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CONSIDERATIONS FOR A CO-LOCATED AQUACULTURE AND WAVE ENERGY DEPLOYMENT: QUANTIFYING DEMAND AND ASSESSING INTEGRATION

By

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In Support of the Pacific Northwest National Laboratory's Research:

Co-locating Wave Energy with an Integrated Multi-trophic Aquaculture System

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ABSTRACT

The co-location of marine energy and aquaculture is a concept of increasing value and interest in the United States, as the desire for sustainably produced seafood and renewable energy continues to grow. With both industries being fairly nascent in their national development and facing challenges, the deployment of a wave-powered aquaculture farm requires numerous considerations. This report analyzes the energy demands of an integrated multi-trophic aquaculture system at various farm scales and discusses the preliminary technical, regulatory, and logistical considerations required for a co-located deployment. A pilot-scale deployment is outlined with potentially ideal characteristics, and an optimized planning and permitting approach is introduced.

1. INTRODUCTION

1.1. Background

Manna Fish Farms, Inc. (Manna) is the industry partner on *Co-locating Wave Energy with an Integrated Multi-trophic Aquaculture System,* a research study led by the Pacific Northwest National Laboratory (PNNL) and funded by the United States Department of Energy's Water Power Technologies Office. Manna is an aquaculture company, growing finfish and researching the integration of shellfish, finfish, and macroalgae, also known as integrated multi-trophic aquaculture (IMTA). Manna has two offshore fish farm permits pending in the United States, one in the Gulf of Mexico and the other in the New York Bight. With a stated commitment to sustainability, Manna is interested in powering its offshore farms with renewable energy. Manna and PNNL are seeking to understand and evaluate the feasibility of co-locating wave energy with offshore IMTA.

1.2. Objectives

This report is based on three primary goals, with each addressed individually in the following chapters. Chapter 2 describes analysis of the theoretical operation of an IMTA system at various production scales, providing quantitative estimates of the resulting power and energy demands. Chapter 3 identifies and discusses the preliminary technical, regulatory, and logistical considerations of a co-located deployment. Finally, using the insights gained from the energy demand analysis and each of the three types of considerations, Chapter 4 outlines the design of a pilot-scale wave powered aquaculture farm and describes a potential approach that could lead to successful permitting.

2. ESTIMATING ENERGY DEMANDS OF AN IMTA SYSTEM

This project has a specific focus on the co-location of wave energy with an IMTA system. Therefore, the analysis and quantification of energy demands described below are focused on the AquaFort - Manna's preferred IMTA platform. As the power and energy required by any aquaculture operation vary significantly with farm scale and farm type, **Chapter 2** discusses the investigation of the AquaFort system's energy demands and how they scale with farm size.

2.1. AquaFort

The AquaFort is an aquaculture system designed and tested by the University of New Hampshire. It is a floating rectangular platform that contains two 20' x 20' finfish net pens, with an outer perimeter designed to support the culture of shellfish and seaweed. The AquaFort has proven its production capabilities with several seasons of harvest of blue mussels, steelhead trout, and sugar kelp in nearshore waters off the coast of New Hampshire (Chambers et al. 2024). With its impressive seakeeping abilities and maximum production capacity of up to approximately 22.5 MT (50,000 lbs) per year, the AquaFort is an ideal candidate for the evaluation of energy demands for co-location.

Figure 1: University of New Hampshire AquaFort platform located off Newcastle Island, NH.

While the current AquaFort design is not submersible, future iterations will likely incorporate submersibility as this will expand the system's ability to be deployed in more exposed, higher energy, offshore locations that are more suitable to wave energy conversion. Therefore, the energy demands below include an airlift system[1] within the AquaFort based on a preliminary submergence design.

2.2. Methodology

The scale of an aquaculture operation is influenced by numerous factors; with the most significant being purpose, location, and operator. Due to the variability among operations, a valuable estimate of an IMTA farm's cumulative energy demand cannot be derived with a

[1] An airlift system utilizes compressed air to adjust the overall buoyancy of the structure and change its position in the water column.

generalized approach. Therefore, a more detailed analysis of energy demand was required to characterize what co-location with wave energy might look like from a quantitative perspective. Four unique farm scales (production scenarios) were defined based on total production capacity (quantity of AquaFort systems) and purpose.

Table 1: Farm scales and defining characteristics.

	Base	Small	Medium	Large
Purpose	Local food production	Local and regional food production for sale	Regional food production for sale and distribution	Regional and national sale and distribution
Number of Systems	1-2	3-4	5-6	7-12
Production Scale	Community-based	Small businesses	Medium/large businesses	Commercial
Production Capacity*	45.5 MT	91.0 MT	136.5 MT	272.5 MT

**Assumes 20m (66ft) site depth, 12.2m (40ft) net, 20 kg/m^3 fish density at harvest*
MT = Metric Ton

With these production scenarios defined, the daily and peak energy demanding components/operations for each farm scale were identified, assuming the maximum number of AquaFort systems per scenario. The resulting power and energy estimates were derived from a collective review of aquaculture industry publications, instrumentation technical data, anecdotal references from farm operators, and Manna's own experience (**Appendix A**).

Daily operations include farm tasks such as feeding, monitoring, and data transmission. Peak operations are tasks that are only performed periodically such as cleaning, maintenance, and harvest, and are typically scheduled in advance. Estimates of cumulative peak power and peak energy demand include all daily operational demands, and conservatively assume that all peak operations occur on the same day. This is conservative in that some of the peak operations will in fact occur on the same day, but others will be scheduled to occur on separate days. For example, harvest and cleaning are both peak operations, but are unlikely to occur on the same day as they are both time and labor-intensive tasks. The following estimates only consider on-site power and energy demands and do not include transient demands stemming from the farm vessel's travel to and from the site.

2.3. Farm Scales

2.3.1. Base Scale

The smallest operation considered is referred to as the base-scale and is representative of a community-based operation for local food production, or a demonstration-scale pilot project. Base-scale consists of one or two AquaFort systems, with daily energy demand limited to only the minimum operational components: video, environmental monitoring, and communication[2]. All other daily operations, such as feeding, are assumed to be performed manually at the base scale. Peak operations considered at this scale were limited to net/cage cleaning with standard pressure washers, and operation of the AquaFort's airlift system. All farm tasks at this scale can be accomplished with the use of a basic fishing vessel.

2.3.2. Small Scale

The small-scale production scenario utilizes two to four AquaFort platforms, and in doing so moves from a community-based or demonstration operation to a farm operated by a small

[2] These three essential operations are included in every scenario, with video and environmental monitoring demands scaling with the quantity of AquaForts deployed. The demands stemming from communication vary significantly due to different technologies used to accommodate the increasing quantities of data and the need for real-time remote monitoring at larger farm scales. See **Appendix A** for further details.

business with the purpose of local and regional food production for sale. With a potential production capacity of over 90 MT, this scale of operation requires a mechanical feed system (assumed to be located on the farm's service vessel), which results in the first significant daily energy demand of up to approximately 40 kWh (4.8 kW at 8 hours of use per day). Peak operations at this scale have the added demand of a small crane, also located on the service vessel, to be used during harvest days. All farm operations can still be reasonably carried out using a basic fishing vessel.

2.3.3. Medium Scale

The medium-scale scenario involves four to six AquaFort systems, operated by medium/large businesses with the purpose of regional food production for sale and distribution. The potential production capacity of nearly 140 MT annually necessitates a change in the operational infrastructure. The amount of feed needed to accommodate the finfish biomass of six AquaForts requires on-site feed storage and delivery in the form of a feed buoy. This floating structure is moored on-site permanently to store feed and remotely deliver it to each AquaFort simultaneously. This simultaneous delivery increases efficiency and reduces hours of use compared to the single mechanical feed system used in the small-scale, but is accompanied by significantly higher power demand (49.5 kW vs. 4.8 kW). The feed buoy also becomes the "brains" of the farm, serving as the centralized point for all data collection and transmission. Additional peak operation demands include a larger crane and cold storage on a now dedicated and larger service vessel, and specialized net-cleaning devices to assist the pressure washers.

2.3.4. Large Scale

The final production scenario is large-scale, which includes seven to twelve AquaFort systems for up to double the production capacity of the medium-scale scenario. This represents a full commercial-scale operation with a purpose of regional and national food production for sale and distribution. The large-scale operation utilizes two strategically located feed buoys to accommodate both the production capacity and spatial characteristics (distance between systems and total site area) of a twelve-system farm. The demand for all daily operations doubles, and peak operation demands increase significantly due to increased cold storage capacity, additional net cleaners, and extended usage. One or more dedicated service vessels are required to support an operation of this magnitude.

2.4. Production-based Energy Scenarios for Powering the AquaFort

The choice to identify and analyze four different farm scales is justified by the wide range of cumulative power and energy demands observed between each scale in **Table 2**. The relationship between the quantity of AquaForts deployed and the subsequent operational demands is not linear for the base, small, and medium-scale production scenarios. Both power and energy demands increase exponentially as the quantity of AquaForts increases from base-scale (two systems maximum) to medium-scale (six systems maximum). This stems from operations changing and/or using different equipment as a result of farm purpose and production capacity evolving. There appears to be a transition point, however, highlighted by the smoothed line fit in **Figure 2**, between the medium and large-scale scenarios at which the increasing demands begin to follow a more linear relationship.

