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Development of PRIMRE, the Portal and Repository for Information on Marine Renewable Energy

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Abstract—**The field of marine and hydrokinetic energy (or marine renewable energy) includes technologies used to convert the energy of waves, tides, currents and ocean thermal gradients primarily into electricity. Compared to traditional energy generation sources, and more established renewables (such as wind and solar), marine and hydrokinetic energy is in the early stages of development (corresponding to low technology readiness levels). The nascent state of marine and hydrokinetics means the field is full of challenges and opportunities, where innovation has the potential to produce a dramatic shift in the direction and commercial success of the industry as whole. Critical at this stage of development is the establishment of a collaborative environment where sharing data is the norm. Data in this context is defined to generally include the following: reports, research findings, lessons learned, industry standards, solutions to common problems, laboratory or field measurements, open source codes, simulations, etc. As demonstrated in other fields, sharing data can reduce cost, accelerate the development of technology, and even spur innovation. This paper describes efforts to enable data sharing and collaboration in the field of marine and hydrokinetic through the development of PRIMRE, the Portal and Repository for Information on Marine Renewable Energy.**

Keywords—**marine and hydrokinetic, marine renewable energy, PRIMRE, data sharing, knowledge hubs**

I. Introduction

Devices that convert the energy of waves, tides, currents, and ocean thermal gradients into electricity or other forms of usable energy are referred to as Marine and Hydrokinetic (MHK) technologies. Although there is often a distinction made between technologies classified as Marine [4]and Hydrokinetic versus Marine Renewable Energy (MRE), in the context of this paper MHK and MRE are used interchangeably. MRE is a nascent industry compared to other energy sectors, and even compared to other more established renewable energy sectors such as solar and wind. The MRE technologies emerging from this industry are still in the early stages of development, corresponding to relatively low technology readiness levels (TRLs), shown in Fig. 1. Companies with new MRE technologies are emerging and performing research in the TRL 1-3 range. More established companies are in the development phase testing prototypes in the TRL 4-6 range. And the most established MRE companies are deploying technology demonstrations in the TRL 7-8 range. However, no companies have achieved commercialization corresponding to TRL 9.

Fig. 1. Stages of the Technology Readiness Level (TRL) scale

The relatively low TRLs, and lack of established industry leaders and design paradigms presents both challenges and opportunities for the MRE industry. In order for MRE technologies to make it to TRL 9, and become commercially viable, they must be cost competitive with other energy sectors (including traditional generation and other renewable sources). If the MRE community gives way to competition rather than collaboration at this early stage, there are inherent risks that could stifle MRE technologies' progression through the TRL stages. This affects the MRE whole community, including: developers, researchers, academics, test centers, stakeholders, investors, and regulators. Significant innovations can fail to reach market if their project is defunded or their parent companies dissolve. Technological advancements not paired with a marketing strategy or ignoring economic considerations can cause potentially viable technologies to be abandoned prematurely. These lost innovations can only be rediscovered through duplicative work, robbing the industry of time and other critical resources. This environment creates an opportunity for the MRE community to collaborate. The sharing of knowledge, experience, and lessons learned could benefit the MRE industry as a whole, increasing efficiency, enabling

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innovation, and promoting scientific discovery for all organizations operating in the global MRE space.

II. Background

A. Value of Data Sharing

Data in the context of this paper is defined to very generally include the following: reports, research findings, lessons learned, industry standards, solutions to common problems, laboratory or field measurements, open source codes, simulations, etc. Sharing these data can reduce cost, accelerate the development of technology, and even spur innovation. An essential component of actualizing the value of data is communication. This point was highlighted by the US Department of Energy (DOE) in their 2011 Strategic Plan, which describes 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." [1]. The upshot is that 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. This is done to ensure that data management and dissemination is required as a throughout execution of the project plan, and not only at the end of the project. Beyond the US DOE, these requirements are supported 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." [2]. 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 [3].

What this means for the data generated by the MRE community through funding by the US DOE, is that all data must be disseminated to the larger MRE community such that they are useable, accessible, and discoverable. This ensures that the data is not isolated on a hard drive or file folder upon completion of a project, but that the data can be used to benefit the MRE community, resulting in cost reductions, acceleration in development of technology, and spurring innovation.

