BLUE ECONOMY
COOPERATIVE RESEARCH CENTRE

Australian Government
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RESEARCH SYNTHESIS REPORT

Scoping Study Projects 2020

A Proposed Research Agenda for the Blue Economy CRC
July 2021

The Blue Economy CRC is funded in part under the Australian Government's CRC Program, administered by the Department of Industry, Science, Energy and Resources. The CRC Program supports industry-led collaborations between industry, researchers and the community.

Confidential Report

This report has been prepared solely for the use of the Blue Economy CRC-Co and its Participants.

This report shall not be provided to any non-CRC Participant without the prior approval of the Blue Economy CRC CEO.

The Blue Economy CRC-Co acknowledges that it is, and will continue to be, solely responsible for making any decisions based on the information contained in this report, or when implementing any advice or recommendations in this report.

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Executive Summary

The Blue Economy Cooperative Research Centre (the Blue Economy CRC) has been established to perform world class, collaborative, industry focused research and training that underpins the growth of the Blue Economy through increased offshore sustainable aquaculture and renewable energy production.

In its first year, the Blue Economy CRC commissioned 17 scoping study projects involving our industry, research and Government participants with the objective of reviewing the current state-of-play, identifying industry challenges and priority research opportunities, and connecting the capability, capacity and interests of the Blue Economy CRC's 40 industry and research partners. While these scoping projects do not cover the full spectrum of the Blue Economy CRC's remit and vision, they are a solid beginning that will be complemented by others (already commissioned or staged into the future) to shape the overall research agenda.

The scoping study projects highlight the work of the Blue Economy CRC in addressing national and international priorities within the following plans and strategies:

- National Food Plan
- Food and Agribusiness Growth Centre, Sector Competitiveness Plan
- National Energy Resources Australia, Sector Competitiveness Plan
- National Marine Science Plan 2015-2025
- National Aquaculture Strategy
- Australia's National Hydrogen Strategy
- Department of the Environment and Energy Corporate Plan 2019-20
- Australia's international commitments, including those established by the United Nations (UN) High Level Panel on the Oceans and the UN System of Environmental-Economic Accounting (the CRC has a strong role to play in key parts of these forward-looking marine plans and processes).

The scoping studies have identified a comprehensive set of research priorities aligned with our five research programs that are discussed in detail in the following report. The report also presents a synthesis of outcomes from those 17 individual scoping study projects, compiling prioritised research challenges into a proposed single multi-disciplinary industry-focused research agenda for the Blue Economy CRC.

Firstly, seven cross-program research opportunities were identified and are proposed for short term (2021-2024) funding:

- The opportunity for development of marine areas that are zoned to promote blue economy activities (not just R&D but also areas for specialised commercial activities where planning and permitting is streamlined across sectors and jurisdictional needs while also remaining transparent and consistent with best practices).
- Monitoring, management and mitigation of risk, of activities and any potential interactions with local ecosystem components in offshore environments.
- Design of novel offshore aquaculture systems to meet the needs of industry in moving into offshore/high energetic sites.
- Demonstration of an Offshore Renewable Energy System.
- Market analysis requirements for emerging blue economy products, with view to building opportunities for offshore renewable electricity and hydrogen, and seaweeds.
- The need for digital infrastructure to support the Blue Economy CRC and emerging marine industries.
- Opportunities for integrated multi-trophic aquaculture systems.
- The importance of social and cultural license to operate in relation to the work of the Blue Economy CRC.

In addition, each Research Program has updated their 10-year Research Roadmap and highlighted short term (1-3 years) research priority areas for potential funding.

The Scoping Studies have raised a number of key opportunities and challenges for the Blue Economy CRC, as well as in general with the move of aquaculture and renewable energy into offshore/remote environments. These include:

- Sea Country - increased awareness of the close links between the blue economy, Sea Country and Australia's and New Zealand's First Nations mean respecting the shared values of Aboriginal and Torres Strait Islander Peoples must be central to CRC activities.
- While marine operational activities will provide the necessary demonstration to gain industry momentum and for the Blue Economy CRC to translate its research into reality, there is likely to be a long lead time on regulatory approvals.
- Multiple use platforms were a key focus of the CRC initial bid description and activities, but they present many operational and planning challenges (e.g., capital cost, policy and regulatory arrangements; site selection; deployment; footprint; production and market demand). Hence, a phased approach will be required to deal with operational constraints and transition from independent deployment activities, to neighbouring, and then co-located deployments, and to scale from single platforms to arrays.
- There are multiple possible pathways to achieving sustainable multi-species aquaculture and the CRC will need to create assessment tools (and potentially find new partners) to assist in determining which pathway is most appropriate for the CRC to pursue.
- The CRC should understand the industry, economic and social drivers for emerging offshore products (e.g., new offshore aquaculture species including seaweeds, electricity, hydrogen) to ensure meaningful and maximum impact.
- Automated and digital development underlies research opportunities across the CRC portfolio; this fast-moving space will require coordinated collaborations in order to avoid duplication and to facilitate funding in this competitive and capital-intensive space (again potentially requiring new partners).
- Biofouling is a key operational concern for aquaculture and energy production, as it triggers engineering problems and increases costs. However, given that biofouling communities (and mitigation options) will likely change with conditions, this area of R&D should be explored and tested with our industry partners to ensure that any effort is targeted to areas of importance to the Blue Economy CRC's partners.
- It is recognised across all research programs that COVID-19 has created dislocation and disruption and that the vision and potential exceed the current budget envelope and capability pool in certain areas. In delivering the overall research program, these issues demand both thoughtful reshaping of research activities (including how to deal with engagement and logistical hurdles) and a targeted and disciplined approach to project development (engaging in co-funding opportunities where applicable or new project partners).

The Scoping Studies also demonstrated new opportunities for collaboration and partnerships for the Blue Economy CRC including,

- Department of Agriculture, Water and Environment (DAWE) – Environmental management accounting, oceans management and policy
- Australian Fisheries Management Authority (AFMA) – regulatory responsibility for fisheries legislation
- NOPSEMA – Offshore oil and gas developments regulator; proposed regulator for future offshore clean energy technology
- Indigenous Land and Sea Corporation (ILSC) on first nations and cultural license
- Integrated Marine Observing System (IMOS) for data collection, storage and data management, and ocean infrastructure
- Geoscience Australia (e.g., AusSeabed and Data61) for NationalMap development, site selection and marine spatial planning
- NERA – Growth Centre supporting relationship growth with oil and gas (O&G) sector
- Unions (e.g., Maritime Union of Australia) for workforce profiling of the blue economy
- International renewable energy organisations (e.g. US Department of Energy, UK ORE Supergen, International Energy Agency) for shared innovation activities and strategic projects
- Other CRC's (e.g., SmartCrete CRC, SmartSat CRC, Future Fuels CRC, FenEx CRC, the CRC for Developing Northern Australia).

This report provides a platform for developing the Blue Economy CRC's short-, medium- and long- term research agenda. The scoping study projects have provided a forum for Participants to articulate their commercial research needs and these have been reflected in the research priorities.

The scope of the Blue Economy CRC is extensive; however, offshore research and development is resource intensive. Decisions about our future research program will necessarily be shaped by the available resources of the Blue Economy CRC and of our current and future partners.

1. Introduction

The opportunities to grow the blue economy are vast. Taken together, Australia and New Zealand have an Exclusive Economic Zone of over 14 million square kilometres of oceans providing enormous potential to increase seafood and renewable energy production sustainably. This puts Australia in a strong position for the coming decades, given its close proximity to rapidly growing markets in South-East Asia, which prioritise high quality seafood and increasingly green energy.

Realising this potential requires moving offshore into remote and more exposed high-energy operating environments. This requires the development of innovative and more robust structures, technologies and production systems that embrace automation in system design to provide safe and functional offshore working structures and conditions. They will need to withstand both regular and extreme weather events, while being safely and economically managed. The blue economy industries of the future will also require a new highly skilled workforce.

Governments are strongly motivated to support industries that will lead to growth in the economy and particularly employment. However, Australia's regulatory and policy frameworks for offshore renewable energy and aquaculture are relatively immature. Moving offshore requires new planning, regulatory and monitoring systems to provide industry confidence to make long-term investments and community confidence that the operations will be environmentally sustainable and socially responsible. In addition, the management and use of Sea Country is of fundamental interest for First Nations people, who desire active and productive inclusion in developing offshore opportunities. This recognition and inclusion are essential for equitable and sustainable blue economy futures.

