PRIMRE: Providing Centralized Access to Marine Energy Data and Information

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***Abstract*— PRIMRE - the Portal and Repository for Information on Marine Renewable Energy - is an interconnected system of seven knowledge hubs that provide access to data, information, and other resources that are of importance for the marine energy community (https://primre.org). Each knowledge hub has its own unique identity, structure, and purpose. PRIMRE was launched in 2019, funded by the U.S. Department of Energy's Water Power Technologies Office (DOE WPTO) and managed by three DOE national laboratories. PRIMRE's centralized search (https://primre.org/search) allows users to easily search, filter, and find content within the PRIMRE universe. The Ask PRIMRE generative AI research assistant (https://primre.org/AskPRIMRE) enables users to get quick answers to contextual questions and guides them to insights beyond simple keyword searches. PRIMRE provides broad public access to marine energy data and information across all knowledge hubs. Additional features on PRIMRE include an events calendar, archived webinars, educational content, a biweekly newsletter, a free use photo library, a variety of online tools, and links to external resources.**

Keywords—marine energy data systems, knowledge hubs, generative AI assistant.

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I. INTRODUCTION

THE marine energy industry is emerging as a piece of the renewable energy portfolio of many coastal nations, with a small number of commercial projects in the water and many more in the pipeline [1]. At the same time, many new devices are being designed and undergoing testing. International specifications are becoming standards and heading towards certification for wave and tidal devices [2]. As demonstrated by other industries, the establishment of a new sector such as marine energy is accelerated by transparency and broad availability of data and information from early adopters and ongoing research [3] [4].

This paper will discuss the development and advancement of the PRIMRE system. PRIMRE – the Portal and Repository for Information on Marine Renewable Energy – is the system developed in the United States (US) to house, collate, and disseminate

information and data in support of marine energy. This work demonstrates the value of new additions to the PRIMRE system including the integration of seven knowledge hubs to provide a single point of contact for marine data and information in the US and increasingly internationally, and the addition of an artificial intelligence (AI) assistant to PRIMRE.

II. METHODS

PRIOR to 2019, several US databases associated with marine energy existed to house and disseminate information of different types, including a documents library and tools for assessing environmental effects, a depository for device testing data, and a geographic information systems (GIS) platform for marine energy resource data. The documents that are collected in PRIMRE include peer-reviewed papers as well as grey literature such as monitoring reports, many of which are not found elsewhere on the internet. The existing databases were not connected or related using a coordinated terminology and thus did not provide a mechanism for relating different aspects of marine energy development to one another, nor were all necessary data and information elements available to support a successful industry.

The US Department of Energy's Water Power Technologies Office (DOE WPTO) directed three DOE national laboratories to create a system to supply necessary information to the marine energy industry and research community. The National Renewable Energy Laboratory (NREL), Pacific Northwest National Laboratory (PNNL), and Sandia National Laboratories (Sandia) created PRIMRE to collate, analyze, and disseminate all the data and information that will assist the growing industry. Existing databases, including Tethys, MHKDR, and the Atlas, were brought into PRIMRE as knowledge hubs, several new knowledge hubs were developed, and the system was integrated to support and enhance interoperability.

In recent years, additions to PRIMRE have included a centralized search that will take the user to the appropriate material on any of the knowledge hubs, using keywords, and a large language model (LLM) developed using artificial intelligence to draw on the extensive material in PRIMRE. The PRIMRE team also recently conducted a user experience (UX) study to help refine the look, accessibility, and applicability of the material on the site.

III. RESULTS AND DISCUSSION

PRIMRE (https://PRIMRE.org) was developed and is hosted across the three US Department of Energy national laboratories.

Although PRIMRE is a US system, supported by the US government, the content is international, to meet the needs of an international marine energy industry. Similarly, the research community supporting the industry is integrated across countries. PRIMRE seeks to serve the international community as well as that in the US.

A. PRIMRE System

The PRIMRE system consists of seven knowledge hubs, each with a specific data or information type, hosted on a platform that is specific to that data or information type (Table 1; Figure 1).

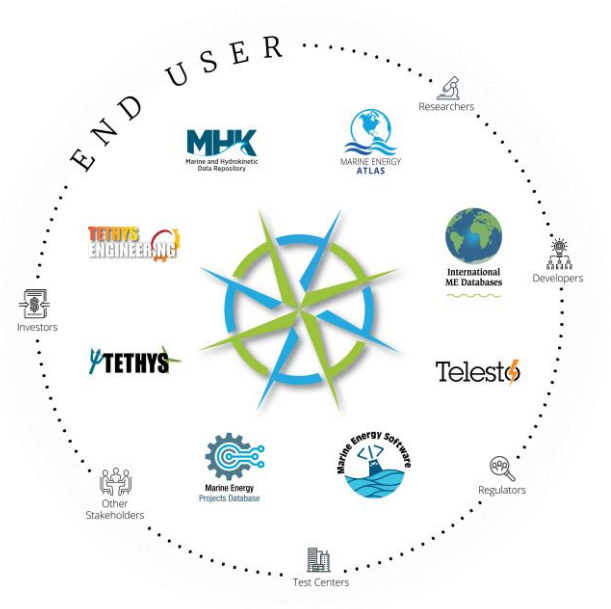

Figure 1. The PRIMRE system with the central PRIMRE integration depicted by the compass rose in the center, surrounded by the seven knowledge hubs, and a space for international collaboration. The end users surround PRIMRE, representing the many different communities it serves; each end user is associated with multiple knowledge hubs.

