Marine Energy to Hydrogen Analysis Project

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Project ID # WPTO001

Project Goal

- To define the opportunity space for non-grid opportunities for integrated marine renewable energy (MRE) and hydrogen systems
  - Focusing on marine and hydrokinetic (MHK) resources: ocean current, tidal current, wave energy, and thermal gradients (OTEC)
  - Performing background research and fact-finding to establish the current state of MRE and hydrogen technologies
  - Communicating findings and unique opportunities to the MRE and hydrogen community

Overview

Timeline and Budget

- Project start date: 12/2019
- FY20 DOE funding: $300k
- Total DOE funds received to date: $300k

Barriers

- B. Stove-piped / Siloed Analytical Capability
- E. Unplanned Studies and Analysis

Partners

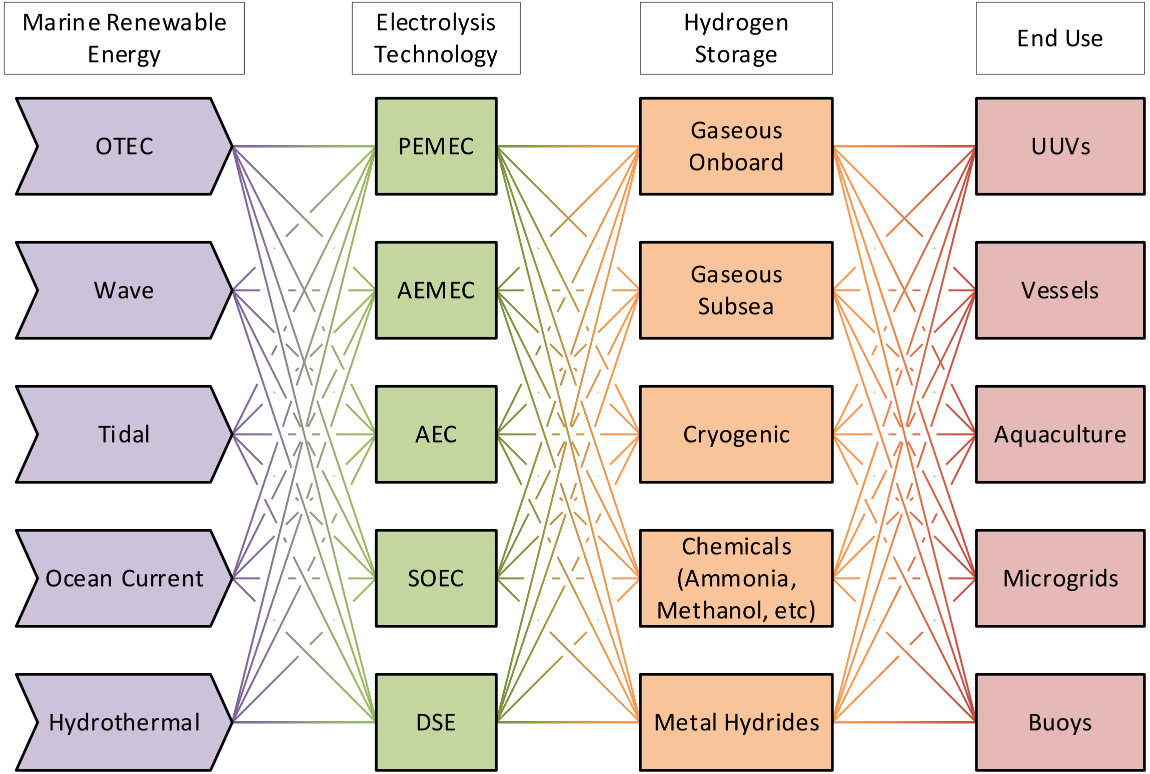
- Project lead: NREL
- DOE Partners: HFTO & WPTO

Relevance: Why MRE and Hydrogen?