B. Obstacles to Data Sharing

The previous section established the inherent value of sharing data, so why isn't data sharing in the MRE industry the norm? After all, data is a fundamental component of scientific and engineering work. Despite this fact, barriers to data sharing can come in a variety of forms. Some of these issues are technical, lack of metadata, poor performance of data sharing platforms, proprietary formats, data security issues, poor search capabilities, or even portal or server availability. Although inconvenient, these technical barriers can be corrected, performance optimized, and metadata added to data. More difficult to overcome are those barriers that are organizational, financial, and cultural, see Fig. 2.

The characteristics of non-technical barriers are quite variable and are significantly influenced by a researcher's position and their age [4]. For example, individual researchers who were the collectors of data (potential data donors) typically felt the cost of collecting the data was too high just to "give it away". Early career data donors were worried about appropriate recognition for the effort of collecting the data set. In addition, they were also concerned with losing control of the data which they believed might affect their ability to maximize the numbers of publications they could produce. Since publications are still the "currency" of the research community, this is a significant barrier to data sharing.

From a business perspective, many financial and cultural barriers exist stemming from the desire to protect intellectual property and maintaining a competitive advantage over competition. Other non-technical barriers are not necessarily driven by researcher beliefs but rather legal issues (unsettled patent claims, ownership issues etc.), funding agencies not requiring data sharing, or ethical issues can produce significant barriers. Finally, the spectre of data falsification, misuse and other malfeasance is always a possibility.

Fig. 2. Obstacles to data sharing in addition to technological

III. Current Landscape

The current landscape of MRE data repositories and information portals funded by the US DOE WPTO is shown in Fig. 3. These sites were developed through DOE funding to promote scientific discovery and advance the commercialization of MRE technologies. To name a few, some of the US DOE funded MRE data repositories and information portals, include: OpenEI (https://openei.org), Tethys (https://tethys.pnnl.gov), the MHK Data Repository (MHKDR, https://mhkdr.openei.org/), and a collection of open source code repositories.

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 end users of MRE developers, researchers, academics, test centers, stakeholders, investors, and regulators have an abundance of MRE data available, as shown in Fig. 3. However, the abundant data pertinent to the MRE community is currently located in numerous repositories and disparate sites, making the usability, accessibility and discoverability of those data difficult. As a result, relevant information may be available to the end user of the many MRE data repositories and information portals, but the end user lacks a common entry point and interconnection of site content in order to easily access the desired information.

The reason for this lack of common entry point and interconnection is that historically these sites have been built in silos, focused on their own specialization without integration, hosting different sources of information, and on unique update cycles. 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. These isolated development strategies create the possibility for information confusion. For example, if the same information is present on two sites, but updated at different intervals, the sites will display 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.

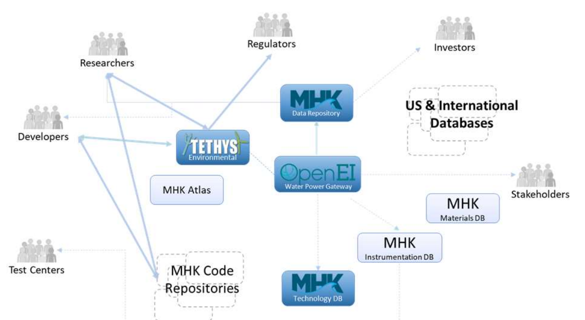

Fig. 3. Current landscape of MHK/MRE data repositories and information portals funded by US DOE

IV. NEEDS ASSESSMENT

Once a baseline understanding of the current landscape of WPTO MRE data repositories and information portals was established, the multi-lab team engaged the domestic and international MRE communities to perform a needs assessment. The objective of the needs assessment was to determine the MRE community's data and information needs to enable data sharing. The needs assessment was performed through a series of workshops, community outreach and engagement events, and online webinars. The multi-lab team grouped the needs assessment findings into six categories, shown in Fig. 4. Details of each category are described in the following sections.