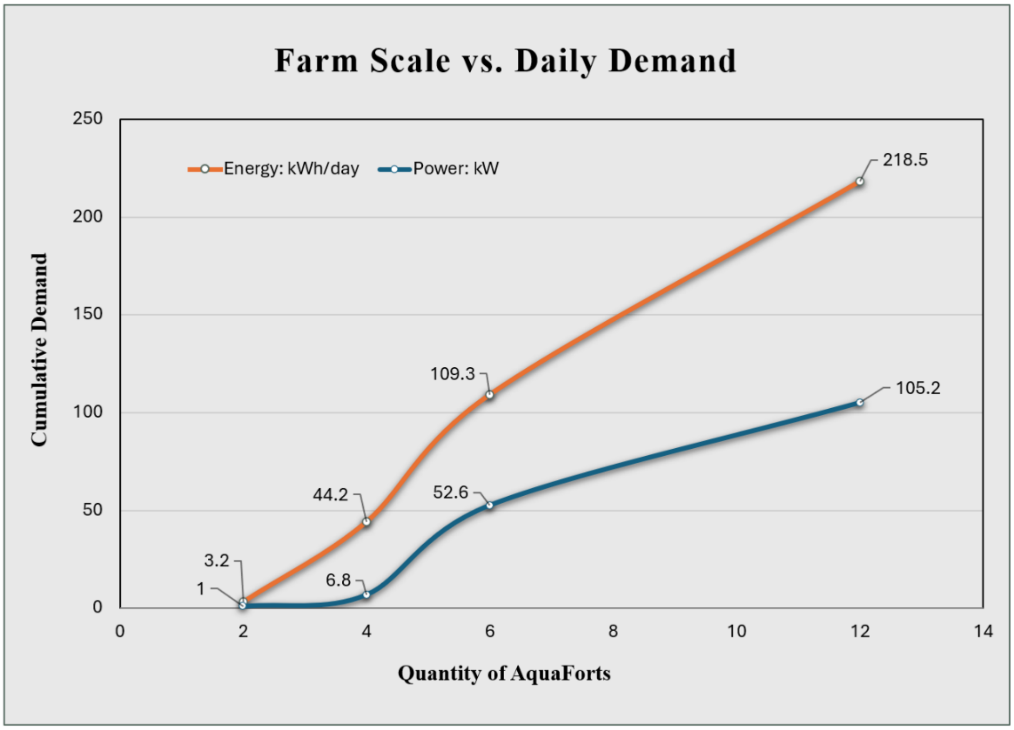

Figure 2: Cumulative daily electrical demand as a function of farm scale.

This can be explained by the farms becoming more operationally efficient at larger scales, with new methods and new equipment no longer being added. Increases in demand from six AquaForts (medium scale) and up are typically the result of multiple pieces of the same equipment and extended usage, rather than new methods. This is exemplified by the doubling of all daily operation demands from approximately 52 kW and 109 kWh cumulatively at the medium scale, to 105 kW and 218 kWh cumulatively at the large scale.

Table 2: Production-based energy scenario summary table. Cells with a grey X indicate the corresponding operational task/characteristic is required at that farm scale.

	Base	Small	Medium	Large
Number of Systems Considered	2	4	6	12
Production Capacity (MT) *	45.5	90.9	136.4	272.7
Site Area Required (ha) **	2.9	6.9	17.1	23.3

Communication	X	X	X	X
Environmental Monitoring	X	X	X	X
Video	X	X	X	X
Mechanical Cleaning System	X	X	X	X
Mechanical Feed System		X	X	X
On-site Feed Storage			X	X
Daily Power Demand (kW)	1.0	6.8	52.6	105.2
Peak Power Demand (kW)	16.2	29.4	102.8	167.8
Daily Energy Demand (kWh/day)	3.2	44.2	109.3	218.5
Peak Energy Demand (kWh/day)	45.2	136.6	392.3	709.0

AquaFort platform has dimensions of 8.5 x 15.9m (28 x 52ft)
All power and energy demand values are cumulative, and do not consider transient demands of the farm vessel's travel to and from the site
Base and small-scale scenarios can be supported by a basic fishing vessel, medium and large-scale scenarios require a dedicated service vessel
**Assumes 20m (66ft) site depth, 12.2m (40ft) net, 20 kg/m^3 fish density at harvest*
***Assumes 20m (66ft) site depth, 4-point individual mooring with 3:1 scope, additional area for farm operations included*
MT = Metric Ton, ha = Hectare, kW = Kilowatt, kWh = Kilowatt-hour

A base-scale operation requires just 1 kW of power and 3.2 kWh of energy for daily operations, which represents a very small demand that could be met with just one small-scale wave energy device. Despite the minimal draw of base-scale daily operations, it is clear even at this production level that peak operations increase the cumulative power and energy demand significantly up to 16.2 kW and 45.2 kWh/day, respectively. This trend of peak operations causing significantly higher demand than daily operations is apparent at each farm scale and is shown in **Figure 3.** The additional design considerations required to accommodate these peak loads accordingly in a co-located deployment are discussed in **Section 3.1.**

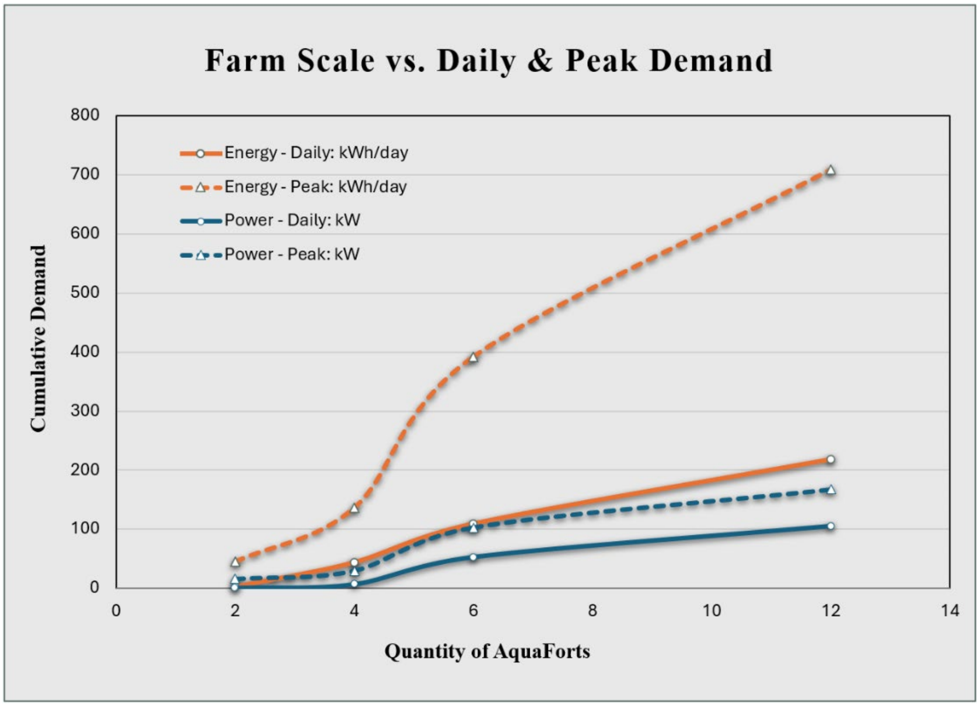

Figure 3: Cumulative daily and peak electrical demand as a function of farm scale.

3. CO-LOCATION CONSIDERATIONS

With both marine aquaculture and wave energy being relatively nascent fields in the United States, a co-located deployment of these systems is novel, not in concept, but in actual execution. As for any ocean project, multiple aspects must be thoroughly considered for a deployment to come to fruition. The majority of these considerations can be categorized as technical, regulatory, and/or logistical.

3.1. Technical

The technical considerations for co-location include variable demand, energy storage, environmental conditions, survivability, proximity, and mooring. The purpose of a co-located aquaculture and wave energy deployment is for the wave energy converter (WEC) to generate and provide on-site power that meets or supplements the energy demands of the aquaculture operation without connecting to a larger grid. Ocean conditions are highly variable, meaning any wave energy system must be able to account for extended periods of non-energy generating conditions, both for lower daily demands and for larger demands during peak operational activities. This dictates that any co-located deployment must incorporate energy storage, in addition to generation. Such storage could be incorporated into the WEC as some designs have done (e.g., Dolphin Labs xNode), in subsea batteries located on the seafloor, or potentially within the aquaculture infrastructure such as within a feed buoy or feed barge (e.g., Scale Aquaculture Hybrid Power Systems). With an energy storage system in place, peak demand operations, which are flexible within predictable constraints, could be strategically scheduled around the real-time quantity of stored energy.

The variability in operating principles and end-users within the wave energy sector has resulted in some WEC's that require a minimum water depth (e.g., Ocean Power Technologies PB3 PowerBuoy), and/or minimum wave climate to operate. IMTA operations also require a minimum water depth (typically around 10 m) to accommodate the nets and/or vertical lines, and must be sited in a wave climate that does not consistently risk the safety of the structure(s), operators, and the species being grown. An ideal IMTA site would typically have daily average significant wave heights of less than 2.0 m (subject to the selected aquaculture platform). As such, co-located deployments must balance these constraints, using both WEC and aquaculture systems that are aligned with their site-specific requirements. While larger-scale aquaculture operations in deeper waters can generally accommodate larger wave climates due to the engineering requirements of the structures to be deployed, it is likely ideal to site a co-located deployment in a small to moderate wave climate (daily average significant wave heights on the order of 1.5-2.5 m) that can appropriately satisfy the constraints of both systems.

The ability to withstand extreme environmental conditions is a shared constraint for both industries. The aquaculture infrastructure, the wave energy system, and their respective moorings must be designed and engineered to include adequate safety factors, methods of survival, and the ability to tolerate extreme conditions. Adding to this importance is the potential escape risk for animals (in the case of finfish) in the event of a WEC breaking free of its mooring, which would pose a threat to the aquaculture structure and the species contained within it. Submerging the systems is a typical method used to help withstand extreme conditions by escaping the higher wave energy associated with the upper portion of the water column. Many wave energy devices also incorporate a "survival mode" which can be activated remotely in preparation for extreme conditions. The survival mode is a programmed adjustment of the device's internal components that makes the WEC less responsive to wave motion, thereby decreasing extreme loads on the power takeoff components and minimizing the risk of damage (Oscilla Power, Inc. 2024).