- Marine renewable energy resources are abundant near the point of use for many offshore and coastal applications.
- Hydrogen enables the capture, storage, and utilization of large amounts of energy.
- **Integrating these technologies could provide reliable, efficient, low-carbon solutions for a variety of difficult-to-decarbonize, offshore and coastal activities.**

Relevance: Identifying MRE-H_2 Pathways

- Combined systems of MRE and hydrogen technologies are still largely unexplored.
- There are many possible system designs, but which are worth pursuing?
- **Need to identify important pathways to focus future efforts**



Approach: Project Plan

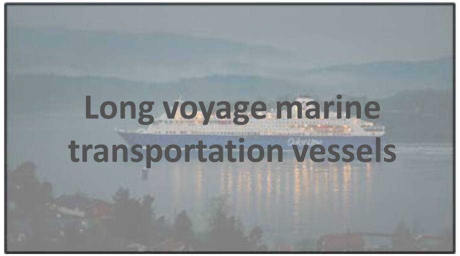
- NREL produced a draft report detailing the results of a fact-finding effort focused on MRE, hydrogen, and possible interactions of the two.
- That draft report was distributed to a large group of stakeholders in related industries, academia, and governments for feedback.
- Those stakeholders also attended an online working meeting to spark conversations and provide additional feedback.
- **The feedback and other information gathered at that meeting are being summarized into publicly available reports.**

Approach: Virtual Working Meeting Breakout Sessions

- Groups of attendees focused on 3 broad topic areas (below).
- Groups discussed opportunities and challenges specific to utilizing marine energy and hydrogen for applications in each of those topics.

Vessels

Photo by Alina Shchurova on Unsplash



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Instrument Platforms

Photo by Bluefin on Wikipedia

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Large-Scale Applications

Photo by Fernando Jorge on Unsplash

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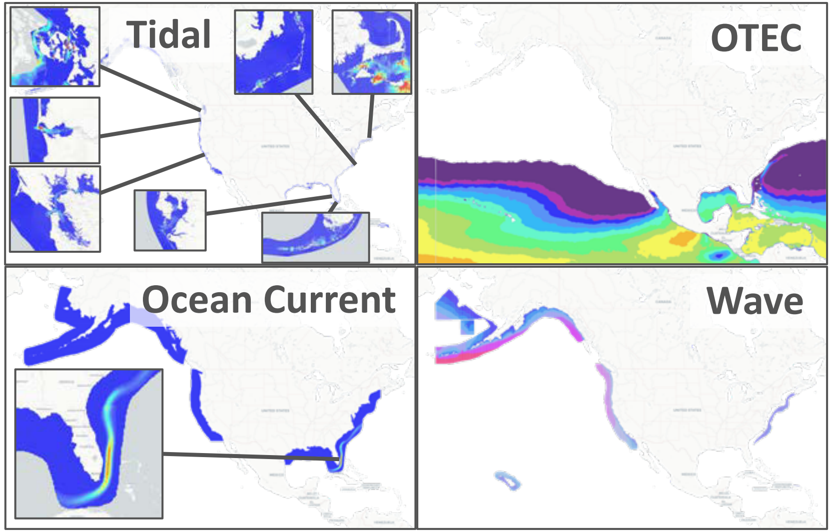
Accomplishments and Progress: Fact-Finding Results

- **Fact finding results were summarized in the first milestone report.**
- Highlights:
  - PEM and liquid alkaline are the most commonly discussed electrolysis technology for offshore applications.
  - More data about MRE device operation and economics are required for detailed analysis and planning.
  - There are few publicly documented examples of completed MRE to hydrogen demonstration projects, but there are many projects in development.

Accomplishments and Progress: Fact-Finding Results

- **Marine renewable energy devices vary greatly in their design, energy output, power profiles, and geographic availability.**

Resource	Tidal Stream	Wave Energy	Ocean Current	Ocean Thermal
Favorable Locations	Tidal Inlets with Specific Geography	Western US Coastline (off-shore and near-shore)	Eastern Florida Coast	Tropics
Capacity Factor	30%	30%	70%	>90%
Typical Unit Power	1 MW (30 GGE/hr)	300 kW (9 GGE/hr)	5 MW (150 GGE/hr)	>100 MW (> 3000 GGE/hr)
Characteristic Size	50 m (160 ft)	20 m (65 ft)	100 m (330 ft)	1 km (Depth) (0.62 miles)
Fluctuation Period	Diurnal to Semi-diurnal	5-20 seconds	Annual	Annual
Variability	Monthly	Seasonal	Days, Seasonal	Seasonal
TRL	4-5	3-5	3-5	3-5