Fig. 4. MRE data and information needs assessment findings

C. *Accessibility and Security*

One category identified through the needs assessment is accessibility and security of MRE data. In this context, accessibility refers to the fact that MRE data must be accessible to the community at the right time, and security means that the MRE data must available to the right people. Data security is very important for protection of data that are proprietary or business sensitive. These data may need to be kept private, or made available only to a select few, and should eventually be made available to the larger community, often after a moratorium period. During this moratorium period the metadata is still valuable to the public because it contains valuable information (i.e. description and contact information). Providing public metadata, even while the data itself is restricted, allows members of the community to know that such data exist, even if they cannot currently access the data. This provides potential data user with a date when the data will become available, and a point of contact of the data owner, so that potential users may request an advanced copy or explore potential collaboration. While the distinction may seem subtle, it is critical to empowering community members to work together on solving common problems, avoid duplication of effort, and keep secure sensitive information. Another aspect of data accessibility is the interaction of MRE Knowledge Hubs with one another. If information located on one site is not available to users accessing another site, they may falsely conclude that the desired information doesn't exist. Accessibility of MRE data can be improved through the interconnectivity of the MRE sites.

D. Discoverability

Another category identified through the needs assessment is data discoverability. Data discoverability refers to the ability of data to be found, because data cannot be used if it cannot be found. Improvements to search and data discoverability are critical to realizing the utility of data. One way to improve data discoverability is through standardization of metadata tags, categories, and terminology used to describe MRE information. Standardization is one way to make it easier for users to find the data they are looking for. The standards 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 a Search Engine Optimization (SEO) and increases the likelihood of successful searches (i.e. discoverability), driving MRE community members to the resources they need.

E. Data Integrity

Data integrity is another important data need identified by the MRE community. Simply generating vast amounts of information does not ensure that the available information will address the needs of the MRE community. Abundance of the wrong data has the risk of making it more difficult to find the right data (i.e. quality over quantity). The proper curation, quality assurance and archiving of data is important to ensure that the data exposed to the MRE community is of high quality, and of persistent availability. Persistent availability is necessary for citation, reproducibility, and consistency. Data that disappear overnight are unusable once gone and call into question conclusions drawn based on those data. Furthermore, in a nascent industry like MRE, new companies are formed and disappear. When companies disappear, their data often goes with them, along with any lessons learned or insights gained. This increases the likelihood that when new companies come along, they will repeat the same mistakes. Improving MRE data integrity can be accomplished through increased participation in public data repositories, knowledge bases, and open source codes. However, these public data repositories, knowledge bases, and open source codes also require curation, quality assurance and persistent availability to be beneficial.

F. Best Practices and Standards

Data best practices and standards are necessary to facilitate collaboration and data sharing. This is a cross-cutting category that also affects data discoverability and data integrity. Data best practices and standards ensure that the MRE community are speaking the same language. The foundation of standards and best practices requires that relevant metrics be quantified consistently (i.e. calculation of device performance testing and levelized cost of electricity), leveraging international standards such as IEC TC114 where appropriate. 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. The sharing of best practices and lessons learned provide useful information to all MRE community members, enable them to avoid common pitfalls, and to solve problems more efficiently. Additionally, metadata standards can be used to ensure the cross-compatibility of MRE knowledge hubs, allowing for better interconnection and integration of existing data. Metadata standards allow for sites to use common descriptors and categories (i.e. riverine versus river current).

G. Outreach and Communication

If new MRE information and data are made publicly available, but the MRE community is not made aware of these new data, their potential benefit to the community will be unmet. As such, the needs assessment defined outreach and communication as an import factor in data sharing. Currently, the MRE community has a selection of sites that provide a window into their corner of the industry, but a coordinated news events hub does not exist. Instead, many groups rely on mailing lists and engaging the community at conferences and events. These are important strategies, but they could be augmented by a central MRE community space.