The Blue Economy CRC has been established to address these challenges and to facilitate a step change in the economic, social and environmental value of Australia's new Blue Economy industries.

The Blue Economy CRC's research program has been developed through an iterative dialogue with industry and government to ensure it is focused on the challenges faced by industries in achieving scale and commercial success in the offshore environment. Key activities are focused around five integrated user-defined research programs:

- **Research Program 1:**
  Offshore Engineering and Technology (RP1)
- **Research Program 2:**
  Seafood and Marine Products (RP2)
- **Research Program 3:**
  Offshore Renewable Energy Systems (RP3)
- **Research Program 4:**
  Environment and Ecosystems (RP4)
- **Research Program 5:**
  Sustainable Offshore Developments (RP5)

In its first year of operations the Company entered into a formal agreement with 40 Participants. These Participants include organisations from the industry, research and government sectors, and collectively 10 countries are represented.

Aside from establishing the Blue Economy CRC governance and organisational structures, a major focus of its first 18 months was the development and roll-out of the initial phase of the research program.

1.1. Context & Scope

In 2020, the Blue Economy CRC commissioned 17 short-term scoping study projects (listed in Table 1 and summarised in Appendix A.4) to help the Company develop a clear understanding of current technologies, knowledge trends and solutions, and identify the major challenges and opportunities in developing sustainable offshore renewable energy and aquaculture.

These scoping study projects were developed in response to an identified industry need, or research knowledge gap, in areas such as:

- Key challenges for offshore high-energy salmon and kelp aquaculture production.
- Integrated offshore aquaculture and renewable energy infrastructure, mooring and vessel requirements.
- Marine energy conversion technologies suited to offshore conditions that support electricity generation, energy export and storage (via hydrogen as an energy carrier) and understanding the market opportunities for these technologies to support offshore industries (aquaculture being an example).
- Understanding the operational and energy requirements of offshore aquaculture systems.
- Robust site selection procedures, and environmental and operational monitoring strategies including the application of remote and autonomous monitoring technologies.
- Decision support tools for identifying trade-offs and synergies among current and emerging blue industries and the community.
- Economic, environmental, and social assessment frameworks for the blue economy.
- Ethical, policy and regulatory frameworks for Australia's emerging blue economy and processes for their integration.

This report provides a platform for developing the Blue Economy CRC's short-, medium- and long- term research agenda. The scoping study projects have provided a forum for Participants to articulate their commercial research needs and these have been reflected in the research priorities.

The scope of the Blue Economy CRC is extensive; however, offshore research and development is resource intensive. Decisions about our future research program will necessarily be shaped by the available resources of the Blue Economy CRC and of our current and future partners.

Table 1. List of scoping studies undertaken in 2020.

Project ID	Project Name
1.20.001	Aquaculture Vessel Requirement Scoping Study
1.20.002	Autonomous Marine Systems at Offshore Aquaculture and Energy Sites
1.20.003	Biofouling Challenges and Possible Solutions
1.20.004	Multi-Purpose Offshore/High Energy Platforms: Concepts and Applications
1.20.005	Review of Fish Pen Designs and Mooring Systems
2.20.001	Seaweed Aquaculture
2.20.002	Key Challenges for Offshore / High Energy Salmon Aquaculture Production
3.20.001	Hydrogen Storage and Distribution
3.20.002	Offshore/High Energy Sustainable Hybrid Power Systems
3.20.003	Energy demand analysis of Offshore Aquaculture Systems
4.20.001	Monitoring and assessing offshore / high energy production structures
4.20.002	Operational modelling for offshore aquaculture and energy
4.20.003	Tools to assess cross-sector interactions
5.20.001	Economic Assessment of Blue Economy
5.20.002	Integrating Blue Economy Governance Integrity Research
5.20.003	Logistics Challenges to Offshore/High Energy Co-location of Aquaculture & Energy Industries
5.20.004	Developing a policy and regulatory research plan for Australia's emerging Blue Economy

Despite challenges presented by COVID-19, the six-month scoping studies commissioned in May 2020 were completed in late 2020 after engagement and extensive discussions amongst Participants (see Appendix A.1) and additional collaborative relationships between industry, Government, researchers and end users. The output of these scoping studies now forms part of the CRC's foundational knowledge platform which, will be used to drive the direction of the Blue Economy CRC's ongoing research investment and the delivery of projects that align with the Blue Economy CRC's purpose, vision and strategies. This knowledge platform will continue to grow throughout the CRC's lifetime, that will be complemented by other research (already commissioned or staged into the future), making a substantive contribution toward achieving our milestones.

