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Abstract

The Marine Renewable Energy (MRE) industry is in the early stages of development corresponding to low technology readiness levels (TRLs) where the ability of the MRE community (developers, researchers, academics, stakeholders, investors, and regulators) to work together to share knowledge, experience, and lessons learned is critical to the advancement of the entire MRE industry. Through collaboration on solving common problems, the MRE community has the potential to reduce cost and accelerate technology development. Currently, the US Department of Energy (US DOE) Water Power Technologies Office (WPTO) is addressing the challenge of storing, curating, and accessing MRE information by sponsoring development of MRE databases and information portals such as Tethys (<https://tethys.pnnl.gov>), OpenEI (<https://openei.org>), the MHK Data Repository (MHKDR, <https://mhkdr.openei.org/>), and a searchable MRE code catalog and open source code repository (MHKiT, currently under development), to name a few. These sites host scientific papers, news articles, reports, databases, open source codes, and stakeholder engagement information, but they are only a step towards facilitating global discovery and use. In short, there is an abundance of information available online, however it is located on many disparate sites and repositories that make the discovery of those data and information difficult.

A DOE national laboratory team from the National Renewable Energy Laboratory (NREL), Pacific Northwest National Laboratory (PNNL), and Sandia National Laboratories (Sandia) is addressing the issues of data discoverability, shared knowledge, and interconnection of existing MRE databases and information portals. To meet the needs of the MRE community, as identified through multiple community outreach and engagement events, and described in this paper, the multi-lab team has developed an implementation plan for PRIMRE, the Portal and Repository for Information on Marine Renewable Energy. PRIMRE will provide broad access to information on engineering and technologies, resource characterization, device performance, and environmental effects of MRE projects. PRIMRE will facilitate the commercial development of the MRE industry by increasing the accessibility and discoverability of this information, integrating the databases and information portals described in this paper, and developing standards and guidelines. Providing consistent, easy access to information can help reduce duplication of

effort and enable the MRE community to learn from past failures and build upon the successes of others to innovate and advance the commercialization of MRE technologies.

Introduction

Marine Renewable Energy (MRE) technologies convert the energy of waves, tides, and ocean and river currents into electricity or other forms of usable energy. In the context of this paper, MRE and Marine Hydrokinetic (MHK) are used interchangeably. The MRE industry is relatively young compared to other energy sectors. The energy conversion technologies emerging from this industry are in the early stages of development. A lack of established industry leaders, design paradigms, and relatively low technology readiness levels (TRLs) presents both challenges and opportunities. While the fledgling MRE industry is proving to be an exciting arena for entrepreneurs and inventors, to be commercially successful it must become cost competitive with other energy industries. If the community gives way to competition rather than collaboration at this early stage, there are inherent risks that could stifle the community as a whole (developers, researchers, academics, stakeholders, investors, and regulators). Significant innovations that fail to pair with an effective business model can be lost when startup companies dissolve. A lack of focus on leveled cost of energy (LCOE) or failure to identify the appropriate market for a device can stifle development or lead to the premature abandonment of a technology that otherwise could have been commercially viable. Even successful companies can suffer as they spend critical resources performing duplicative work, whether it is solving common problems, writing standard testing code, or repeating the unpublished research of others. This climate presents a real opportunity for the MRE community to come together to share knowledge, experience, and lessons learned. The results could benefit to the MRE industry, increasing the rate of innovation for all companies, and making MRE technologies more competitive in the global energy marketplace.

The Value of Sharing Information

Sharing data, research findings, establishing industry standards, and collaborating on solutions to common problems can reduce cost, accelerate the development of technology, and even spur innovation in the MRE industry. Communication of knowledge is an essential component of actualizing the value of data and information. In their 2011 Strategic Plan, the US Department of Energy (DOE) describes their own success as something that, “should be measured not when a project is completed, or an experiment concluded, but when scientific and technical information is disseminated.” (DOE 2011). Data collected do not advance the state of the art or fully actualize their value until they have been disseminated to the MRE community. To this end, the DOE Water Power Technologies Office (WPTO) requires data management and dissemination plans in many of their funding opportunities. These requirements are being supported above the department level by a series of memos from the Executive Office, which assert that “making information resources accessible, discoverable, and usable by the public can help fuel entrepreneurship, innovation, and scientific discovery.” (Burwell 2013). Simply making data available does not automatically make them useful. As Burwell and his colleagues address in their memo, in order to be useful to others, data must also be useable, accessible, and discoverable. Through the establishment of PRIMRE, the multi-lab team aims to increase the usability, accessibility and discoverability of MRE data.