Another consideration is the proximity of the WEC and aquaculture system. The variability of aquaculture operations and wave energy converter structures, their mooring system designs, and site characteristics all influence how a co-located deployment is laid out from spatial, logistical, and engineering perspectives. Specifically, it is necessary to optimize the physical proximity of the aquaculture and wave energy systems in a way that enables effective integration, while minimizing the risk of accidental contact. The ideal proximity of these structures will be informed by site-specific and system-specific analysis.

It is theoretically possible for a co-located deployment of aquaculture and wave energy to share a mooring system. Assuming neither piece of equipment requires its own specialized mooring, a submerged grid system could be designed to securely moor both to the seafloor. Submerged grid mooring systems are frequently used in offshore net pen aquaculture farms (Fredriksson et al. 2004), and involve one cohesive system consisting of multiple lines, with multiple “berths” available for structures to be moored within. These berths allow multiple aquaculture net pens, or other structures, to be moored to the seafloor without each requiring their own anchors, lines, etc. Submerged grid moorings such as the one shown in **Figure 4** are designed to support both surface and submerged configurations. This flexibility could allow a WEC to operate at the surface, while an aquaculture system is submerged below.

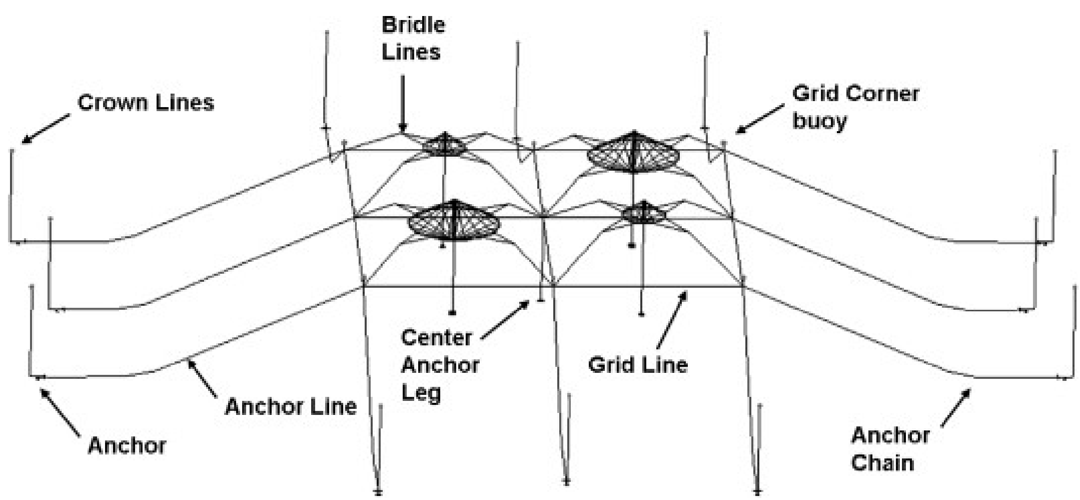

Figure 4: Submerged four-cage aquaculture grid system (Fredriksson et al. 2004).

All submerged grid moorings require extensive hydrodynamic analysis and numerical modeling to ensure a safe and viable design, but one intended for a co-located deployment would require elevated consideration given the added risks and complexities discussed above. These additional needs likely make a submerged grid shared mooring unrealistic for smaller scale operations from a cost and resource perspective, but larger scale farms (medium to large) might benefit from considering this type of approach. Additionally, small-scale operations with minimal power demands may have the ability to moor a WEC alongside the aquaculture structure. Assuming the

WEC is physically small, and its operation not dependent upon a specific mooring system, a shared mooring could be designed in which a WEC is attached to the aquaculture structure via a compliant tether. This design would likely not be viable for all types of small-scale WECs, and potentially not viable for a submersible aquaculture system, but a use case exists in which a WEC's mooring relies primarily on attachment to the aquaculture structure it is powering.

3.2. Regulatory

The regulatory landscape for marine projects in the waters of the United States is complex. This ultimately stems from the numerous laws, acts, and regulations put in place to foster ocean stewardship and environmentally sound practices that set the United States apart from many other countries. However, this creates challenges and long timelines to permit novel and innovative offshore projects. In the United States, there have only been a small number of WECs deployed and there are currently no offshore IMTA projects in federal waters. Due to this, there is much uncertainty surrounding these two activities and therefore permitting is likely to take several years, even for demonstration projects[3].

The social license is also an important component of permitting. The nature of the United States regulatory landscape allows for public comment on proposed federal actions and decisions, requiring consideration of both regulatory and public perspectives. Aquaculture in particular has faced scrutiny from the public as well as via legal challenges[4]. Therefore, it is likely that co-location may run into similar challenges.

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[3] 'It should not be this hard': US environment agency finally permits first Gulf of Mexico offshore fish farm | Intrafish

[4] United States Court of Appeals for the Fifth Circuit: Gulf Fishermen's Association vs. NOAA Fisheries

Generally an effective approach that offers the best chance for success at receiving authorization is to keep a project as simple as possible to avoid excessive complexity that could extend the review process and/or decrease likelihood of approval. Additionally, an emphasis on keeping a project small, in all aspects (e.g., footprint, production capacity, etc.), would increase likelihood of successful permitting, ability to streamline processes, and may minimize impact. In addition to potentially increased regulatory efficiency, smaller projects require less space; reducing survey costs, decreasing likelihood of conflict with marine-based activities, and may be more easily accepted by the public and other ocean users. The caveat to minimizing project size and complexity is that it's highly advisable to structure a project in a way that provides degrees of operational flexibility (e.g., slightly larger footprint, greater than anticipated production capacity, etc.) to account for future uncertainties. Specifying design envelopes for key project attributes is a viable way of striking a balance between reduced project scope and operational flexibility, especially in the case of a co-located deployment.

Despite those ideal approaches, it remains unlikely that the regulatory process would be streamlined for a co-located deployment of aquaculture and wave energy. The use of a WEC within an aquaculture operation may be viewed as a significant and novel component with impacts, both individual and cumulative, that would likely require additional review by the governing agencies. Public concerns and legal challenges could also potentially increase the duration of the permitting process (Randolph 2022). Areas of additional review for including a WEC would likely pertain to:

- General effects on marine life: underwater noise, risk of hazardous material spills or leaks.

- Effects on marine mammals: potential entanglement risk associated with additional mooring lines, habitat change, behavioral disruption.
- Additional risk of damage: WEC breaking free and colliding with aquaculture structures causing damage or potential escape risk, navigational hazards.
- Engineering: hydrodynamic and structural modeling of the wave energy device and it's mooring system, as well as potential flow-field impacts of being sited within or near an aquaculture operation.
- Public safety: limited or restricted site access may be required, additional approvals needed for such a designation.

While it may not be "easier" to permit an outright co-located deployment as opposed to individual projects, there are similarities in the planning and permitting processes of aquaculture and wave energy, as well as flexibility in the approaches that could potentially mitigate the regulatory burden. Both types of projects involve permits/authorizations from the United States Army Corps of Engineers, the National Marine Fisheries Service, and the United States Coast Guard, to name a few. In addition, the majority of environmental, economic, social, and biological characteristics necessary for planning and identifying a target location for aquaculture and marine energy overlap for an ideal co-located deployment (Garavelli et al. 2022). Baseline environmental surveys are typically carried out for siting, which may also have similar in-situ data requirements such as bathymetry, current profiles, wave characteristics, benthic habitat, and geophysical properties. Subsets of data obtained by these surveys are also required by multiple federal and state agencies to assist in their reviews and analyses. These shared characteristic and data needs could enable siting and planning work for a co-located deployment to be satisfied by one comprehensive assessment, which would reduce the significant cost and effort associated with this portion of the permitting process.

3.3. Logistical

The logistical aspects of a co-located deployment require thorough consideration from both aquaculture and wave energy perspectives. The operations and management of each must work efficiently not only on their own, but integrated with each other as well. WECs are typically designed to operate independently with minimal downtime and long-term maintenance schedules. These are ideal qualities from an integration perspective and should be required characteristics of a WEC selected for co-location, as aquaculture farms have daily operational tasks and regular maintenance that can't afford to be obstructed or interfered with. A simple design with minimal and/or contained moving parts is also preferred to minimize risk of interference with aquaculture equipment and operations.

The logistics of how power and data will flow between the WEC and the aquaculture infrastructure is one of the most immediate challenges that will need to be solved. The use of external energy storage locations, either in subsea batteries or in feed buoys/barges as mentioned in **Section 3.1**, in conjunction with properly sized compliant cables connecting all points, are likely solutions to be explored. Whether an aquaculture farm is powered by one WEC or an array of multiple WECs will strongly influence how everything is interconnected.

The decision to deploy a single WEC versus an array of multiple devices will primarily depend on the scale of the aquaculture operation, and its associated energy needs (see scenarios described in **Chapter 2**). The base-scale scenario, with just two IMTA platforms, has minimal energy and power demands that can easily be met by a single WEC, even one of smaller physical size. With the purpose of the base-scale scenario being a very simplistic aquaculture farm, typically one operated by community members for local food production, the ability to satisfy the electrical demands with just a single, small WEC is ideal. A single WEC minimizes physical footprint, visual impact, operating logistics, and overall complexity.