H. Tools and Codes

The final category, but not the least important, is the need for publicly available, MRE specific, open source tools and codes. These tools and codes could be used to assist in a variety of tasks, from processing MRE data to simulation of MRE technologies. A selection of MRE codes are already publicly available, but similar to the state of other MRE data, these codes are hosted on a series of disparate sites and lack a common hub. The MRE data needs assessment established that a searchable code hub, housing MRE relevant tools and codes would greatly benefit the industry. For example, if a member of the MRE community wanted to find and compare codes (i.e. for mooring dynamics or data processing), a go to platform for this does not exist. The added benefit of a suite of MRE tools and codes is that similar to data guidelines and best practices, established codes and tools provide a common platform for direct comparison of different technologies.

V. PRIMRE

To address each of the six needs identified by the MRE community, the DOE WPTO has funded the multi-lab team for the development of PRIMRE, the Portal and Repository for Information on Marine Renewable Energy [5]. An overview of PRIMRE is shown in Fig. 5, and a description of PRIMRE Knowledge Hubs is given in Table 1. A brief description of how PRIMRE will address each of the six need categories is provided below.

Accessibility and Security:

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:

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:

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:

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:

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:

To address this need, the PRIMRE team is working with the developers of DOE funded open source codes to include a searchable MRE code catalog and open source code repository on PRIMRE, named MHKiT (currently under development).

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,

TABLE I

PRIMRE KNOWLEDGE HUBS

Knowledge Hub	Purpose
PRIMRE https://primre.org	PRIMRE landing page for MHK/MRE knowledge hubs
Tethys https://tethys.pnnl.gov	MHK knowledge base and collaborative engagement platform
MHKDR https://mhkdr.openei.org/	MHK Data Repository for US DOE funded data
MHKiT https://code.primre.org/	MHK Code Hub for US DOE funded open source codes
MHKTD https://mhktd.primre.org	MHK Technology Database of projects, technologies and companies
Tethys Engineering https://tethys-engineering.pnnl.gov/	MHK knowledge base and collaborative engagement platform

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 (Fig. 5). 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.

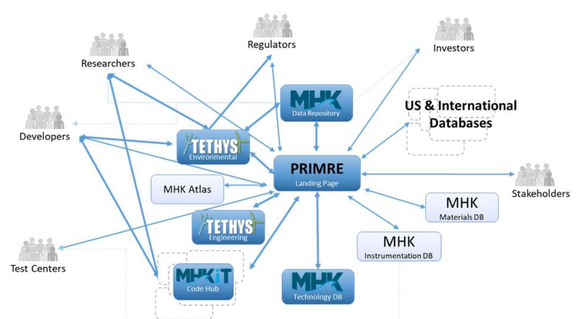

Fig. 5. Future landscape of MRE Knowledge Hubs after PRIMRE

I. Connection to Data Partners

The dissemination of information to the greater MRE community is a critical component of the PRIMRE strategy. Building upon the success of sites like the MHDR, which has been built from the ground up to disseminate information, PRIMRE will facilitate the connection of critical systems across the MRE landscape to improve the availability and discoverability of MRE data.

Metadata describing the data stored in the MHKDR are made available to a network of data partners through a variety of standard metadata formats, including Catalogue of Services for the Web (CSW), a standard CKAN endpoint, and Project Open Data's data.json format. By exposing MHKDR metadata in these formats, references to data housed within the MHKDR will appear in the search results of sites like Data.gov, the DOE Office of Science and Technical Information's (OSTI's) DOE Data Explorer, and Science.gov, as shown in Fig. 6. Users of any of these sites are able to find and access MHKDR data directly from those sites, increasing the discoverability of MRE data housed in the data repository by several orders of magnitude and making the data more accessible across the MRE landscape.

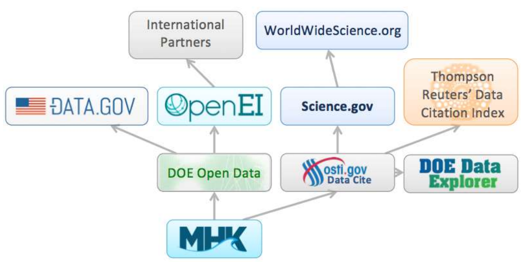

Fig. 6 MHKDR's Existing Data Sharing Network

PRIMRE will adopt these principals, building upon the MHKDR framework for interconnectivity to first connect the MHKDR with Tethys and Tethys Engineering, then expand the network to include other sites and tools across the MRE space. The end result will be a network of interconnected sites capable of sharing information rapidly with one another, providing users of any of the sites with consistent access to broader MRE content.