The Current MRE Data Landscape

To promote scientific discovery and advance the commercialization of MRE technologies, the DOE WPTO has funded the development and maintenance of several MRE data repositories and information portals, including OpenEI (<https://openei.org>), Tethys (<https://tethys.pnnl.gov>), the MHK Data Repository (MHKDR, <https://mhkdr.openei.org/>), and a searchable MRE code catalog and open source code repository (MHKiT, currently under development). These sites host scientific papers, news articles, reports, data, open source codes, and other information, each with a thematic focus, targeting a portion of

the MRE community or addressing a specific category of information. The specialization of these tools allows them to be more effective at providing utility to the communities they serve, but the number of tools available to the community presents its own challenge. The abundance of information that may be pertinent to the MRE community online is currently located in numerous repositories and disparate sites, making the discovery of those data and information more difficult (Figure 1 – left side). These sites have traditionally been built in silos, focused on their own specialization without integration, hosting different sources of information, and on unique update cycles. The isolated development strategies create the possibility for information confusion. If the same information present on two sites is updated at different intervals, the sites could be displaying different versions of the same information. Further complicating matters, if one or more of the sites do not display proper attribution for the versioning and sourcing of their data, users of the sites may be unable to tell which information is more accurate or current.

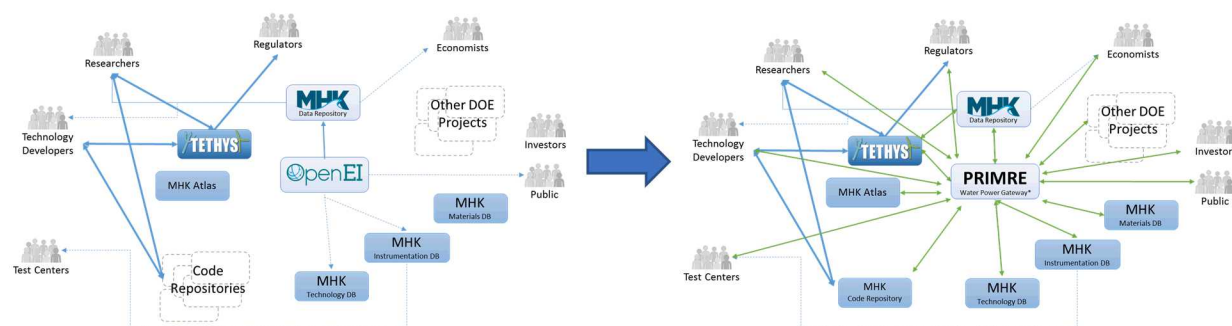


Figure 1. MRE Data Community before (left) and after PRIMRE (right)

To address these issues, DOE has funded several of their national laboratories to examine and improve upon the system of data accessibility and usability. Data and MRE experts from the National Renewable Energy Laboratory (NREL), Pacific Northwest National Laboratory (PNNL), and Sandia National Laboratories (Sandia) form the team that developed a phased approach to addressing the issues of data discoverability, shared knowledge, and interconnectivity among existing MRE databases and information portals. The first phase is the creation of PRIMRE, the Portal and Repository for Information on Marine Renewable Energy. Acting as a central access point or portal to the disparate MRE information, PRIMRE will provide broad access to resource characterization, engineering and technologies, environmental, and device performance information on projects across the MRE landscape. Users of PRIMRE will be able to access the various MRE data tools directly, from a central location (Figure 1 – right side). Additionally, connections between the disparate sites themselves will be made through the adoption of data standards, the federation of metadata (i.e. sharing of catalogs or data between sites), signposting (i.e. simple but relevant links from one site to another), and improved cross-site search capabilities.

The goal of these improvements is to provide users of any one of these sites with more access to relevant information, more consistency among the sites in terms of data organization and accuracy, and better data discoverability.

