Marine Energy to Hydrogen Working Meeting: Workshop Report

Jacob Thorson and Christopher Matthews

National Renewable Energy Laboratory

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Contract No. DE-AC36-08GO28308

Technical Report
NREL/TP-5700-79711
May 2022

Marine Energy to Hydrogen Working Meeting: Workshop Report

Jacob Thorson and Christopher Matthews

National Renewable Energy Laboratory

Suggested Citation

Thorson, Jacob and Christopher Matthews. 2022. *Marine Energy to Hydrogen Working Meeting: Workshop Report*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5700-79711. https://www.nrel.gov/docs/fy22osti/79711.pdf

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Contract No. DE-AC36-08GO28308

Technical Report
NREL/TP-5700-79711
May 2022

National Renewable Energy Laboratory
15013 Denver West Parkway
Golden, CO 80401
303-275-3000 • www.nrel.gov

NOTICE

This work was authored by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Hydrogen and Fuel Cell Technologies Office. The views expressed herein do not necessarily represent the views of the DOE or the U.S. Government.

Cover Photos by Dennis Schroeder: (clockwise, left to right) NREL 51934, NREL 45897, NREL 42160, NREL 45891, NREL 48097, NREL 46526.

NREL prints on paper that contains recycled content.

Table of Contents

1 Background

The Marine Energy to Hydrogen Working Meeting was held virtually on February 17, 2021. The meeting was sponsored by the U.S. Department of Energy Hydrogen and Fuel Cell Technologies Office (HFTO).

1.1 Overview

Marine renewable energy (MRE) resources include the energy that is made available for capture through wave motion, tides, ocean currents, and thermal/chemical gradients. The technical potential of these resources in the regions around the contiguous United States is estimated to total in the thousands of terawatt hours per year (DOE WPTO 2021). MRE resources are also geographically distributed across the ocean and along the coasts.

The marine environment is also the place of business for a variety of human activities. These activities include transportation of people and goods as well as the production and/or extraction of goods like food and minerals. Many marine industries are difficult to decarbonize but new possibilities open when considering the transition away from traditional fossil fuels. Shipping emitted 1,056 million metric tons of carbon dioxide in 2018, which was an increase of nearly 10% from 2012 and made up 2.89% of global greenhouse gas emissions (Saul 2020).

1.2 Objective

The purpose of this meeting was to identify potentially interesting integrated MRE-to-hydrogen applications and the associated challenges and opportunities. This was made possible by bringing together stakeholders with a broad knowledge base and enabling them to collaborate in smaller breakout sessions.

A diverse group of more than 100 stakeholders from relevant industries attended the meeting. The attendees included representatives from industry, academia, national labs, and government entities. The attendees also included experts with specialization in different technologies that could be important in a combined MRE-to-hydrogen application.

The meeting format consisted of a mix of introductory presentations and two group breakout sessions. The full meeting agenda is included in Appendix A. The breakout sessions divided the larger group of meeting attendees into six smaller groups that were focused on one of three categories of offshore activities that could be viable MRE-to-hydrogen consumers. Those categories were:

1. Seagoing vessels (long and short haul)
2. Smaller instrumentation platforms (unmanned underwater vehicles and buoys)
3. Larger stationary activities (microgrids and offshore industry).

Each breakout group met twice with a break for presentations between the two sessions. The first of the sessions was formulated to identify opportunities of interest for different application groupings, and the second was focused on the challenges and opportunities for integrating MRE and hydrogen technologies related to the opportunities identified in the first session.

2 Presentation Synopses

Presentations from the meeting are available on the HFTO website: https://www.energy.gov/eere/fuelcells/marine-energy-hydrogen-working-meeting.

2.1 Plenary

Jennifer Garson and Eric Miller from DOE's Water Power Technologies Office (WPTO) and HFTO, respectively, opened the meeting. During their joint presentation, they discussed their respective offices' visions and highlighted some aspects that are relevant to the topic at hand. Their insights set the stage for the meeting by illustrating the breadth of opportunities that are of interest in this space.

2.2 Potential of the Hydrogen and Marine Energy Vectors

Bill McShane from DOE's WPTO presented further background information regarding the potential of MRE as an abundant source of energy for offshore activities. In his presentation he highlighted the size of the opportunity in both geographic area and energetic resource. He closed his presentation with his perspective on how hydrogen could be a solution to some of the challenges that are present in marine applications.

Richard Ainsworth from the European Marine Energy Centre (EMEC) and Elias Greenbaum from GTA, Inc. presented their experiences with hydrogen production technologies utilizing offshore energy resources. The GTA system that was presented consisted of a liquid alkaline electrolyzer that was designed for deployment on the seafloor colocated with offshore wind resources. Elias also presented the current state of the GTA prototype and plans to demonstrate it at larger scales. The work from EMEC that was presented included their offshore wind and wave testing facilities. A polymer electrolyte membrane (PEM) electrolyzer was installed for utilization with both those energy resources and the local electrical grid. Richard also discussed plans to increase the electrolysis capacity from 0.5 MW to 1.5 MW by 2021 and promote the hydrogen economy in the Orkney Islands.

