Portal and Repository for Information on Marine Renewable Energy (PRIMRE)

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I. INTRODUCTION

When marine energy data and information are openly available, they can be used to guide research and development, inform siting and consenting, and increase stakeholder buy-in through transparency. The impact of making them available can be enhanced by also ensuring they are easily accessible and discoverable for everyone. The U.S. Department of Energy's Portal and Repository for Information on Marine Renewable Energy (PRIMRE) (https://primre.org) provides broad access to data, information, and other resources intended to support the international marine energy community, including researchers, developers, and students. PRIMRE also links to other marine energy data systems to encourage data sharing for universal and transparent access. This paper highlights some of the key resources available within PRIMRE and discusses recent efforts made towards increased data sharing and interoperability in the United States and internationally.

II. METHODS

The U.S. Department of Energy (DOE) Water Power Technologies Office (WPTO) directed Pacific Northwest National Laboratory, National Renewable Energy Laboratory, and Sandia National Laboratories to enhance the accessibility and discoverability of information relevant to marine energy (e.g., wave, current) research, development, and deployment in the United States.

In 2019, the joint lab team launched PRIMRE to serve as a centralized system for marine energy data, information, and resources that can be used to advance the industry. PRIMRE is primarily made up of seven knowledge hubs (Figure 1), each with its own unique identity, structure, and purpose: the Marine and Hydrokinetic Data Repository (MHKDR) hosts datasets, Tethys hosts environmental documents, Tethys Engineering hosts technical documents, the Marine Energy Projects Database hosts deployment activities, Marine Energy Software hosts software, Marine Energy Atlas hosts geospatial data, and Telesto hosts development guidance. The PRIMRE aggregate search allows users to easily search, filter, and find content from across all seven knowledge hubs.

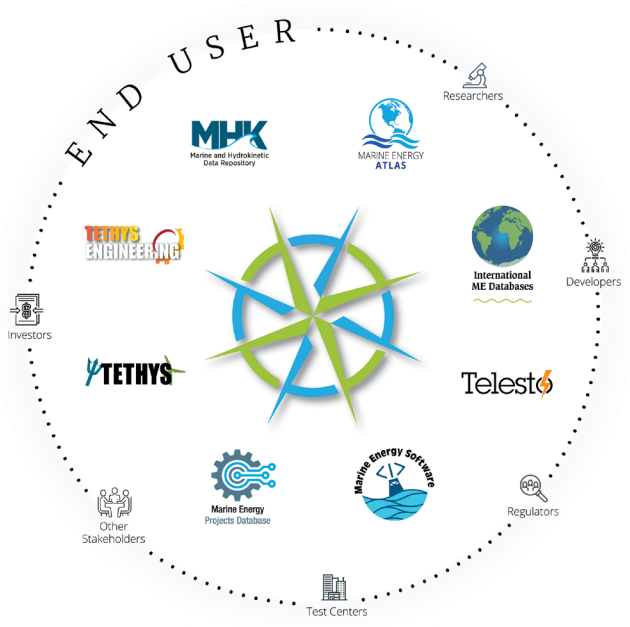

Fig 1. The Portal and Repository for Information on Marine Renewable Energy (PRIMRE) knowledge hubs and relevant users.

PRIMRE also hosts a variety of additional resources, including an events calendar, educational content, archived webinars, online tools, and a free use photo library. The PRIMRE Blast , a bi-weekly online newsletter, highlights content from the PRIMRE knowledge hubs; relevant announcements, opportunities, and upcoming events; and news articles of international interest.

The PRIMRE team places substantial focus on outreach, engagement, and search engine optimization to ensure the site is reaching and serving the international marine energy community. The development of PRIMRE and its knowledge hubs is also guided by a steering committee and regular user reviews.