Identifying the Needs of the Community

To provide a robust basis for this work, the multi-lab team engaged both the domestic U.S. and international MRE communities to develop an understanding of their data and information needs. Through a series of workshops, community outreach and engagement events, and online webinars, the multi-lab PRIMRE team identified numerous needs, which were organized into six categories (Figure 2):



Figure 2 MRE community data needs by category

Accessibility and Security. MRE data must be accessible to the community at the right time. Data that are proprietary or business sensitive should eventually be made available to the larger community, but during a period of sensitivity, may need to be kept private or made available only to a select few. However, during this period of restricted access, it is still valuable to make the metadata (i.e. description and contact information) about those data available to the public. This allows members of the community to know that such data exist, even if they cannot access them at the moment, and provides them with either a date on which the data may become available or the means of contacting the data owners to request an advanced copy or explore potential collaboration. This distinction may seem subtle, but it is critical to empowering community members to work together on solving common problems, to avoid duplication of effort, and to keep secure sensitive information. It is a lot easier to collaborate if one knows what others are working on. PRIMRE will serve as a central access point to the MRE community providing easy access to major databases and knowledge hubs in the MRE space as well as informing users of upcoming events and workshops. PRIMRE will also define and encourage the adoption of metadata standards for the databases and knowledge hubs lists, including the attribution of contact information for project data. By keeping the community more informed and connected, PRIMRE will increase the accessibility of MRE information and make it easier for members of the MRE community to identify potential collaborators.

Discoverability. The most useful information in the world will not be used if it cannot be found. Improvements to search and data discoverability are critical to realizing the utility of data, both within the tools themselves and externally. Internally, PRIMRE aims to standardize the metadata tags, categories, and terminology used to describe MRE information. This standardization will make it easier for users to find the data they are looking for anywhere in the PRIMRE universe. The standards will include metadata necessary for each site to expose their information to search engines (e.g. Google) to ensure that the appropriate content displays in relevant searches. This practice is commonly referred to as Search Engine Optimization (SEO) and increases the likelihood of successful searches (i.e. discoverability), driving MRE community members to the resources they need. PRIMRE will adopt modern SEO strategies on several

major databases and repositories, including the MHKDR and Tethys, and will feature essential MRE tools prominently to help users discover the information they need.

Data Integrity. Generating vast amounts of information will not necessarily address the needs of the MRE community. Overexposure of questionable data can dilute the pool of information and increase the difficulty of discovering critical data. The data exposed to the MRE community should be of high quality, preferably curated, and of persistent availability. Persistent availability is necessary for citation, reproducibility, and consistency to allow the MRE community to build upon previous work and advance the industry. The need for data integrity accentuates the need for community participation in public data repositories. Data that disappear overnight are obviously unusable once gone, but also call into question any projects built upon those data. Furthermore, in an industry such as MRE, new companies are formed and disappear semi-frequently. When companies disappear, their data often goes with them, along with any lessons learned or insights gained, increasing the likelihood that the next company to come along could repeat the same mistakes. PRIMRE will pull from the successful data integrity and provenance strategies already employed by tools like the MHKDR and Tethys to ensure that data hosted within the PRIMRE network have a permanent place online and a clearly defined versioning strategy.

Best Practices and Standards. In order to facilitate collaboration, members of the MRE community must first speak the same language. The foundation of standards and best practices requires that relevant metrics be quantified consistently (for example: calculation of device performance testing and LCOE). Development of international standards for MRE technologies through IEC TC114 is an ongoing effort forwards this objective. Consistent application of these standards across the MRE community is necessary to ensure the same methods are used to calculate metrics and thus compare technologies. Having guidelines and standards provides a benchmark for understanding. The sharing of best practices and lessons learned provide useful information to all MRE community members, enable them to avoid common pitfalls, to and solve problems more efficiently. The PRIMRE team will work with community members and other stakeholders to develop and make available a document outlining best practices and standards in the MRE community.

Outreach and Communication. The MRE community currently lacks a coordinated events hub, a place for community members to stay in touch with industry trends and upcoming events. Many of the sites within the MRE community currently serve up a portion of this information or provide a window into their corner of the industry, the PRIMRE team identified through their community engagement efforts that there is a need for a central MRE community space. PRIMRE will serve as that central access point. Additionally, the multi-lab PRIMRE team will continue to hold community and outreach events in conjunction with MRE industry workshops and conferences.

Tools and Codes. The MRE community has expressed a need for MRE application specific, open source, publicly accessibly tools and codes to assist in the processing of MRE data and simulation of MRE technologies. Ideally, these codes would solve common problems in the MRE space, and developed in a modular, open source manner in order for them to be easily embedded into whatever suite of tools an organization uses. To address this need, the PRIMRE team is working with the developers of DOE funded to include a searchable MRE code catalog and open source code repository on PRIMRE, named MHKiT (currently under development).