The large-scale scenario requires significantly more energy and therefore would likely benefit from an array of multiple WECs. With the significant demand of twelve AquaFort platforms, attempting to meet these numbers with just one 100 kW scale WEC is not advisable for multiple reasons. Primarily, a twelve-platform farm requires a large physical area for adequate spacing between systems and their mooring components, which then poses a technical challenge relating to the distances the power and data cables would have to span with only one WEC. Multiple devices strategically located throughout the farm could provide power to certain designated groups of aquaculture platforms (similar to multiple feed buoys/barges supplying specific net pens with feed) with shorter and fewer cables needed. Similarly, multiple WECs with multiple battery storage systems would prevent against catastrophic power failure. If a WEC happened to break down or break free from its mooring, it would not result in the entire farm losing power. Lastly, and perhaps the most salient of the arguments for multiple devices, an array of smaller capacity WECs (sized appropriately to the wave climate) could more reasonably meet the large power demands in an area suitable for an aquaculture operation, compared to a single large device that is not optimized to perform in smaller wave climates. Ultimately the use of a single WEC versus an array is best determined on a case-by-case basis once project and site-specific details are known.

3.4. Integration Constraints

There are several broad constraints that apply when designing for the co-location of WECs with an aquaculture farm. Many have been discussed in the previous sections. The integration table shown below (**Table 3**) summarizes the various constraints to consider and shows the influence of farm scale on each.

Table 3: Production-based wave energy converter co-location constraints

	Base	**Small**	**Medium**	**Large**
Number of IMTA Systems	1-2	3-4	5-6	7-12
Onboard / On-site Energy Storage req.	Yes			
Shallow Depth Operation req.	Yes	Yes	No	No
Power Generation in Small Wave Climate req.	Yes	Yes	No	No
Shared Mooring Plausible	Yes			
Non-renewable Backup Power Source req.	No	Yes	Yes	Yes
Proven Performance req.	No	Yes	Yes	Yes
WEC Minimum Rated Power (kW)*	0.6	7.6	52.6	73.8

Req. = required
See Table 2 for operational details of each production scenario.
**Assumes only one WEC is deployed to support the entire farm, is based on the minimum quantity of IMTA systems for each scale (e.g., 1 for Base, 3 for Small, etc.), and only considers the farm's daily demands.*

Smaller-scale operations (base to small) typically operate in sites closer to shore to capitalize on calmer waters, easier site access, and shallower depths that simplify operations. Whereas larger operations (medium to large scale) are less restricted by wave energy and often require greater depths due to the size of the aquaculture infrastructure needed for the desired production capacity. Therefore, selection of a WEC with characteristics best suited for powering an aquaculture farm will have to consider these constraints.

For nearly every scale of aquaculture operation, it will be necessary to have a backup power source that could satisfy the farm's demands, or at least the minimum essential demands, should the WEC(s) not be able to provide power over a period of time that exceeds the capacity of the battery systems. The backup power source is likely to be a marine diesel generator due to their proven reliability. However, the uniquely minimal demands and manual labor emphasis of the base-scale scenario may enable the daily demands to be met with other renewable sources, such as a small wind power generator and/or a small solar array connected to a simple battery bank. Similarly, the base-scale scenario is likely the only scale that could accommodate the testing of a prototype WEC with minimal risk. At any larger scale, the aquaculture operation is more complex, and the risk may be too high, particularly regarding feeding (the most critical and frequent energy intensive task).

Using the results of the production-based energy scenarios, it is possible to estimate minimum power ratings for WECs to be used at each of the different farm scales. The minimum required rating of a WEC is subject to whether the co-located deployment utilizes one device or multiple. For simplicity, the minimum rated power values listed in **Table 3** assume only one WEC is used, and are solely based on the farm's daily demands due to the significant variability in the peak demands. Unlike the demand values listed in **Table 2**, the listed ratings below are based on the cumulative daily power demands stemming from the *minimum* number of IMTA systems at each scale to more accurately convey the smallest capacity WEC that could be used to power the farm. Each rating was estimated with a safety factor of 1.2 applied to account for variations in equipment used, and the lack of redundancy stemming from reliance on a single WEC. Ultimately, these minimum ratings are only estimates, and proper WEC selection will require collaboration between the aquaculture developer who knows the intricacies of the farm's demand profiles, and the wave energy developer who knows the intricacies of power generation, energy storage, and their device's ability to ensure a consistent, reliable power supply.

4. OUTLINING A PILOT SCALE CO-LOCATED DEPLOYMENT

Despite a co-located deployment of wave energy and offshore aquaculture being a novel combination of activities in the United States with several challenges to consider, some methods and approaches can be taken to yield the best possible chance of success for a pilot-scale project. The following sections build on the preliminary considerations of Chapter 3, and outline key project attributes and strategic planning and permitting approaches. Implementation of these attributes and approaches would in theory streamline the process to the greatest extent practicable, and provide the best chance of achieving a pilot-scale wave powered aquaculture demonstration.

4.1. Key Project Attributes

The optimal characteristics of a pilot-scale co-location project fall into three categories: the aquaculture operation, the wave energy operation, and the overall project. Several of these attributes have been identified based on the Environmental Protection Agency's (EPA) National Pollutant Discharge Elimination System (NPDES) program[5] and the Federal Energy Regulatory

[5] Aquaculture NPDES Permitting | US EPA

Commission's (FERC) published criteria for pilot project licensing of marine hydrokinetic projects[6], and are aimed at lessening potential impacts.

4.1.1. Aquaculture

Potentially ideal aquaculture characteristics include:

- Aquaculture type: integrated multi-trophic - shellfish, seaweed, and finfish
- Species: regionally appropriate, native, established markets, established culture protocols
- Production: finfish harvest quantities below EPA NPDES Concentrated Aquatic Animal Production (CAAP) thresholds[7], shellfish and seaweed quantities sufficient to provide a substantial offset of finfish-related nitrogen production
- Minimal infrastructure: 1-2 IMTA platforms, ideally an already proven design
- Duration: 5 years or less

4.1.2. Wave Energy

Potentially ideal wave energy characteristics include:

- Production: significantly less than FERC's stated pilot-project limit of five megawatts
- Minimal infrastructure: one WEC, 1-2 battery systems (assuming external to the WEC)
- Duration: 5 years or less
- Degree of permanence: removable and able to shut down on short notice

[6] FERC Hydrokinetic Pilot Project Licensing Process
[7] 20,000 lbs for cold water species, 100,000 lbs for warm water species

4.1.3. Overall Project

Potentially ideal project characteristics include:

- Scope: research-focused, non-commercial, pilot-scale demonstration operated by a university or research institution (can have industry partners to assist)
- Site selection: nearshore, state-water site, minimal farm footprint, avoids sensitive locations and habitat, minimal user conflicts
- Monitoring: implementation of best practice environmental monitoring protocols
- Decommissioning: full removal prior to end of permit/license term (unless new permit/license is granted)
- Draft application: sufficient in detail to support environmental analysis, incorporation of design envelopes for key attributes

It should be noted that these specific project attributes were identified on the basis of maximizing the likelihood of receiving authorization for the deployment of a research-focused pilot scale demonstration in the most efficient manner possible. Aside from the operational and financial benefits, the preference for siting the project in state waters rather than federal waters is based on slightly simplified permitting procedures and generally shorter timelines. The justification for the project being owned and operated by a university or research institution stems from the social license component. Established research entities have an inherent degree of credibility and trustworthiness that plays an important role in easing public and regulatory concerns alike. These institutions also possess the financial and scientific resources needed to design, deploy, monitor, operate, study, and ultimately decommission such a project. A deployment of this kind is the first step in expanding the realm of possibility for wave powered aquaculture, and one with these characteristics should only be viewed as a starting point. Once there are demonstrative and educational examples, then the industry can begin to pursue more economically viable deployments. The strategic planning and permitting approaches below are still applicable at larger operational scales, and will remain relevant at least until such time as the regulatory landscape evolves.

4.2. Optimized Planning and Permitting Procedure

Considering the difficulties currently faced by marine aquaculture facilities in the permitting domain (DeVoe 2000, Rubino 2023), it is likely that the aquaculture component of a co-located deployment would be the more difficult part. Given that, and the overlaps in regulatory requirements between the two types of projects, it's possible that permitting the aquaculture demonstration first, and then pursuing an Army Corps permit modification to include a WEC, might be a viable approach. The addition of a small, pilot-scale WEC would only require the installation of one structure (with minimal ancillary components), with similar characteristics and a mooring system to what has already been reviewed and authorized for the aquaculture farm. These similarities and the minimal complexity associated with one small WEC could justify a simple permit modification, as opposed to a new permit application. Ultimately, the validity of an Army Corps permit modification is subject to the decision of the District Engineer and the input of the other regulatory agencies consulted[8].

[8] USACE Part 325.7 Modification, suspension, or revocation of permits.

Due to the general uncertainty surrounding authorization for a co-located deployment, it is also possible that co-location may require permitting the aquaculture and wave energy projects separately. This would entail pursuing the standard permitting pathways for each respective entity, but doing so at the same time, with both projects to be deployed in essentially the same location. Thorough planning with pre-application interagency discussions regarding the site and specific data needs of each project could enable the applicant to obtain one comprehensive baseline environmental survey, as opposed to two separate surveys. Each respective application package would need to include a reference to the other project to provide a properly detailed application, but care should be taken to establish and maintain independence between the two. The theoretical benefit of keeping the two project applications separate is that doing so would minimize the potential of one holding up the other. Ideally, both would move along at their respective paces, with the wave energy pilot project likely to receive permits and licenses first (FERC has indicated the goal of their pilot project licensing program is to render a decision in as few as six months after filing of the application). This would likely prove beneficial, in that the wave energy operation could be deployed and begin demonstrating its operational viability in the selected site, as well as collecting data about any potential environmental effects. The inclusion of environmental monitoring instrumentation deployed with and powered by the wave energy system would maximize the research opportunity of the early WEC deployment, and provide critical data and insight to be incorporated into the aquaculture operation. When the aquaculture application receives final approvals and permits, it could then be deployed and integrated with the already proven WEC system.