Following the FAIR principles for scientific data management and stewardship [1], PRIMRE was designed to make data and information findable, accessible, interoperable, and reusable. All content is free and available to the public, except for datasets protected under temporary moratoriums and copyrighted publications. Metadata for these resources is still made available to the public to promote their discovery and public release dates.

Interconnectivity between the knowledge hubs is powered by a published metadata standard and uniform Application Programming Interface (API) exchanges. The PRIMRE team created a simplified metadata schema based on DCAT-US, a metadata schema designed by the U.S. Project Open Data [2], which, when combined with APIs, allows the exchange of standardized metadata between the knowledge hubs and external databases (Figure 2). Adoption of the PRIMRE metadata standards allows any online organization to join the PRIMRE community by displaying their content within the PRIMRE search results or by incorporating PRIMRE content into their site, ultimately improving overall discoverability.

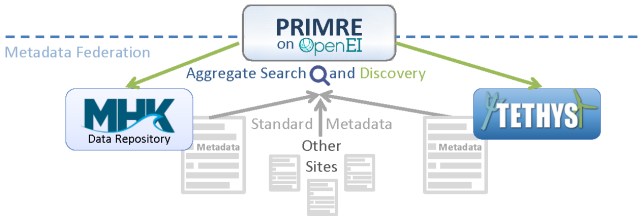

Fig 2. A standard metadata schema and metadata federation allow for the Portal and Repository for Information on Marine Renewable Energy (PRIMRE) aggregate search to search for content across the knowledge hubs.

III. PRIMRE Knowledge Hubs

A. MHKDR

MHKDR is the repository for all data collected by marine energy research and development projects funded by the DOE's WPTO, including data from tank and open water device testing, resource characterization data and model outputs, techno-economic analyses, and more.

The data repository features a marine energy data pipeline that automatically recognizes select data submitted and translates it into standardized formats before making the data publicly available. By automating data ingestion and standardization, MHKDR and the pipeline can reduce the burden of data translation on project teams, especially for large and streaming data.

MHKDR is also integrated with the DOE Open Energy Data Initiative (OEDI) to host a cloud-accessible marine energy data lake, which provides big data storage and analysis solutions for research and development projects. The goal of PRIMRE's marine energy data lake is to provide universal access to marine energy data.

B. Tethys

Tethys hosts over 8,500 documents on the environmental effects of both marine and wind energy development, including journal articles, scientific reports, and conference papers. The content covers a range of topics, such as underwater noise effects on marine mammals and fish collision risk with tidal turbines.

Tethys also serves as a collaborative space and dissemination platform for the Ocean Energy Systems (OES) Environmental initiative, which is a collaboration among 16 countries to examine the environmental effects of marine energy development around the world. OES-Environmental develops useful tools and publications for researchers, regulators, and other stakeholders, including the public. For example, the Educational Resources page features materials and resources that can be used by students of all ages and educational backgrounds, including short videos, coloring pages, and an interactive video game: *Marine Energy Adventure: Collision Risk*.

Like the PRIMRE Blast, the bi-weekly Tethys Blast newsletter provides up-to-date information on upcoming events, funding and job opportunities, international wind and marine energy news, and new publications in Tethys.

C. Tethys Engineering

Tethys Engineering hosts over 7,500 documents on the technical and engineering aspects of marine energy research and development. The content covers a range of topics, including site characterization, testing and design, device survivability, control and power take off systems, cost assessment, and power performance.

Tethys Engineering also features a Photo Library that contains over 600 hundred high-resolution photos and illustrations of marine energy devices, arrays, and facilities, that have been graciously provided by developers worldwide. The images are available for free third-party use with attribution.

D. Marine Energy Projects Database

The Marine Energy Projects Database contains up to date information on marine energy projects and devices around the world; highlights the devices deployed at these locations used by these projects; and points to companies and other organizations active in the marine energy field. Each of the pages in the database are semantically linked to one another, creating a rich data structure to explore the relationships between organizations operating in the marine energy sector, their projects, and the devices that they are developing and deploying.