Tying it all Together

The multi-lab PRIMRE team has developed a phased approach to addressing the community needs, development of which is integral to innovate and advance the commercialization of MRE technologies.

Phase 1. The creation of PRIMRE, the Portal and Repository for Information on Marine Renewable Energy. True to its name, PRIMRE will be a portal or central access point allowing users to quickly and easily navigate to the various tools and repositories that make up the online MRE community. More than that, PRIMRE will provide users with the information they need to understand the differences among those tools so that they may navigate more intelligently. Built on OpenEI, the Open Energy Information

platform, PRIMRE will leverage OpenEI's existing, distributed, cloud-based architecture for easy implementation, scalability, and performance; and OpenEI's rigorous search engine optimization for dissemination and discoverability. PRIMRE will provide consolidated access and integration of these individual databases to maximize the utility of the data they contain. A prototype of the PRIMRE concept already exists on OpenEI's MHK landing page (OpenEI 2018):

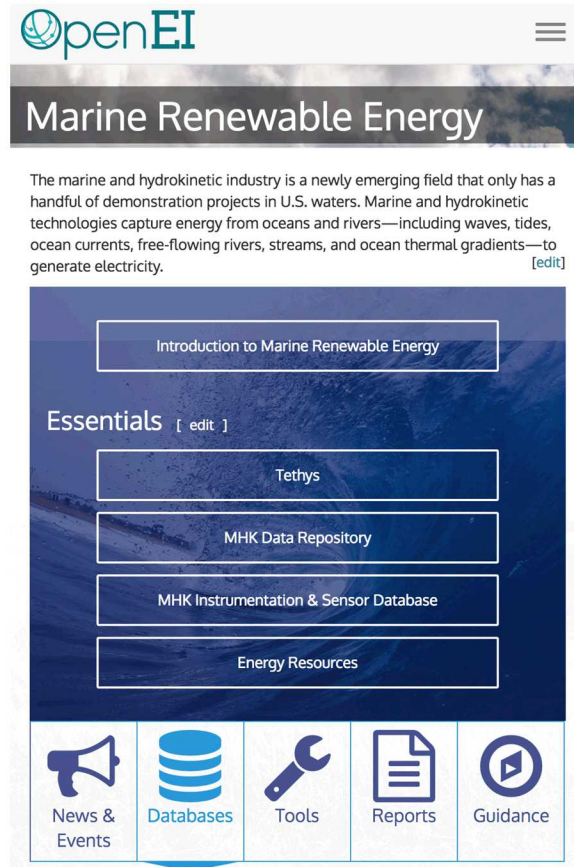


Figure 3 PRIMRE gateway on OpenEI (mobile version)

Tethys Engineering. Also planned in *Phase 1*, is the development of Tethys Engineering. The current Tethys knowledge base collects and disseminates information on environmental effects of MRE, making information readily available to accelerate permitting of devices and arrays. Filling a gap identified by the MRE community during outreach events, PRIMRE will facilitate the expansion of Tethys to include an engineering area. Functionally similar to the existing Tethys, Tethys Engineering will provide a comprehensive database of papers, reports, and data related to the engineering of MRE technologies. Both Tethys portals feature robust faceted search and discovery mechanisms conforming to the metadata standards identified by PRIMRE, allowing them to be interoperable with other PRIMRE tools.

Phase 2. The PRIMRE portal will reside at <https://primre.org> and will feature a searchable catalog of MRE data and resources across multiple domains. This will be done by federating the metadata catalogs of sites within the MRE community, starting with the MHKDR and Tethys, to allow their content to be aggregated into a centralized search on PRIMRE. In order to facilitate this, the metadata from each of the integrated sites must be standardized. The multi-lab team is working with the MRE community on the development of a standardized metadata schema to facilitate integration at this level. The MHDR and Tethys serve as the ideal initial candidates because of their functional similarity and their organizations' involvement in the early stages of the PRIMRE project.