Resource maps from the NREL MHK Atlas:
https://maps.nrel.gov/mhk-atlas/

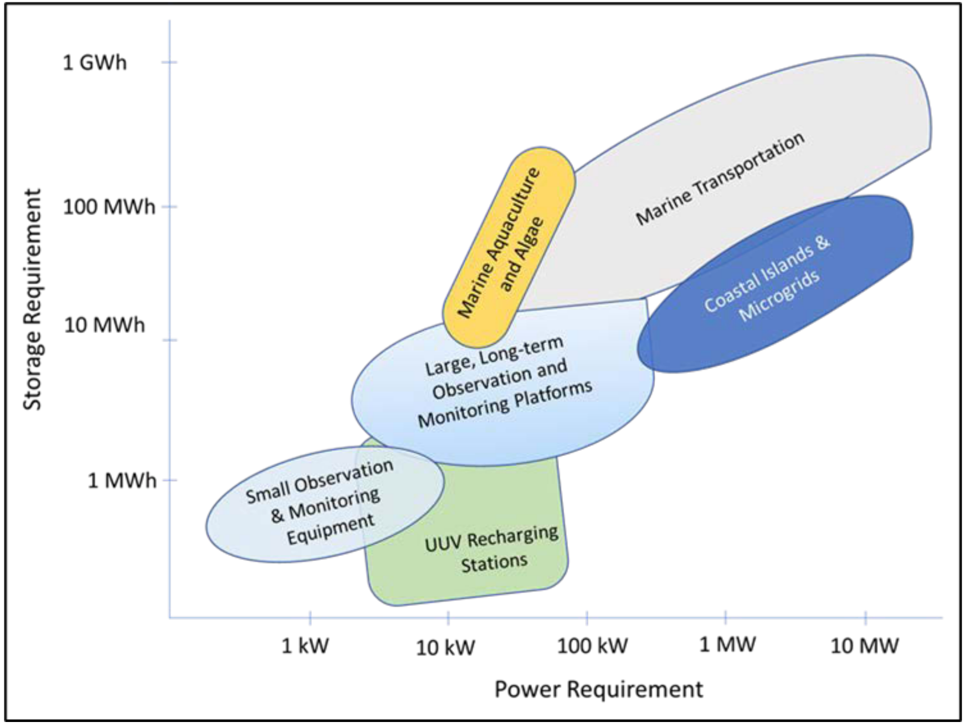
Accomplishments and Progress: Fact-Finding Results

- **PEM and liquid alkaline are the most common electrolysis devices in consideration for offshore hydrogen applications.**
- Direct seawater electrolysis has promise for offshore applications because it reduces the costs and complexity related to water filtration.
- Solid oxide electrolysis could be competitive in large, high-utilization applications where the high operating temperature could be maintained.

Technology:	AEC	PEMEC	SOEC	AEMEC	DSE
Operating Temperature	60°-100°C	50°-90°C	650°-1000°C	40°-60°C	TBD
Typical Outlet Pressure	< 435 psi (3 MPa)	< 2900 psi (20 MPa)[a]	< 363 psi (2.5 MPa)	< 508 psi (3.5 MPa)	-
System Electrical Conversion (kWh/kg)[b]	50-79	50-83	39.8-50[c]	57-69	-
Dynamic Response Speed	Seconds	Milliseconds	Seconds	Milliseconds	-
Electrolyte	Aqueous alkaline electrolyte	Polymer membrane	Ceramic membrane	Polymer membrane	Seawater
Demonstrated Stack Durability	60,000-90,000 hr	20,000-80,000 hr	< 35,000 hr	> 5,000 hr	-
Produced H_2 Gas Purity (%)	> 99.3	> 99.9	> 99.9	> 99.9	-
Cold Start Time (min)	< 60	< 20	< 60 - 600	< 20	-
Lower Dynamic Range (%)	10–40	0–10	30	5	-
System Capital Cost ($/kW)	~500-1,600	~450-2,800	~500-2,400+	-	-

Accomplishments and Progress: Fact-Finding Results

- End uses that were identified in the Powering the Blue Economy Report vary greatly in terms of energy storage and power requirements.
- **Hydrogen-based fuels are often most promising in applications with high energy storage requirements.**