Strategies for streamlining the aquaculture application process and/or increasing the odds of approval would include thorough and detailed documentation describing all aspects of the operation, early and frequent communication with the interagency regulatory group, and the proposal of a phased cultivation plan. Not only does an IMTA system have proven environmental benefit (Chambers et al. 2024), it also enables flexibility in how and when the various species are cultured. Stocking the system initially with only shellfish and seaweed, and then adding the finfish component later on may be viewed more favorably than the typical approach of cultivating all three in the first growout season. This would also enable the wave energy system to power the aquaculture operation's monitoring and communication equipment, while providing a season's worth of data and sea-trial experience without the potential risks associated with the inclusion of finfish. These observations of the dynamic interaction between the two systems in a real-world marine environment would validate the current designs and/or inform design modifications needed to ensure a successful co-located deployment.

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APPENDIX

Appendix A:

Production-based Energy Scenarios Presentation – November 2023

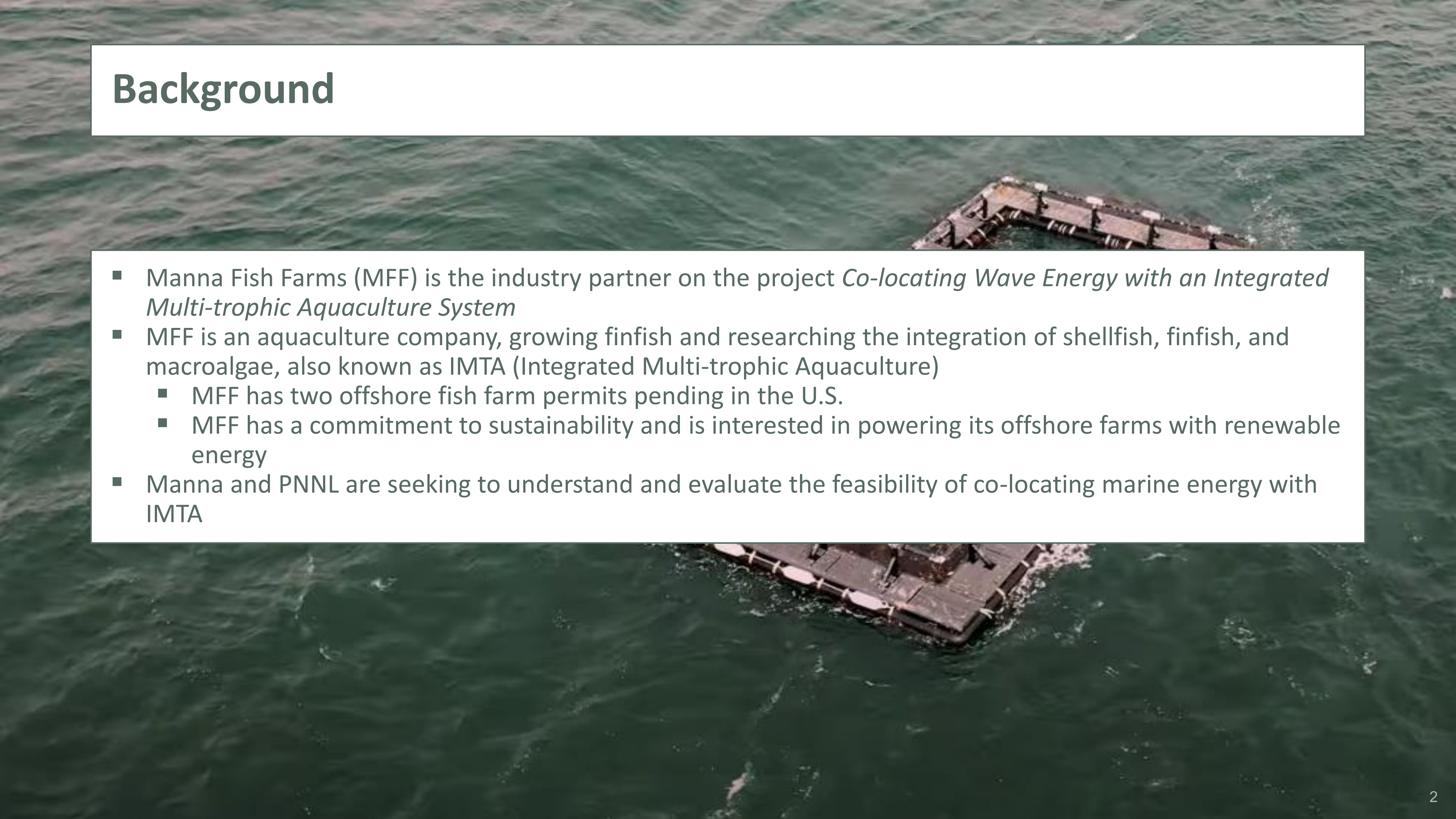
MANNA FISH FARMS, INC.™

Production-based Energy Scenarios for Powering the AquaFort IMTA System

November 17, 2023

Zachary Davonski, Ocean Engineer

Source: New Hampshire Sea Grant

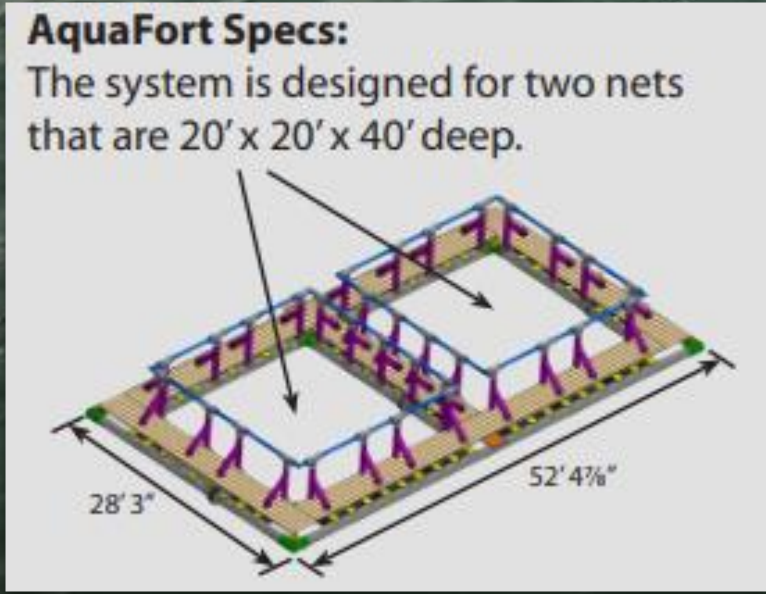


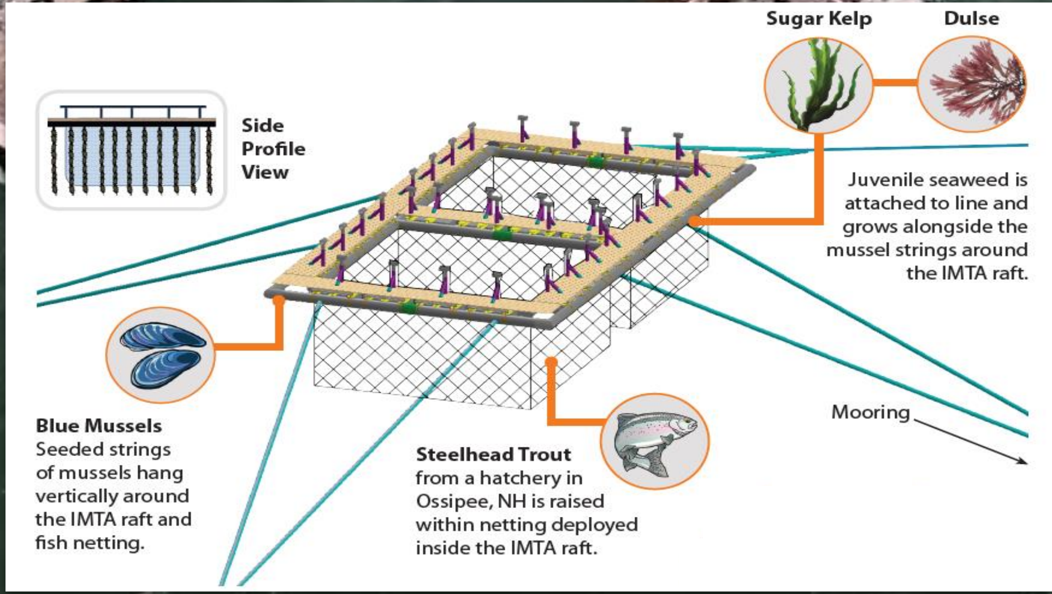
Background

- Manna Fish Farms (MFF) is the industry partner on the project *Co-locating Wave Energy with an Integrated Multi-trophic Aquaculture System*
- MFF is an aquaculture company, growing finfish and researching the integration of shellfish, finfish, and macroalgae, also known as IMTA (Integrated Multi-trophic Aquaculture)
  - MFF has two offshore fish farm permits pending in the U.S.
  - MFF has a commitment to sustainability and is interested in powering its offshore farms with renewable energy
- Manna and PNNL are seeking to understand and evaluate the feasibility of co-locating marine energy with IMTA

AquaFort IMTA System

- AquaFort (AQF) was designed and tested by the University of New Hampshire
- Proven production capabilities in nearshore waters off the coast of New Hampshire
  - Produced several harvests of blue mussels, steelhead trout, and sugar kelp
- Able to produce approximately 22.5 MT (50,000 lbs.) per year*
  - 18.0 MT finfish
  - 4.0 MT shellfish
  - 0.5 MT macroalgae
  - *quantities vary with species, location, cultivation plan, etc.