B. PRIMRE Centralized Search

The PRIMRE centralized search (Figure 2) was created by developing standardized APIs on each of the knowledge hubs that supply the search with standardized metadata for each of their digital assets using the PRIMRE Metadata Schema [5]. For example, using "whales", "tidal turbines", and "collision risk" as search terms, results may include papers and webinars on interactions of whales and tidal turbines from Tethys; papers on the development, testing, and efficiency of tidal turbines from Tethys Engineering; information on organizations and projects dedicated to tidal energy development from the Marine

Energy Projects Database; and risk modelling tools from Marine Energy Software. Additional search results may include links to information on project planning and compliance on Telesto, including the Marine Energy Environmental Toolkit, and datasets from the Marine and Hydrokinetic. Data Repository (MHKDR).

TABLE 1. THE KNOWLEDGE HUBS OF PRIMRE, THEIR PURPOSE, THE TYPE OF PLATFORM ON WHICH EACH IS HOSTED, AND THE US DEPARTMENT OF ENERGY NATIONAL LABORATORY WITH PRIMARY MANAGEMENT OF THE SYSTEM. EACH KNOWLEDGE HUB IS OF USE TO MULTIPLE USER GROUPS.

Knowledge Hub	Purpose	Platform	Managed by
MHKDR (https://mhkdr.openei.org/) Marine and Hydrokinetic Data Repository	Data collected by marine energy research and development projects funded by DOE.	xDR (extensible Data Repository)	NREL
Tethys (https://tethys.pnnl.gov/)	Hosts documents, educational resources, and online tools on the environmental effects of marine and wind energy development.	Drupal	PNNL
Tethys Engineering (https://tethys-engineering.pnnl.gov/)	Hosts documents on the technical and engineering aspects of marine energy research and development.	Drupal	PNNL
Marine Energy Projects Database (https://primre.org/Projects_Database)	Contains up-to-date information on marine energy projects, devices, companies/organizations, and test sites around the world.	Semantic MediaWiki	PNNL NREL
Marine Energy Software (https://software.primre.org/)	A collection of open-source and commercial software relevant to marine energy research and development.	React + GitHub	Sandia PNNL
Marine Energy Atlas (https://maps.nrel.gov/marine-energy-atlas/)	A geospatial mapping tool that allows users to visualize, analyse, and download geospatial datasets relevant to marine energy resources.	React + VADR	NREL
Telesto (https://primre.org/Telesto)	Hosts information about the development life cycle of marine energy, as well as information on lessons learned, metrics, economics, and standards.	Semantic MediaWiki	Sandia NREL

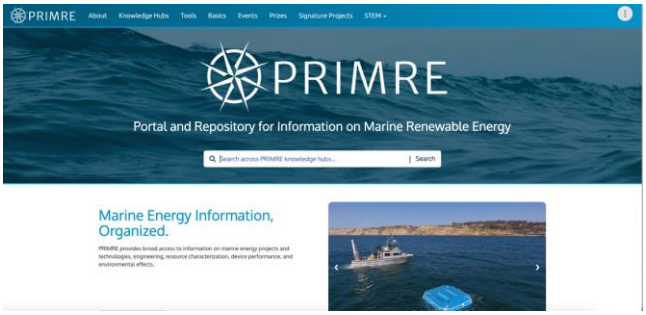

Figure 2. Landing page for PRIMRE, with the centralized search bar in the center.

C. *AskPRIMRE*

The centralized PRIMRE search relies only on keyword matching, making it suitable for simple queries (e.g., wave energy tank testing data), but it cannot handle complex or abstract questions (e.g., what are the major environmental concerns related to marine energy development?). AskPRIMRE (https://primre.org/AskPRIMRE) was developed to address these more complex questions and provide additional contextual understanding. It functions as an Artificially Intelligent (AI) Research Assistant, providing insight and answering questions on a broad range of marine energy research topics.