Accomplishments and Progress : Virtual Working Meeting

- When: February 17th, 8:00am – 12:30pm
- **The meeting was attended by a diverse group of experts (115 total)** from:
  - US Universities (UW, UNLV, GA Tech, OSU, UI-UC, UC-D, UNH, USF, VA Tech, Lehigh, Purdue)
  - International Universities (NUI Galway, University of Edinburgh, University of Naples Parthenope, NTU Singapore)
  - National Labs (PNNL, NREL, SNL, US NRL, NASA JPL, LBNL)
  - Governments (US DOE, US ARPA-E, Gov’t of Canada, CHBC)
  - US Military (Army, Coast Guard, Marines , Navy)
  - Hydrogen Electrolyzer and FC OEMs (NEL, Giner, Ballard)
  - Marine Energy Device Experts (PacWave, POET, CalWave)
  - Demonstration Projects (Golden Gate Marine, EMEC, Farwind Energy, GTA, Ocean Hyway Cluster)
  - Other Industry (Northrop, Boeing, Kongsberg Maritime, Tokyo Boeki Machinery, UMBRAGROUP)
- Attendees were divided into 6 breakout groups to discuss MRE to hydrogen pathways

Accomplishments and Progress: Breakout Group Findings

- **Breakout groups for each topic area identified markets and locations where MRE-H_2 was a potential energy pathway.**
- Each pathway also offers unique opportunities relative to incumbent technologies.
- Challenges related to scaling were discussed in groups assigned to each pathway.
- Breakout groups identified opportunities to integrate into a larger hydrogen economy.
- Many of the technical challenges that were identified could be addressed with near-term technological advances.

Accomplishments and Progress:
Response to Previous Year Reviewers' Comments

- This project was not reviewed last year.

Collaboration and Coordination

- Participated as a panelist in the TMA BlueTech "Smart and Green Ports Panel" – November 19, 2020
- Hosted the "Marine Energy to Hydrogen Working Meeting" – February 17, 2021

Remaining Challenges and Barriers

- Systems to supply purified water for consumption by an offshore electrolyzer system add complexity and cost.
- MRE power take off (PTO) device designs have not coalesced on “typical” designs, making analysis more complex.
  - There are still substantial knowledge gaps regarding the costs, power production, and other important aspects of MRE devices that will impact system designs.
  - Some metrics like power capacity ratings are not standardized across different designs for PTO devices.
- There is still significant uncertainty regarding the future of hydrogen’s role in decarbonizing offshore applications.

Any proposed future work is subject to change based on funding levels.

Proposed Future Work

- Work with offshore experts to understand the opportunities and challenges associated with marine deployments
- Collaborate with maritime end users to better understand unique design constraints that will affect adoption of hydrogen-based fuels
- Develop high-level models to identify technically feasible MRE to hydrogen system integration techniques
- Conduct boundary-level TEA for the most promising pathways identified in this project's reports to further narrow the scope of feasible applications

Any proposed future work is subject to change based on funding levels.

Summary

- Combined marine renewable energy (MRE) and hydrogen systems have promise in a broad swath of non-grid applications.
- The diversity of MRE technologies provides a large opportunity space but also makes analysis significantly more complex.
- Hydrogen electrolysis is a promising technology for utilizing highly variable MRE resources without temporal dampening.
- Hydrogen-powered offshore devices could decarbonize challenging applications while also realizing additional benefits like improved range and reduced chemical and acoustic emissions.

Thank You

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Technical Backup and Additional Information

Technology Transfer Activities

- No technology transfer outcomes to date.

Progress Toward DOE Targets or Milestones

- This project will contribute to achievement of the following DOE milestones from the Systems Analysis section of the Hydrogen and Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan:
  - Milestone 1.20: Complete review of fuel cell and hydrogen markets.
  - Milestone 3.3: Complete review of status and outlook of non-automotive fuel cell industry.

Special Recognitions and Awards

- No special recognitions in the review period.

Publications and Presentations

- Jacob Thorson. 2020a. "MHK to Hydrogen Analysis Project Update." Presented at the HFTO Monthly Analysis Meeting, July 20.
- Jacob Thorson. 2020b. "Decarbonizing Ports with Hydrogen." Smart & Green Ports Panel presented at the BlueTech Week 2020, November 19.
- Jacob Thorson, Kevin Hartmann, Chris Matthews, Todd Ramsden, Mark Ruth, and Dale Scott Jenne. 2020. "Marine and Hydrokinetic Power to Hydrogen." Milestone Report.