interagency/inter-entity collaboration, seem to offer the means to best leverage BOEM/BSEE research funding toward co-development of technological approaches and regulatory guidance focused on H_2-OSW. Section 3 provides an overview of existing research efforts, while topics below suggest an initial trajectory for BOEM to engage through the Technology Assessment Program leveraging the stakeholder engagement process.

6.1 Proposed H_2-OSW Advancement Strategy

Existing and future trends in technological implementation of hydrogen will have profound impacts on permit application contents to be reviewed by BOEM. While Europe is currently the primary proving ground for emerging technological implementation, specific site conditions within BOEM's OCS jurisdiction are likely to spawn new site-specific approaches that would require a testing and evaluation component in order for BOEM to adequately evaluate them. Therefore, it is recommended that BOEM implement an H_2-OSW Advancement Strategy with a collaborative approach to bringing together diverse stakeholders and further define areas of interest for H_2-OSW industry development in the US The basic elements of the strategy are provided in this section.

6.2 Recommended Priority H_2-OSW Research Topics

Using offshore wind for hydrogen production is a novel concept that requires further validation before large-scale commercial deployment can be undertaken. Technology assessment can support research on safety and environmental considerations to inform regulations, rules and operational guidelines for deployment of hydrogen production systems with offshore wind projects. The BSEE Technology Assessment Program (TAP) and BOEM's Environmental Studies Program can support research on technical and environmental topics respectively to further understanding of technical failure risks and potential environmental impacts during the construction, operations and decommissioning phases of projects. Collaborative funding opportunities may exist or emerge through the DOE H2@Scale Program (Section 3.1.1.2 and Section 6.4). Research findings can inform strategies and solutions to mitigate technical and environmental risks. The potential research topics listed below will be further refined in the final draft following discussions with BOEM.

- Development of seawater electrolyzers
- Lowering costs for electrolyzers
- Testing of seawater desalination options
- Small-scale demonstrations
- Marinization
- Remote Monitoring
- Electrical configuration
- O&M philosophy
- Production profiling
- Subsea coolers
- Floating platform hydrogen liquefaction
- Energy islands with OSW and blue hydrogen
- Long term environmental impacts of brine discharge

6.3 H_2-OSW Stakeholder Outreach

Current interest in renewable energy sources and the continual advancement of emerging technologies will provide a diverse group of stakeholders with interest in H_2-OSW activities. BOEM and BSEE can fund and support knowledge exchange meetings and workshops to engage stakeholders from industry, academia, and environmental NGOs as well as federal agencies, state agencies, and tribal governments. Initial discussions should focus on identifying key data needs and research gaps, ranking near-term priorities, and developing partnerships for application-inspired research to inform policy and regulatory decisions. Such efforts will be in line with previous initiatives by BOEM, including the Atlantic Wind Energy Workshop in 2011 and the Offshore Wind and Maritime Industry Knowledge Exchange Series in 2021. Lists of the recommended stakeholders are provided below.

6.3.1 Agencies

- DOE
- DoD
- NOAA
- USFWS
- EPA
- USACE
- OSHA

6.3.2 Environmental NGOs

- NRDC
- Audubon
- NWF
- UCS
- Other potential entities that may not be directly engaged in OSW, but are H_2-focused

6.3.3 Academic Institutions and Research NGOs

- Rutgers
- Penn State University
- Stanford University
- University of Central Florida
- University of Wyoming
- University of North Dakota
- Southwest Research Institute
- Other potential entities that may not be directly engaged in OSW, but are H_2-focused

6.3.4 Industries/Industry Associations

- Offshore wind developers
- BNOW
- ACP
- NOIA
- Transportation sector?
- Natural gas sector?

6.4 Collaboration Opportunities

International collaboration and partnerships on technology and environmental research can facilitate pooling of resources and expertise to address issues of common interest. These partnerships can also be forums for regulatory and technical capacity building between countries with significant technical experience and others. As part of this H_2-OSW Advancement Strategy, BOEM can create partnerships to foster sharing of technical expertise and build much needed regulatory capacity among interested regulators.

Potential domestic partnership opportunities include the following DOE offices:

- DOE Hydrogen Program:
    - Hydrogen and Fuel Cell Technologies Office (HFTO), which focuses on hydrogen applications across various industries
    - Hydrogen Shot Initiative, which refines approaches to reach US national energy goals for the hydrogen energy economy
    - H2@Scale, which links Hydrogen Program priorities and Hydrogen Shot goals with collaborative funding opportunities and CRADAs
- Wind Energy Technologies Office, which has a proven record for funding research to enable development and deployment of offshore wind technologies; project funding includes support for research on market acceleration to understand barriers that limit deployment of offshore wind and advanced technology demonstration and deployment to support new innovations
- BOEM has previously partnered with the DOE on wind activities including the DOE and DOI Workshop to Inform the 2016 National Offshore Wind Strategy

These programs—largely undertaken in partnership with industry, academic, and national laboratories—can provide valuable support for initial offshore wind-hydrogen projects.

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US Department of the Interior (DOI)
DOI protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors the nation's trust responsibilities or special commitments to American Indians, Alaska Natives, and affiliated island communities.

Bureau of Ocean Energy Management (BOEM)
BOEM's mission is to manage development of US Outer Continental Shelf energy and mineral resources in an environmentally and economically responsible way.

BOEM Environmental Studies Program
The mission of the Environmental Studies Program is to provide the information needed to predict, assess, and manage impacts from offshore energy and marine mineral exploration, development, and production activities on human, marine, and coastal environments. The proposal, selection, research, review, collaboration, production, and dissemination of each of BOEM's Environmental Studies follows the DOI Code of Scientific and Scholarly Conduct, in support of a culture of scientific and professional integrity, as set forth in the DOI Departmental Manual (305 DM 3).