All resources in PRIMRE have significant amounts of machine-readable data which aids in the development of AskPRIMRE. However, users might have additional questions that metadata alone cannot anticipate, leading to frequent and repeated inquiries. To clarify any uncertainties, users have had to manually sift through documents or data documentation, causing delays and missing important information. AskPRIMRE addresses these inquiries too by integrating related resources (i.e., datasets, publications, and supporting documents) from PRIMRE's many knowledge hubs. It consolidates the metadata and related documentation into a Large Language Model (LLM), allowing it to provide efficient, in-depth answers to complex technical questions—saving time for POCs and offering faster insights for users. All information accessed by AskPRIMRE is available on PRIMRE and can be cited to verified sources; as new papers and information becomes available, those resources are added to PRIMRE. This exclusivity ensures that AskPRIMRE is using only known and verified sources.

D. *User Experience*

In 2024, a User Experience (UX) study was carried out by UX experts at the three national laboratories, surveying and interacting with users of the PRIMRE site, while the users were actively exploring and finding information on the site. The focus was on the overall PRIMRE site as well as the Marine Energy Atlas, Telesto, and the Marine Energy Projects Database. The UX researchers met with 22 users of PRIMRE, including researchers, students, developers, and other users. They sought to understand how the users learned about PRIMRE, their average use intervals and timing for PRIMRE, and to assess the overall user experience of PRIMRE including navigation, filters, and way-finding. This information was used to identify opportunities for improving PRIMRE's functionality or usability, and to better articulate the benefits of PRIMRE to the community.

The results of the UX study led the PRIMRE team to an overhaul of the PRIMRE homepage and About page to provide easier access to frequently used materials and better articulate PRIMRE's mission and purpose. In addition, several knowledge hubs have undergone reorganization and upgraded filters for easier access.

E. *International Data Hosting and Sharing*

PRIMRE has become the home of the Ocean Energy System's (OES) geospatial database of projects and related data. The Marine Energy Atlas, the GIS platform on PRIMRE, began hosting the OES data layers in 2022, with annual updates of the information provided by OES representatives from the participating nations [1]. This integration brings together other data layers that are generated by specific nations or through global cooperation, such as bathymetry layers (Figure 3).

In addition, PRIMRE has hosted an annual International Data Sharing Workshop. By invitation, marine energy data system administrators, researchers, device and project developers, as well as regulators and advisors, have come together online to discuss the challenges and opportunities to collecting, curating, analysing, and disseminating marine energy data.

Figure 3. Screenshot of Marine Energy Atlas, showing project information provided by OES, as well as worldwide bathymetry and US wave resource data.

PRIMRE and OES hosted the first international data sharing workshop online in 2021 to see if there was interest among data systems administrators to share information. The PRIMRE team quickly discovered that there is an appetite for understanding the needs, requirements, challenges, and value of sharing information on marine energy data systems, and also in developing processes for sharing data across systems. The workshops have been well attended each year, with one or more systems showcased from around the world (e.g., Marine Data Exchange, MARENDATA, RESCORE), paving the way for more collaborations and data sharing between systems. The focus of the workshops varied from year to year (Table 2), with the 2024 workshop addressing the issue of equitable and accessible data standards through the FAIR (Findable, Accessible, Interoperable, Reusable) principles. The participants also discussed the emerging FARR principles (FAIR in machine learning, AI Readiness, and Reproducibility) that seek to plan for ongoing and future AI capabilities for broad dissemination of data.

The 2025 workshop was the fifth annual gathering and focused on how we assess the value of data systems such as PRIMRE and others in the marine energy space. The frequent use of analytics to track database usage, as well as means to better understand the users through UX and other tools, all contribute to the perceived value of a data portal, and are likely to influence funding decisions in the future.

TABLE 2. SUMMARY OF FIVE YEARS OF INTERNATIONAL MARINE ENERGY DATA SHARING WORKSHOPS. WORKSHOP REPORTS ARE AVAILABLE ON TETHYS ENGINEERING.

Date of Workshop	Focus of Workshop	Additional Details and outcomes
May 2021	Value of data sharing, the barriers to data sharing, and potential solutions	Strong consensus on the value of reconvening the group to discuss data sharing opportunities & progress
May 2022	Levels of data sharing, standardization, and opportunities to connect databases	Updates on PRIMRE, MARENDATA (EC), & RESCORE (France)
May 2023	Geospatial data sharing and potential expansions of the Marine Energy Atlas	Interoperability demonstrated
May 2024	Sharing science with FAIR and FARR data principles	Updates on PRIMRE and Marine Data Exchange (UK)
June 2025	Measuring impact of data systems, tracking metrics, knowing the audience	

IV. CONCLUSION

PRIMRE is an integrated data and information system specifically designed to support the marine energy industry. The PRIMRE team is supported by the US Department of Energy to develop and maintain the system. The system is international in scope and has the potential to bring together data system operators, researchers, device and project developers, and other stakeholders around the world in supporting this newest source of the renewable energy generation. The PRIMRE team welcomes collaboration, data sharing, and contributions of data, papers, project information, geographic data layers, and other media as additions to the system.

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