J. Tethys Engineering

The MRE community is familiar with Tethys (https://tethys.pnnl.gov) for the collection and dissemination of information on environmental effects that supports siting and efficient permitting of devices and arrays. That community has expressed interest in having a similar capability for engineering and technology materials. Under the first phase of PRIMRE, Tethys will be expanded to include engineering and technology-specific information. Functionally similar to the existing Tethys, Tethys Engineering will provide a comprehensive database of papers, reports, and metadata related to the design, testing, deployment, and operation of MRE technologies. Like the environmental side of Tethys, Tethys Engineering will feature robust faceted search and discovery mechanisms conforming to the metadata standards identified by PRIMRE, promoting close ties and operability with other portions of PRIMRE.

K. Enhanced Data Search

PRIMRE is working with the developers of sites within the MRE space to improve the organization and searchability of their data. Beginning with the identification and classification of standard industry terms, the PRIME team has developed a hierarchical taxonomy of MRE terminology that has been vetted by a steering group of experts representative of the community as a whole. This list serves as the foundation for search facets on multiple PRIMRE sites, including Tethys, the MHKDR, the MHK Technology Database, Tethys Engineering, and other. The use of a consistent taxonomy provides a consistent experience for users across the MRE landscape, ensures that MRE-specific terminology is used consistently, and lays the foundation for enhanced data search.

Having adopted PRIMRE's standardize metadata classification, MRE sites will be able to incorporate the content of other sites directly in their search results without duplication of effort. Using lesson learned from the MHKDR's network of data sharing partners, PRIMRE will work to enhance the search capabilities of MRE sites, starting with the MHKDR and Tethys. In addition to improving the discoverability of MRE data on these sites, the adoption of this enhanced search capability will leverage the community-vetted taxonomy described above, serving as a standard for other sites and insuring data integrity across the MRE landscape through the adoption of consistent data organization methods.

L. Technology Database

One of the PRIMRE Knowledge Hubs is the MHK Technology Database (MHKTD). The MHKTD is housed on OpenEI, a platform that allows for user input and development. Through development of PRIMRE, the database will be accessible directly through PRIMRE at https://mhktd.primre.org, and still housed on the OpenEI platform. In its current form, the MHKTD is a database of MHK projects, technologies and companies. As part of PRIMRE, the MHKTD will be updated to be more functionally interactive through improved facts and filters. For example, if a user wanted to search the MHKTD by devices tested at a certain facility. Additionally, the MHKTD will pass metadata to/from the other MHK Knowledge Hubs to improve the discoverability and accessibility of data on PRIMRE.

M. Continued Engagement

As identified in the needs assessment, outreach and communication is an import aspect of data dissemination and import way to reduce barriers to data sharing. The PRIMRE multi-lab team established a stakeholder engagement plan, including the following activities: steering committee meetings, public webinars, workshops, panel discussions, news blasts, and publications. Each of these activities are intended to inform the user community about PRIMRE and educate the user community on how to contribute. The multi-lab team will develop PRIMRE, and initially populate content, but will encourage the MRE community to help update content and improve functionality. While PRIMRE is largely focus on US DOE funded MRE data, the structure of PRIMRE is developed to lay the groundwork for a larger international effort.

VI. Conclusion

In conclusion, through funding from the US DOE WTPO, the multi-lab team from Sandia, PNNL, and NREL is collaborating on development of PRIMRE, the Portal and Repository for Information on Marine Renewable Energy. PRIMRE's development is the direct result of a needs assessment, performed by the multi-lab team through direct engagement of the MRE community. The needs assessment determined six categories of need, identified in Fig. 4 as: Accessibility and Security, Discoverability, Data Integrity, Best Practices and Standards, Outreach and Communication, and Tools and Codes. The development of PRIMRE is focused on targeting each of the six MRE data needs by establishing a MRE landing page and relevant knowledge hubs. Development of PRIMRE will be led by the multi-lab team and will involve continued interaction with the community.

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