Trond Strømgren from GCE Ocean Technology also presented the Deep Purple project that is an offshore wind to hydrogen project led by TechnipFMC. This project will utilize PEM electrolysis devices located on a centralized platform that draws power from a nearby offshore wind farm. The produced hydrogen will then be stored on the seabed in gaseous storage tanks and used in fuel cells to balance electrical demand.

2.3 Funding Opportunities

Grigorii Soloveichik from DOE's Advanced Research Projects Agency–Energy (ARPA-E) and Neha Rustagi from DOE's HFTO both discussed funding opportunities from their respective organizations. Neha outlined the breadth of funding opportunities at HFTO that span from early- to late-stage development and highlighted some recent products of HFTO-funded projects. Grigorii focused on the OPEN 2021 FOA from ARPA-E. He highlighted that this specific FOA presented an opportunity for projects that do not fit into other, more focused funding opportunities at ARPA-E. He reported that this pilot project has been funded for deployment at a Norwegian offshore wind farm.

2.4 Technical Considerations for Marine Energy and Hydrogen Deployments

Chris Matthews and Jacob Thorson from the National Renewable Energy Laboratory presented a technical overview of MRE and hydrogen technologies, respectively. Chris reviewed the MRE resources of interest for this meeting and described important characteristics of the energy resource and the technologies used to capture that energy.

3 Findings from the Breakout Sessions

The following section summarizes the results of the breakout sessions and is divided into the same categories that the individual breakout groups focused on.

3.1 Seagoing Vessels: Long and Short Range

In the two breakout groups that focused on seagoing vessels, the large energy transfer required to refuel most vessels was identified as a critical design consideration. The amount of hydrogen required to fill a single vessel was estimated to range from the hundreds of thousands to millions of kilograms for vessels ranging in size from passenger ferries to international shipping vessels. This primary constraint focused later conversations toward solutions that could produce, transfer, and store large amounts of energy.

The two primary markets that were considered by the groups were those of long-haul international shipping and regional passenger ferries. Offshore fueling of these vessels was highlighted as a potential market for MRE-to-hydrogen technologies because it could reduce the amount of fuel storage required on each vessel and increase the available cargo capacity.

Other selected observations in this breakout session are summarized below.

- Producing large amounts of hydrogen requires a similarly large energy resource. Wave energy was highlighted by the breakout groups because of the relatively high power densities associated with wave power. Wave energy is also available across much of the ocean, potentially enabling offshore fueling operations.
- Large shipping vessels can be expected to have operational lifetimes on the order of 15–30 years, leading one of the groups to consider options for retrofitting the existing fleet. One of the groups considered the options for retrofitting vessels when they are due for major drivetrain maintenance.
- Quickly and safely transferring such a large amount of energy presents challenges that depend on the specific application. Groups specifically identified the hazards that could be presented by fuels that could enable storing large amounts of energy onboard vessels but are cryogenic (liquid hydrogen) and/or toxic (ammonia).
- Operators of shipping vessels will require immediate, rapid fueling to be available as soon as a ship arrives, which will likely require large amounts of on-site storage. Subsea storage of gaseous hydrogen could utilize the higher pressures at depth while also reducing the footprint of the platform. However, gaseous hydrogen is often disfavored because it will occupy a large volume of storage on the vessel itself.

- The safety risks associated with hydrogen and many hydrogen carrier fuels were identified as an important consideration, especially for applications transporting people who are not working on the vessel (e.g., ferries).
- Safety regulations may restrict or disallow fueling when passengers are aboard a vessel. This could require a second location that is apart from the public where fueling can occur. This second location could be colocated with an MRE resource that produces and stores hydrogen between fueling events.
- Large vessels are also subject to a variety of regulations regarding the safety and emissions when fueling, storing, and utilizing fuels. It was stated that regulations for no- or low-carbon shipping are under development. These regulations are complex and expensive to create and implement and could have significant implications for the selection of fuels by vessel owners and manufacturers. This was highlighted by one member as a reason to engage and educate regulators about the available options in order to allow them to consider them during the development of important regulations. The operators of ports and vessels may also need to be retrained to safely operate and maintain vessels with new fuels and drivetrains. The selection of specific fuels will also be driven by the specific pollutants that are covered by various regulations because the emissions from a ship will be governed by the fuel used and the method by which that fuel is utilized (e.g., in fuel cells versus combustion engines).
- Some of these challenges may be addressed by producing renewable diesel or other liquid fuels that are interchangeable with modern fuels, although with an efficiency penalty. Group members also identified the challenges of operating a chemical processing plant in an offshore environment as another possible barrier to this pathway. It was, however, noted that the fossil fuel industry has experience operating chemical processing facilities on offshore platforms, and some of that knowledge may be applicable to producing renewable fuels.