1.2. Blue Economy CRC's Research and Development Plan

Figure 1 describes the Blue Economy CRC's overarching research and development (R&D) plan that will make a significant contribution to delivering the blue economy. This R&D plan captures the short-, medium- and long- term R&D opportunities which are described in more detail in the following sections, and as well as the five research program priorities and plans described in Section 2.2 and Appendix A.2

SHORT TERM — MEDIUM TERM — LONG TERM

Delivering offshore engineering solutions

- Design of improved and novel offshore production systems, moorings, & support vessels
- Development of autonomous marine systems
- Biofouling reduction & reuse
- Multi-use platforms
- Validation, & prototyping
- Codes of practice
- Evaluating performance (sea trials)
- Demonstrations and applying of actual systems

Delivering seafood and marine products

- Seaweeds, salmon, oysters & by-products: Products, policy and social licence
- Maintain and enhance production
- Species selection & production assessment
- Monitor, manage & mitigate risk
- Integration & closed system aquaculture
- Tropical aquaculture production

Delivering offshore renewable energy systems

- Offshore electricity & hydrogen market opportunities & demand
- Energy system model integration ORES design & assessment
- DC Microgrids
- Phased demonstration
- Offshore electricity
- Phased demonstration
- Offshore electricity & hydrogen production

Delivering sustainable ecosystems & environments

- Marine spatial planning & site selection
- MetOcean prototyping
- Risk & opportunity - hazard analysis
- Sediment footprint & Biosecurity
- Decision criteria & assessment tools
- Life cycle & integrated assessments
- Biosecurity
- Adaptive Management

Delivering sustainable offshore developments

- Policy & regulation mapping
- Environmental management accounting
- Economic options
- First Nations & Cultural values
- Ethics, values & Social licence
- Policy and regulatory scenarios
- Environmental management accounting
- Supply chain analysis and Non-Market valuations
- Integrity systems: certification and assessment
- Blue economy reporting

DELIVERING TO THE BLUE ECONOMY

Blue Economy Zones

Autonomous data collection systems

Portal & data Infrastructure

Offshore production systems: energy and aquaculture

Integrated Multi-Trophic Aquaculture

Guidelines for certification & standards

Blue Economy CRC research and development plan

2. Research Synergies & Synthesis

Each scoping study project delivered a comprehensive final report and provided a short science summary articulating the key points, challenges, gaps and opportunities. The short science summaries are found in Appendix A.4.

From the outcomes of these scoping studies, the Blue Economy CRC has identified the following research priorities that informs the proposed longer-term research strategy.

These priorities are described below in relation to our milestones (see Appendix A.3) and highlight the cross-program opportunities. We present key overarching insights and challenges arising from operating in offshore environments, that apply CRC-wide.

Collaboration and opportunities are also explored that can enable the Blue Economy CRC to: (i) deliver to its purpose; (ii) be a trusted source of Blue Economy knowledge, capability and expertise; and (iii) provide the knowledge to create a step-change in the economic value of the Blue Economy.

2.1. Cross-Program Opportunities

Several research activities spanning all five research programs were identified during the scoping study projects and these would address strategic industry, government and community needs and achieve multiple CRC milestones. These seven research topics are as follows (with more detail given in the following sections), and they will be considered for prioritisation in the short term.

- The opportunity for development of marine areas that are zoned to promote blue economy activities (not just R&D but also areas for specialised commercial activities where planning and permitting is streamlined across sectors and jurisdictional needs while also remaining transparent and consistent with best practices).
- Monitoring, management and mitigation of risk, of activities and any potential interactions with local ecosystem components in offshore environments.
- Design of novel offshore aquaculture systems to meet the needs of industry in moving into offshore/high energetic sites.
- Demonstration of an Offshore Renewable Energy System.
- Market analysis requirements for emerging blue economy products, with view to building opportunities for offshore renewable electricity and hydrogen, and seaweeds.
- The need for digital infrastructure to support the Blue Economy CRC and emerging marine industries.
- Opportunities for integrated multi-trophic aquaculture systems.
- The importance of social and cultural license to operate in relation to the work of the Blue Economy CRC.