Source: New Hampshire Sea Grant

Potential species for a Caribbean deployment

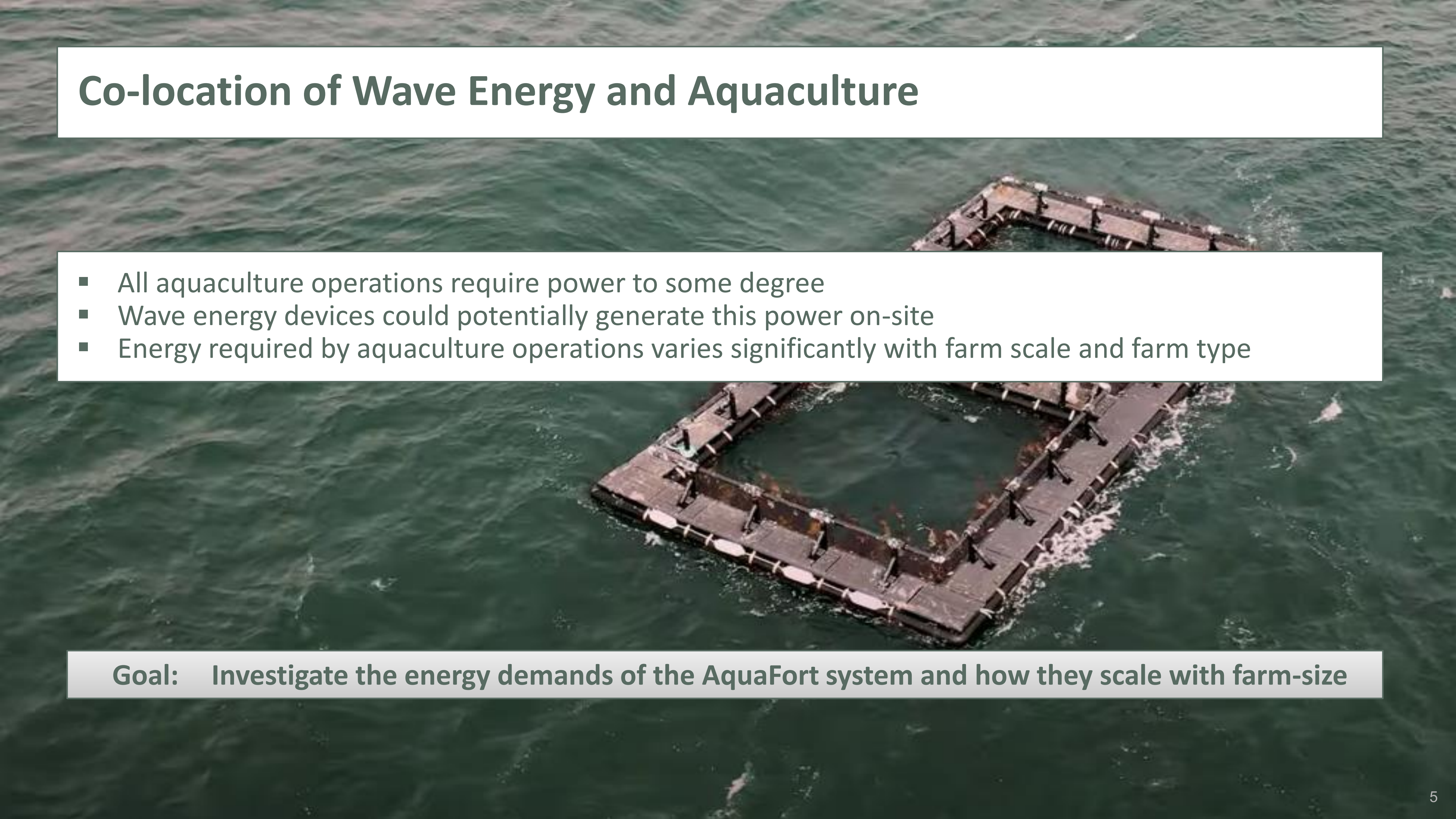
- **Finfish**
  - Cobia
  - Yellowtail Snapper
  - Red Snapper
  - Mahi Mahi
  - Grouper




- **Shellfish**
  - Mangrove Oyster
  - Rock Mussel
  - Queen Conch
  - Spiny Lobster




- **Macroalgae**
  - Eucheuma spp.
  - Gracilaria spp.

Co-location of Wave Energy and Aquaculture

- All aquaculture operations require power to some degree
- Wave energy devices could potentially generate this power on-site
- Energy required by aquaculture operations varies significantly with farm scale and farm type

Goal: Investigate the energy demands of the AquaFort system and how they scale with farm-size

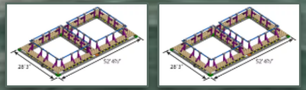
Methodology

- Farm scale is influenced by numerous factors (e.g., purpose, location, operator, etc.)
- Case-by-case analysis of energy demands was required to characterize what co-location with marine energy might look like
- Defined four unique farm scales based on production capacity (# of AquaFort systems) and purpose
- Identified the average <u>daily</u> energy demanding components / operations of each farm scale
  - Peak operational demands were identified, but not included in daily estimates
- Estimates were derived from a collective review of:
  - Aquaculture industry publications
  - Instrumentation technical data
  - Anecdotal references from farm operators
  - MFF’s own experience

Farm Scales

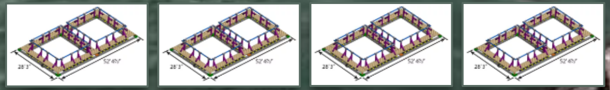
BASE

- Local food production
- Community-based
- 1-2 Systems
- ~45.5 MT production capacity



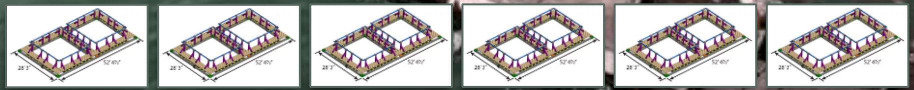
SMALL

- Local and regional food production for sale
- Small businesses
- 3-4 Systems
- ~91.0 MT production capacity



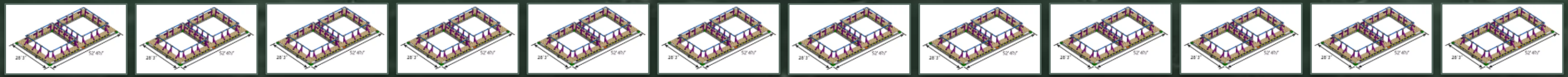
MEDIUM

- Regional food production for sale and distribution
- Medium businesses
- 5-6 Systems
- ~136.5 MT production capacity



LARGE

- Regional and national sale and distribution
- Commercial
- 7-12 Systems
- ~272.5 MT production capacity



Source: New Hampshire Sea Grant

Summary Table

	Base	Small	Medium	Large
Purpose	Local food production	Local and regional food production for sale	Regional food production for sale and distribution	Regional and national sale and distribution
# of Systems	1 - 2	3 - 4	5 - 6	7 - 12
Production Scale	Community-based	Small-business	Medium-business	Commercial
Production Capacity (MT) *	45.5	90.9	136.4	272.7
Site Area Required (acres) **	7.2	17	42.2	57.6
Communication	X	X	X	X
Monitoring	X	X	X	X
Video	X	X	X	X
Mechanical Cleaning Systems	X	X	X	X
Mechanical Feed System		X	X	X
On-site Feed Storage			X	X
On-site Feed Storage Recommended Capacity (MT) ***			30	60
Serviceable via basic fishing vessels	X	X		
Designated service vessels required			X	X
Daily Power Demand (kW)	1.0	6.8	52.6	105.2
Daily Energy Demand (kWh)	3.2	44.2	109.3	218.5

Notes

AquaFort platform has dimensions of 8.5 x 15.9m (28 x 52ft)

Base scale involves manual / by-hand operations wherever possible

All values reflect the maximum # of systems per scenario

Power and energy demand considerations are cumulative and limited to daily operations

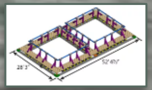
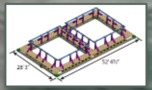
*Assumes 20m (66ft) site depth, 40ft net, 20kg/m3 fish density --> ~18.1 MT fish, 4.5 MT shellfish, .5 MT seaweed (production will vary based on species and cultivation plan)

**Assumes 20m (66ft) site depth, 4-point individual moorings with 3:1 scope, additional area needed for farm operations is included

***Assumes fish grown to 1.5 kg, eating 3% of body weight daily at an FCR of 1.5, refilling feed storage units every 6 days when all systems contain harvest size fish

MT = Metric Ton, kW = Kilowatt, kWh = Kilowatt-Hour, FCR = Feed Conversion Ratio

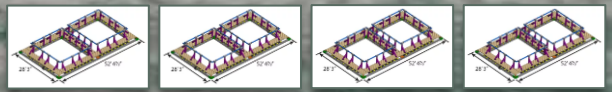
Base Scale: 2 Systems

Daily Operations							
System Operation Components	**Peak Power Demand** (kW)	**Peak Usage** (hrs per day)	**Base Power Demand** (kW)	**Base Usage** (hrs per day)	**Energy Demand** (kWh)	**Notes**	**Source / Reference**
Camera System	--	--	1.0	3.0	3.0	0.5 kW per AQF, Usage is per camera system - feed duration and observations per system	Moller 2019, MC Mariculture
Sensor System	--	--	0.0024	24.0	0.0576	1.2 W base sensor demand per AQF	Akva environmental buoy sensor specs
Data Storage / Transmission	--	--	0.006	24.0	0.144	3.0 W per AQF, UHF radio or cellular telemetry, communications/remote telemetry	Innovasea AquaHub, SATEL UHF Radio, SOFAR Spotter Buoy
Cumulative Power Demand (kW)						**1.01**	
Cumulative Energy Demand (kWh/day)						**3.20**	