3.2 Small-Scale Instrument Platforms: Unmanned Underwater Vehicles and Buoys

The breakout groups focused on small scale instrument platforms considered both unmanned underwater vehicles (UUVs) and stationary buoys. Groups identified many similar applications for UUVs and buoys. Because many of these systems are relatively small and low-power, hydrogen systems may be at a disadvantage when compared to other energy storage devices like batteries. To focus more narrowly on systems with larger energy requirements where hydrogen could be more viable, many of the identified markets included applications that require long deployments, large operational ranges, or even integrated buoy and UUV systems.

When considering applications of MRE-to-hydrogen systems to UUV platforms, groups focused on resource extraction, ocean exploration, and defense. In each of these applications, the abilities to refuel at sea and to store large amounts of energy as hydrogen were identified as the key benefits of MRE to hydrogen.

Other selected observations in this breakout session are summarized below.

- Battery technologies were identified as the primary competitor to hydrogen energy storage in part because they are also the incumbent technology for many UUVs.

- Many UUVs also need to return to the surface periodically to transmit data and/or acquire their position via GPS, which is not generally feasible below the surface. The requirement for periodic resurfacing provides an opportunity to refuel if energy from an MRE resource is available for recharging or refueling.
- Resurfacing requirements would likely limit the range of a UUV, which would in turn reduce the benefit of hydrogen for enabling long range operations. Hydrogen could, however, enable higher-power activities during deployments of a given range or duration.
- Storing that energy as hydrogen could be beneficial if the energy resource varies on long timescales, requiring seasonal energy storage to allow year-round operation. It could also be beneficial if fast fueling was required to, for example, enable near-continuous operation or monitoring.
- Low-noise operation was identified as a benefit of hydrogen fuel cells. In defense applications, low-noise operation is important for avoiding detection. For ocean exploration applications quiet operation can be important if one is working around fauna that could be disturbed by loud noise.
- Although hydrogen is flammable and must be handled with care, it is not a toxic substance, and electrolysis devices like PEM electrolyzers do not generally contain hazardous liquids. The low risk of serious environmental contamination in the event of a failure could be an advantage relative to alternative technologies like fossil fuels and large batteries.
- One of the challenges that is present when operating UUVs with hydrogen fuels is accessing oxygen for combustion or reaction at the fuel cell—a consideration that is largely taken for granted for applications on the surface. This oxygen could be captured when it is produced by the electrolyzer and then compressed and stored for use by the UUV.
- Fuel cell systems can also be larger than comparable battery systems at small scales. This again limits hydrogen as a feasible UUV fuel to larger devices.

3.3 Large, Stationary Activities: Coastal and Island Microgrids and Aquaculture

The breakout groups that focused on large, stationary applications considered onshore applications like microgrids for coastal and island communities and offshore applications focused on various forms of aquaculture. The term aquaculture as used here refers to the managed production of aquatic flora and fauna for use as food or for other commercial uses.

The conversations around microgrids and resilience focused on geographic regions that could contain communities where MRE-to-hydrogen systems could succeed. These included island communities in the global south, in the North and Baltic Seas, and off the east coast of the United States. Onshore communities that were considered were those that are at the edge of the grid and are vulnerable to failures caused by severe weather or other extreme events. For example, communities on the coast in the Pacific Northwest region of the United States were identified as including some areas with vulnerable grid connections. These communities and their grid providers may benefit from the additional energy resource represented by MRE and the energy storage capability that is enabled by hydrogen.

Other selected observations in this breakout session are summarized below.

- Many of the barriers to adopting MRE to hydrogen in coastal and island communities were centered around the question of economics. This is especially cogent for the communities being considered because they are generally quite small, and therefore the costs associated with implementing an energy system can't be as easily defrayed.
- The relatively small scale of these communities also limits the carbon reduction that can be achieved by implementing a renewable energy system in any single community, but in aggregate it is possible that significant improvements could be realized. Aggregation could also address some of the challenges associated with costs for designing small, one-off systems by integrating the communities into a larger hydrogen economy.
- In many of these communities, some of the largest single consumers of fuel are the planes and/or vessels that bring supplies and people to-and-from the community. If these transports need to refuel at the community, an MRE-to-hydrogen system could be a viable fuel provider.
- MRE-to-hydrogen systems could also provide an energy source to capture and store large amounts of backup energy for times that it is not possible to import energy either via grid or by deliveries of fuel from mainland sources.
- These could be coupled with wind and/or solar installations to provide balance to the grid both by adding a renewable energy source with complementary seasonality to other renewables and by adding a demand-response device in the form of a large electrolyzer that could reduce curtailment of excess energy.
- Coupled MRE and hydrogen systems could also be attractive in island environments where land area is scarce. In those situations, collecting and storing energy offshore could be attractive relative to onshore installations.
- If MRE-to-hydrogen systems were to act as resilient energy sources for a coastal community, it would also be necessary to demonstrate that they can be operated with a very high reliability and provide energy during emergencies. Demonstrating that reliability could be challenging and will likely involve both technical demonstrations as well as community engagement.