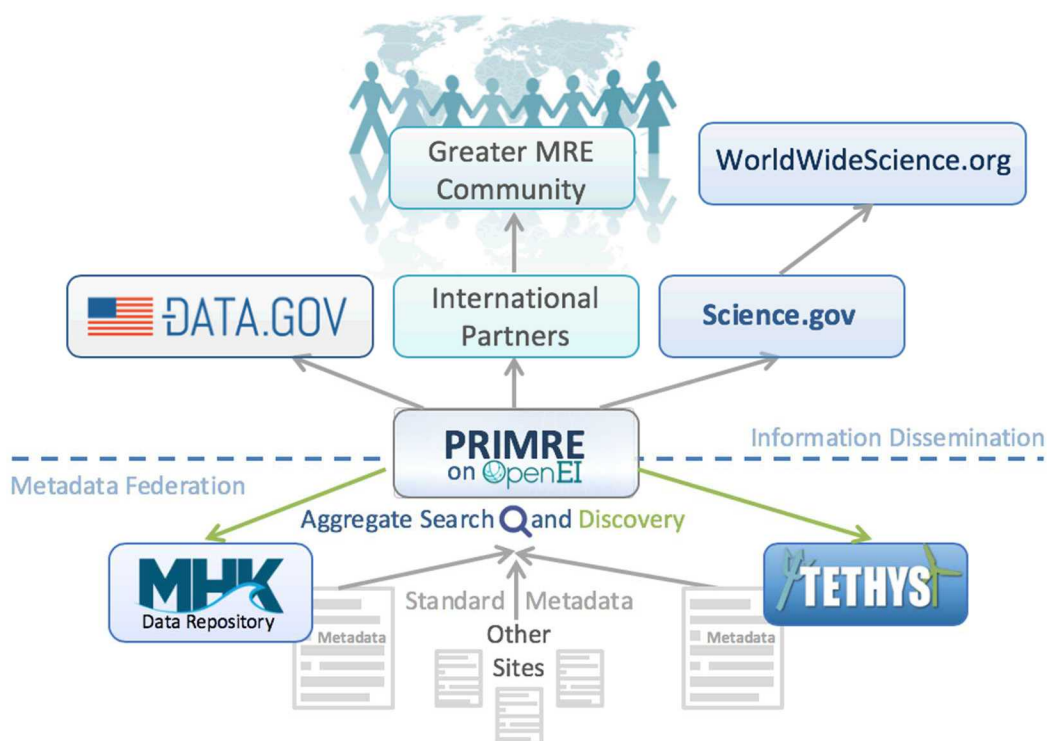


Figure 4 Network diagram illustrating the federation of metadata from the MHKDR and Tethys to support aggregate search and discovery on PRIMRE and dissemination of information to the MRE community

Once the metadata standards are established, the developed aggregate search functionality will be able to accommodate other sites conforming to the standards, allowing any online organization in the MRE community to participate and have their information portal appear in PRIMRE search results.

The development of a central, curated repository for news and events during this phase will help unite the community and provide a consistent incentive to revisit PRIMRE.

Phase 3. The widespread adoption of codes and standards by the MRE community will assist in the solving of common problems and reduce duplication of efforts. The PRIMRE team is working with the developers of MHKiT, a catalog and repository of MRE software codes and modular tools currently under development, to ensure that the codes and standards developed conform to the needs of the MRE community and that the MHKiT will be fully integrated with PRIMRE. PRIMRE will also include sections that overview standards development efforts and international collaborations, including those through IEA-OES.

Staying on Target

The PRIMRE team established a representative group of the MRE community, including experts from industry, academic leaders, technology developers, test center operators, regulators, national labs, federal organizations, and non-governmental organizations (NGOs), to serve as the MRE Data Steering Committee. Meeting quarterly, the Steering Committee assists the multi-lab team with vision alignment to make sure the ongoing efforts of PRIMRE continue to address the needs of the MRE community as it grows and changes. The Steering Committee also assists the PRIMRE project with coordinating events and international collaboration, including the adoption of standards, as well as community buy-in.

Conclusion

Each of the needs identified by the MRE community have been incorporated in the implementation plan for PRIMRE and are inherently interrelated. In order for data to be useful they must be discoverable,

usable, and accessible. Furthermore, users of those data must have confidence in their quality and their consistent availability. Data that are not hosted permanently cannot be cited, relied upon in research, or used consistently, and are at risk of disappearing before realizing their full value.

The goal of PRIME is to provide users of sites in the MRE online community with increased access to relevant information, more consistency among the sites in terms of data organization, and accuracy, and better data discoverability. By increasing access to relevant information, PRIMRE will enable the MRE community to build upon the successes of others to innovate and advance the commercialization of MRE technologies.

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