Peak Operations							
Mechanical Net/Cage Cleaning System (power washers)	4.8	8.0	--	--	38.4	4.8 kW per washer, 3300psi powered by 6.5hp engine, Usage is 2hrs per net --> 4hrs per AQF	Simpson PS3228-S specs, MC Mariculture
Airlift System (air compressor)	10.4	0.35	--	--	3.64	10.4 kW compressor, 24 cfm powered by 14hp engine, Usage is for raising submerged system --> ~10.5min per AQF	EMAX-EGES1830ST specs, Preliminary submergence design
Cumulative Power Demand (kW)						**16.21**	
Cumulative Energy Demand (kWh/day)						**45.24**	

Small Scale: 4 Systems



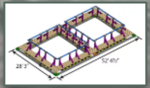
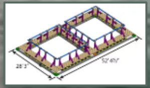
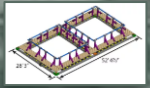
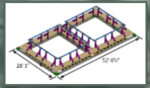
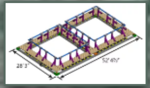
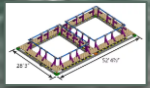
Daily Operations

System Operation Components	Peak Power Demand (kW)	Peak Usage (hrs per day)	Base Power Demand (kW)	Base Usage (hrs per day)	Energy Demand (kWh)	Notes	Source / Reference
Camera System	--	--	2.0	2.5	5.0	0.5 kW per AQF, Usage is per camera system - feed duration and observations per system	Moller 2019, MC Mariculture
Sensor System	--	--	0.0048	24.0	0.1152	1.2 W base sensor demand per AQF	Akva environmental buoy sensor specs
Data Storage / Transmission	--	--	0.028	24.0	0.672	7.0 W per AQF, Dual-mode cellular telemetry & iridium satellite, communications/remote telemetry/media/cloud storage	Skylink 5100/6100
Mechanical Feed System (on service vessel)	4.8	8.0	--	--	38.4	4.8 kW portable blower system, 8hrs based on 4 AQFs (30min per bay, 2x per day, 8 bays)	IAS AeroSpreader S250 specs , MC Mariculture
Cumulative Power Demand (kW)						**6.83**	
Cumulative Energy Demand (kWh/day)						**44.19**	

Peak Operations

System Operation Components	Peak Power Demand (kW)	Peak Usage (hrs per day)	Base Power Demand (kW)	Base Usage (hrs per day)	Energy Demand (kWh)	Notes	Source / Reference
Mechanical Net/Cage Cleaning System (power washers)	9.7	8.0	--	--	77.6	9.7 kW per washer, 1 washer, 4000psi powered by 13hp engine, Usage is 2hrs per net --> 4hrs per AQF	BE PE-4013HWPAGEN specs, MC Mariculture
Airlift System (air compressor)	10.4	0.7	--	--	7.28	10.4 kW compressor, 24 cfm powered by 14hp engine, Usage is for raising submerged system --> ~10.5min per AQF	EMAX-EGES1830ST specs, Preliminary submergence design
Service Vessel Equipment: crane	2.5	3.0	--	--	7.5	2.5 kW for 1MT boom crane, Usage is harvesting 1 full AQF	MaxLift 110S specs
Cumulative Power Demand (kW)						**29.43**	
Cumulative Energy Demand (kWh/day)						**136.57**	

Medium Scale: 6 Systems

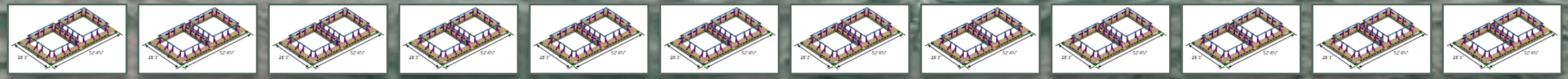
Daily Operations

System Operation Components	Peak Power Demand (kW)	Peak Usage (hrs per day)	Base Power Demand (kW)	Base Usage (hrs per day)	Energy Demand (kWh)	Notes	Source / Reference
Camera System	--	--	3.0	2.5	7.5	0.5 kW per AQF, Usage is per camera system - feed duration and observations per system	Moller 2019, MC Mariculture
Sensor System	--	--	0.0072	24.0	0.1728	1.2 W base sensor demand per AQF	Akva environmental buoy sensor specs
Feed Buoy: Data Storage / Transmission / Automation for (1) 30 MT feed buoy	--	--	0.108	24.0	2.592	90.0 W per feed buoy + 3.0 W per AQF, buoy uses L-band or VSAT SATCOM to receive commands & transmit all farm data & live video, each AQF has data relay device	Intellian FB500, Sailor 600, Innovasea AquaHub
Mechanical Feed System (w/in feed buoy, 6 lines total)	49.5	2.0	--	--	99.0	8.25 kW per waterborne feed line, All 6 lines running at once, Usage is per line - 2hrs total per AQF per day (15min per bay 4x per day, 12bays)	Moller 2019, AKVA waterborne feeding specs, MC Mariculture
Cumulative Power Demand (kW)						**52.62**	
Cumulative Energy Demand (kWh/day)						**109.26**	

Peak Operations

System Operation Components	Peak Power Demand (kW)	Peak Usage (hrs per day)	Base Power Demand (kW)	Base Usage (hrs per day)	Energy Demand (kWh)	Notes	Source / Reference
Mechanical Net/Cage Cleaning System (power washers)	19.4	4.0	--	--	77.6	9.7 kW per washer, 2 washers, 4000psi powered by 13hp engine, Usage is 2hrs per net --> 4hrs per AQF	BE PE-4013HWPAGEN specs, MC Mariculture
Airlift System (air compressor)	10.4	1.05	--	--	10.92	10.4 kW compressor, 24 cfm powered by 14hp engine, Usage is for raising submerged system --> ~10.5min per AQF	EMAX EGES1830ST specs, Preliminary submergence design
Service Vessel Equipment: crane, cold storage	3.8	1.5	5.6	18.0	106.5	3.8 kW for 2.5MT boom crane, Usage is harvesting 1 full AQF, 5.6 kW for cold storage on service vessel	MaxLift 380 specs, Walk-in freezer specs
Mechanical Net Cleaning System (net cleaner)	11.0	8.0	--	--	88.0	11.0 kW per Stingray net cleaner, Usage is 2hrs per AQF	LP Stingray E320 Series, MC Mariculture
Cumulative Power Demand (kW)						**102.82**	
Cumulative Energy Demand (kWh/day)						**392.28**	

Large Scale: 12 Systems



Daily Operations

System Operation Components	Peak Power Demand (kW)	Peak Usage (hrs per day)	Base Power Demand (kW)	Base Usage (hrs per day)	Energy Demand (kWh)	Notes	Source / Reference
Camera System	--	--	6.0	2.5	15.0	0.5 kW per AQF, Usage is per camera system - feed duration and observations per system	Moller 2019, MC Mariculture
Sensor System	--	--	0.0144	24.0	0.3456	1.2 W base sensor demand per AQF	Akva environmental buoy sensor specs
Feed Buoy: Data Storage / Transmission / Automation for (2) 30 MT feed buoys	--	--	0.216	24.0	5.184	90.0 W per feed buoy + 3.0 W per AQF, buoys use L-band or VSAT SATCOM to receive commands & transmit all farm data & live video, each AQF has data relay device	Intellian FB500, Sailor 600, Innovasea AquaHub
Mechanical Feed System (w/in feed buoy, 12 lines total)	99.0	2.0	--	--	198.0	8.25 kW per waterborne feed line, All 12 lines running at once, Usage is per line - 2hrs total per AQF per day (15min per bay 4x per day, 12bays)	Moller 2019, AKVA waterborne feeding specs, MC Mariculture
Cumulative Power Demand (kW)						**105.23**	
Cumulative Energy Demand (kWh/day)						**218.53**	

Peak Operations

System Operation Components	Peak Power Demand (kW)	Peak Usage (hrs per day)	Base Power Demand (kW)	Base Usage (hrs per day)	Energy Demand (kWh)	Notes	Source / Reference
Mechanical Net/Cage Cleaning System (power washers)	19.4	8.0	--	--	155.2	9.7 kW per washer, 4000psi powered by 13hp engine, Usage is 2hrs per net --> 4hrs per AQF	BE PE-4013HWPAGEN specs, MC Mariculture
Airlift System (air compressor)	10.4	2.1	--	--	21.84	10.4 kW compressor, 24 cfm powered by 14hp engine, Usage is for raising submerged system --> ~10.5min per AQF	EMAX EGES1830ST specs, Preliminary submergence design
Service Vessel Equipment: crane, cold storage	3.8	3.0	7.0	18.0	137.4	3.8 kW for 2.5MT boom crane, Usage is harvesting 2 full AQFs, 7.0 kW for cold storage on service vessel	MaxLift 380 specs, Walk-in freezer specs
Mechanical Net Cleaning System (net cleaner)	22.0	8.0	--	--	176.0	11.0 kW per Stingray net cleaner, 2 cleaners, Usage is 2hrs per AQF	LP Stingray E320 Series, MC Mariculture
Cumulative Power Demand (kW)						**167.83**	
Cumulative Energy Demand (kWh/day)						**708.97**	

Summary Table

	Base	Small	Medium	Large
Purpose	Local food production	Local and regional food production for sale	Regional food production for sale and distribution	Regional and national sale and distribution
# of Systems	1 - 2	3 - 4	5 - 6	7 - 12
Production Scale	Community-based	Small-business	Medium-business	Commercial
Production Capacity (MT) *	45.5	90.9	136.4	272.7
Site Area Required (acres) **	7.2	17	42.2	57.6
Communication	X	X	X	X
Monitoring	X	X	X	X
Video	X	X	X	X
Mechanical Cleaning Systems	X	X	X	X
Mechanical Feed System		X	X	X
On-site Feed Storage			X	X
On-site Feed Storage Recommended Capacity (MT) ***			30	60
Serviceable via basic fishing vessels	X	X		
Designated service vessels required			X	X
Daily Power Demand (kW)	1.0	6.8	52.6	105.2
Daily Energy Demand (kWh)	3.2	44.2	109.3	218.5