Aquaculture was the other primary focus of the two breakout groups focused in this area. The specific geographic areas in which the combination of MRE, hydrogen, and aquaculture would apply were not discussed at length in the breakouts, but some conversations highlighted the possible overlap between aquaculture applications and the applications discussed regarding microgrids and island communities. Many of these communities have aquaculture as an important component of their local economy. This is important not just because hydrogen systems used for aquaculture could be integrated into nearby hydrogen economies but also because the ecological impacts of installing and operating MRE-to-hydrogen systems near these islands could have acute impacts in those communities. This was highlighted in discussions because it illustrates the importance of partnering with local agencies and community organizations when considering MRE-to-hydrogen installations.

- Aquaculture markets that could be of interest for MRE-to-hydrogen systems include fish farming, kelp forests, algae-based fuel production, and ecological restoration.
- The energy consumption of aquaculture facilities can be highly sporadic, with high energy demands during feeding and harvesting activities, and relatively low energy use at

other times. On-site energy production from a local MRE resource and storage of that energy as hydrogen could be attractive as a means to provide high power and energy storage without depending on external fuel providers.

- Aquaculture may be an application where byproducts from electrolysis could have meaningful value. For example, the low pressure, high purity oxygen that is produced at the anode could be used in some aquaculture applications by bubbling it through seawater. The low-grade waste heat (typically less than 100°C) could also be used to support aquaculture applications that can thrive in warm environments.
- Some regenerative aquaculture activities were also identified as possible applications of MRE-to-hydrogen systems. An example that was specifically suggested for consideration was that of electro mineral accretion, a technology that can support the growth of artificial reefs by applying a low voltage to a metallic subsea structure and causing important minerals to precipitate from the seawater.

4 Actions Going Forward

The combination of hydrogen and water power technologies can be considered in a breadth of applications as exemplified by the many concepts discussed in the Marine Energy to Hydrogen Working Meeting. There were, however, many questions and concerns that were raised in the meeting that have not yet been answered. These unanswered questions increase the technical and financial risk, which, in combination with the high costs associated with many of these systems, create challenging conditions for first-movers.

Some of the unanswered questions that were identified in this meeting, especially those regarding the technical or economic feasibility, may be answerable through numerical analyses at the system level. Some applications will require the gathering of fundamental research like the quantification of the energy density at a certain location or the further development of water purification technologies. Addressing other open questions like the feasibility of these technologies for a specific application or industry may require experimental demonstrations in order to uncover the hidden challenges that are often only discovered after construction and deployment of a prototype in a representative environment.

References

DOE WPTO. 2021. "Marine Energy Resource Assessment and Characterization." Energy.gov. 2021. https://www.energy.gov/eere/water/marine-energy-resource-assessment-and-characterization.

Saul, Jonathan. 2020. "Shipping's Share of Global Carbon Emissions Increases." Reuters, August 4, 2020. https://www.reuters.com/article/us-shipping-environment-imo-idUSKCN2502AY.

Appendix A. Meeting Agenda

Marine Energy to Hydrogen Working Meeting

February 17, 2021, 8:00–12:30 MST

Plenary.. 8:00–8:15

Jennifer Garson and Eric Miller

Presentations 8:15–8:45

- Potential of the Hydrogen and Marine Energy Vectors
  Bill McShane, Richy Ainsworth, and Elias Greenbaum
- Introduction to the Meeting Format
  Jake Thorson

Break.. 8:45–8:55

Breakouts (Maritime Opportunities)................ 8:55–9:40

- Identifying opportunities of interest for different application groupings

Breakout Session Recap................................ 9:40–10:10

Presentations 10:10–10:40

- Funding Opportunities
  Grigorii Soloveichik and Neha Rustagi
- Technical Considerations for Marine Energy and Hydrogen Deployments
  Trond Strømgren, Chris Matthews, and Jake Thorson

Break.. 10:40–10:45

Breakouts (Technical Integration)............... 10:45–11:30

- Identifying challenges and opportunities for integrating marine energy resources and hydrogen technologies

Breakout Session Recap.............................. 11:30–12:00

Open Networking Session 12:00–12:30