Project developers can easily submit project information using simple web forms, allowing the international marine

energy community to stay informed on industry progress and developments worldwide.

E. Marine Energy Atlas

The Marine Energy Atlas is an interactive platform that can be used to visualize, analyze, and download geospatial datasets relevant to marine energy. The mapping tool allows users to map wave, tidal, river, ocean current, and ocean thermal resources in the United States to explore the potential for marine energy projects. Through a partnership with OES, international Geographic Information System (GIS) data layers, including locations for marine energy projects, bathymetry, ports, population densities, exclusive economic zones, and marine protected areas, are also available.

The Marine Energy Atlas supports everything from project siting to device design through comprehensive, high-resolution datasets and useful in-app analytical tools. For example, the Capacity Factor Tool offers the ability to create Capacity Factor maps of specific wave energy converters based on their power matrices.

F. Telesto

Telesto is home to open-source wiki pages and structured databases that provide information about the development life cycle of marine energy, including planning, design and build, testing, deploying, and decommissioning. Incorporated within each section is information on performance metrics, economics, industry standards, and lessons learned from lab and field testing.

For example, the PRIMRE team conducted interviews with subject matter experts to collect lessons learned from past and present marine energy research, development, and deployment projects in the United States. Telesto presents the main lessons learned across a variety of themes and features links to relevant resources throughout PRIMRE. Telesto also provides useful information for calculating the levelized cost of energy of devices, a sensor and instrumentation database, a testing facilities database, an environmental permitting toolkit, and more.

G. Marine Energy Software

Marine Energy Software is a collection of over 240 open-source and commercial software that are relevant to marine energy research and development. The content covers a variety of software packages used by the marine energy community to aid in analyses across the scope of marine energy such as engineering and technical design, operations and maintenance, environmental assessment, economics and performance metrics, optimization, and data analytics and visualization.

IV. INTERNATIONAL DATA SHARING

On behalf of OES and the U.S. DOE, the PRIMRE team hosts annual international workshops to explore the potential for sharing marine energy data internationally. Workshop participants are invited to attend based on their knowledge and experience with, or responsibilities for, marine energy databases and portals in their nations. Each workshop features presentations on some of the various marine energy resources available around the world (e.g., databases, portals, tools), followed by discussions focused on the value of data sharing, the barriers to data sharing, and solutions to overcome those barriers.

During the inaugural workshop in 2021, participants were introduced to PRIMRE and its knowledge hubs, explored whether international collaboration in this arena is feasible and useful, and identified a series of solutions needed to enable international marine energy data sharing. There was strong consensus that an annual workshop that updates the international marine energy community on the status of marine energy databases and portals and the potential for sharing data across platforms is needed and useful.

Building on the first workshop, the 2022 workshop featured presentations on two new marine energy databases from Europe (MARENDATA and RESCORE), updates on the PRIMRE team's activities, and discussions around the possible levels of data sharing between sites (i.e., linking, deep linking, and metadata federation). Following the workshop, the PRIMRE and MARENDATA teams worked together to integrate MARENDATA's content into the PRIMRE search using standardized APIs.

Finally, the 2023 workshop featured updates from several marine energy and geospatial databases from around the world and highlighted MARENDATA and PRIMRE's interoperability as a unique success to be repeated with other sites. Participant discussions focused specifically on geospatial data sharing, its challenges, and potential expansions to the Marine Energy Atlas.

V. CONCLUSION

The PRIMRE team is continuously updating and expanding PRIMRE and its knowledge hubs to improve marine energy data and information organization. Recent successes include enhancements to marine energy data pipelines and data lake architectures within MHKDR; the reorganization of Telesto and Marine Energy Software; and the incorporation of international GIS data into the Marine Energy Atlas. The PRIMRE team also continues to pursue API exchanges and other connections with related marine energy knowledge repositories around the world to encourage sharing for universal and transparent access.

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