Notes

AquaFort platform has dimensions of 8.5 x 15.9m (28 x 52ft)

Base scale involves manual / by-hand operations wherever possible

All values reflect the maximum # of systems per scenario

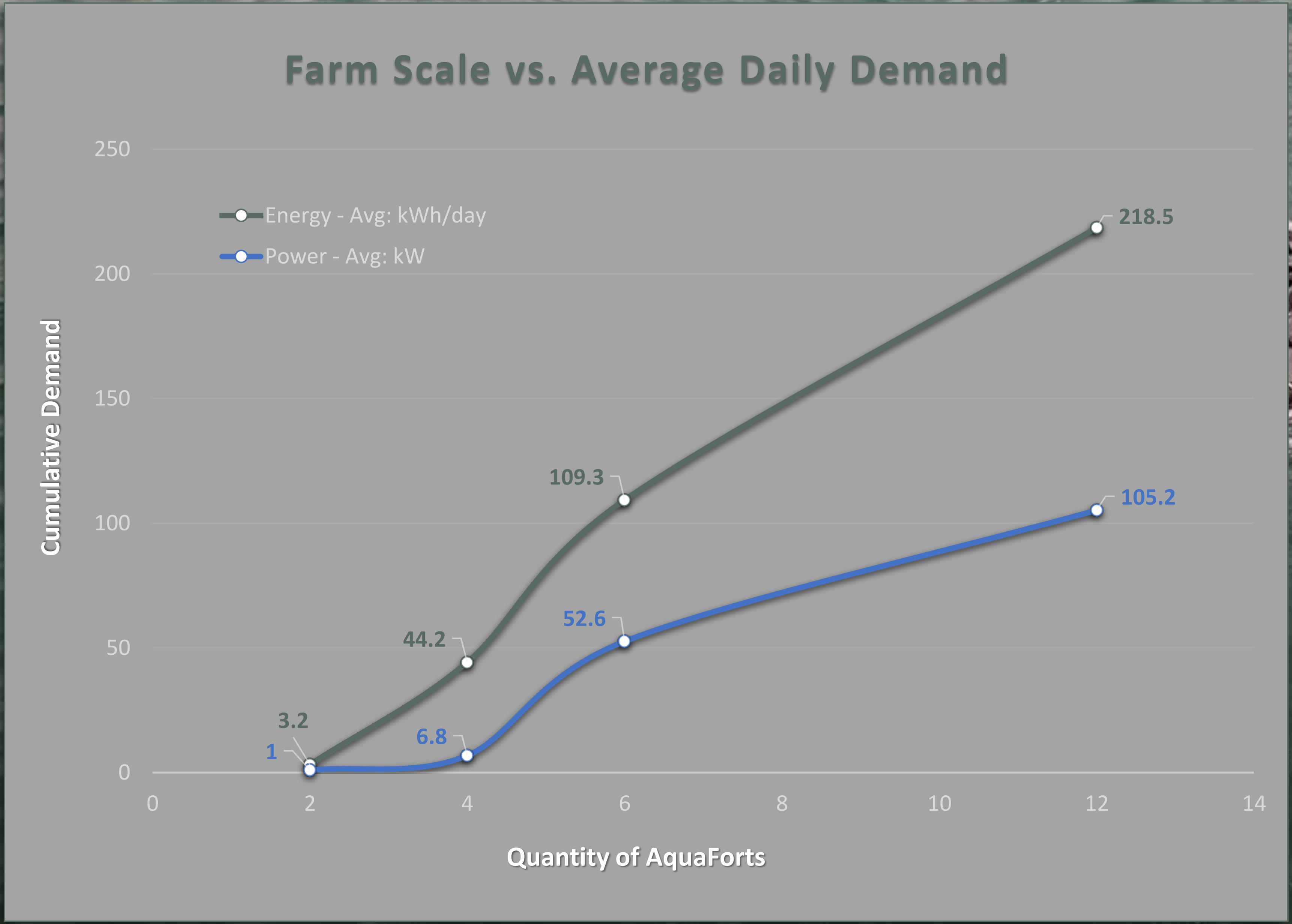
Power and energy demand considerations are cumulative and limited to daily operations

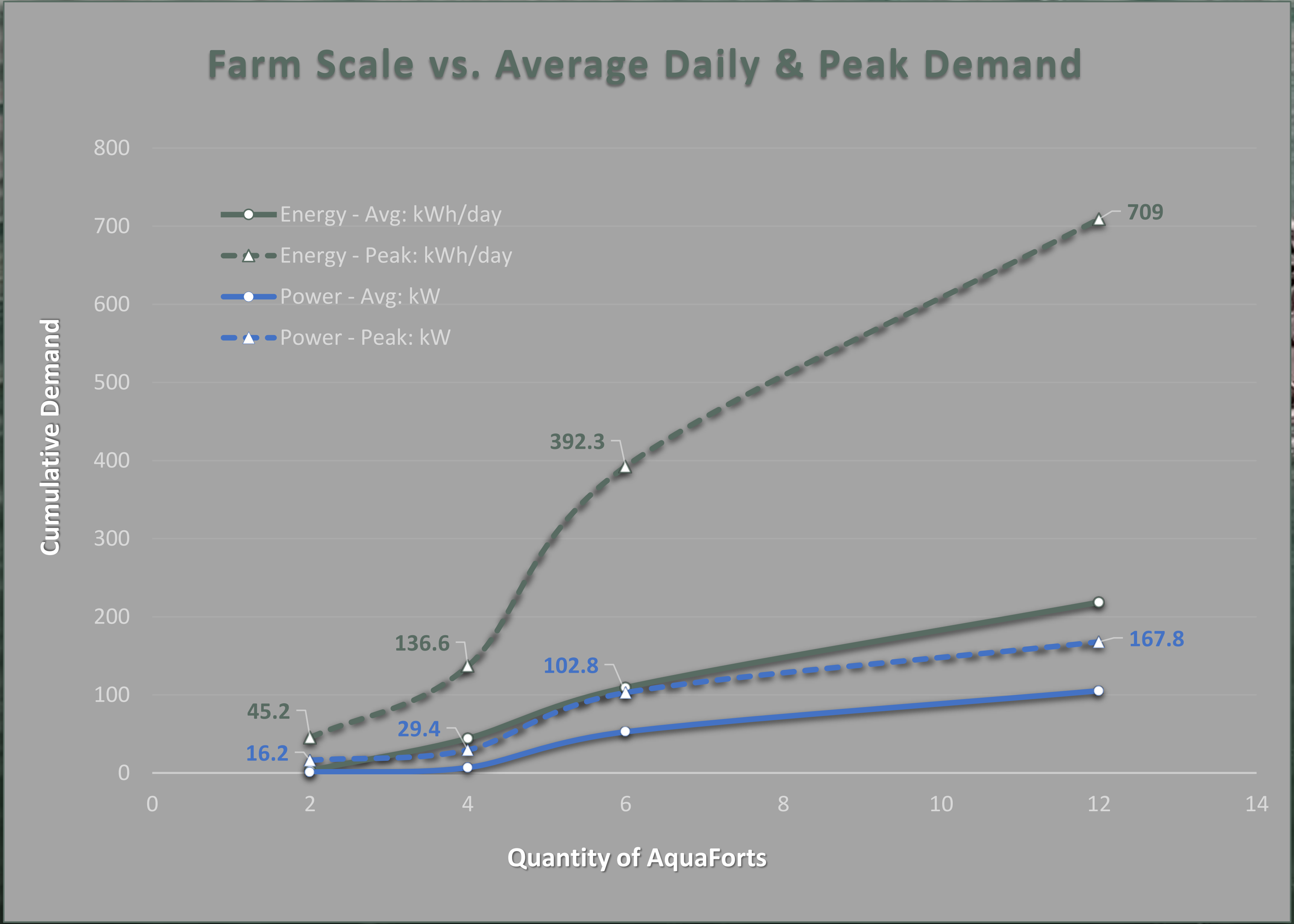
*Assumes 20m (66ft) site depth, 40ft net, 20kg/m3 fish density --> ~18.1 MT fish, 4.5 MT shellfish, .5 MT seaweed (production will vary based on species and cultivation plan)

**Assumes 20m (66ft) site depth, 4-point individual moorings with 3:1 scope, additional area needed for farm operations is included

***Assumes fish grown to 1.5 kg, eating 3% of body weight daily at an FCR of 1.5, refilling feed storage units every 6 days when all systems contain harvest size fish

MT = Metric Ton, kW = Kilowatt, kWh = Kilowatt-Hour, FCR = Feed Conversion Ratio


Farm Scale vs. Average Daily Demand
Energy - Avg: kWh/day
Power - Avg: kW
Cumulative Demand
Quantity of AquaForts
250
200
150
100
50
0
0
2
4
6
8
10
12
14
3.2
1
44.2
6.8
109.3
52.6
218.5
105.2



Farm Scale vs. Average Daily & Peak Demand
Energy - Avg: kWh/day
Energy - Peak: kWh/day
Power - Avg: kW
Power - Peak: kW
Cumulative Demand
800
700
600
500
400
300
200
100
0
709
392.3
136.6
45.2
167.8
102.8
29.4
16.2
0
2
4
6
8
10
12
14
Quantity of AquaForts

Next Steps

- Identify which farm scale(s) are logical and viable candidates for co-location with marine energy
- Consider how peak operational demands could be addressed
- Investigate technical and logistical aspects of co-location
    - Moorings
    - Power management
    - Energy storage
    - Physical connections

Questions?

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