2.1.1. Development of a blue economy zone

Under Australia's federated system of government, State Governments have jurisdiction over inshore waters (generally to 3 nautical miles offshore) and the Australian Government has jurisdiction from State waters out to 200 nautical miles offshore, the limit of the EEZ. With multiple jurisdictions responsible for administration of Australia's oceans, there is a complex arrangement of planning and regulatory controls. There is currently no coordinated pathway for planning and approval of key commercial and R&D Blue Economy activities (including aquaculture and renewable offshore energy) in Commonwealth waters.

The Blue Economy CRC seeks to initiate and facilitate the integration of sustainable mariculture and renewable energy production activities, on behalf of its industry Participants, and the creation of an appropriate framework to establish special marine activity zones - Blue Economy zones - in Australian waters. Blue Economy zones could provide 'investment ready' platforms with strategic environmental approvals and management policies already in place, allowing both commercial and R&D activities to be initiated more seamlessly and with less need for lengthy, complex and expensive approval processes.

The zoning process could be led by Federal or State Government(s) with stakeholder participation, fed by relevant information and supported by relevant regulations. The Blue Economy CRC can play an important role in catalysing the development of zoning specific to the Blue Economy, contributing to better coordination amongst the public agencies involved in licensing and monitoring, facilitating collective action and joint management across various users, and enabling the development of Australia's Blue Economy. Realising this opportunity will require commitment from Governments to implement contemporary planning and regulatory systems to facilitate sustainable development.

The Blue Economy CRC has used a range of physical, production and socioeconomic factors to identify an offshore region in Commonwealth waters in the Bass Strait (northern Tasmania) as a potential demonstration zone. This demonstration zone (the first example of a dedicated Blue Economy Zone – 'BE Zone') provide a testbed not only for technology, but also for all the processes and standards required around marine spatial planning, site characterisation, data collection, baselines, standards etc. This first BE Zone will act as a template and testbed for additional zones into the future. The earliest monitoring phases for the new zone have begun (with the beginning of a baseline survey, starting late 2020) but larger general projects will be required to shape the requirements for marine spatial planning and site characterisation. These nascent projects will be the first of many potential CRC projects associated with the BE Zone or deployments within it. The development of a BE Zone provides opportunities to engage with all existing Participants and new stakeholders such as NOPSEMA, IMOS and Geoscience Australia (via AusSeabed program), to ensure data sharing, shared infrastructure and integration of knowledge of benefit to broader community. The site can also provide a test bed for new infrastructure, sensors and digital platforms under development (within and external to the Blue Economy CRC). Ultimately the lessons learnt will help revise offshore planning approaches and shape new guidelines for strategic spatial and industry plans, which can feedback into state and federal processes.

Several Blue Economy CRC milestones are aligned at translating R&D to the real environment. There are particularly explicit links to RP4 (site selection, marine spatial planning and smart observing programs, operational modelling); the demonstration projects and sea trials in RP1-3; monitoring and mitigation involving automated technologies (e.g., AUV, ROV); and the policy, regulatory, social licence, ethics, supply chains and market analysis to be undertaken by RP5. These links will also provide new opportunities as the reality of permitting, deployment and operation raise matters beyond theoretical considerations or that have been witnessed in other international jurisdictions and ecosystem types.

2.1.2. Monitoring, management, and mitigation of risk in offshore environments

The Scoping Project on *2.20.002 Key Challenges for Offshore / High Energy Salmon Aquaculture Production* identified the need for research focused on using multiple approaches to monitor the health and welfare of salmon and to combine these to provide mitigation responses and strategies. The ability to predict the risk of planktonic biological threats such as bacterial and viral pathogens, harmful algal blooms (HABs), and jellyfish is dependent on the existing knowledge around species occurrence and remains highly challenging. An in-depth understanding of the relationship between specific biological indicators and the monitoring technologies used to measure these variables will be critical for biological threat prediction. The monitoring of seals and other large predators poses different challenges as their presence or absence is more easily determined, but their movement is more independent of the physicochemical characteristics of water masses. As well as monitoring the biological threat, it is also important to recognise the need to monitor the fish to assess their current and changing status, together with the monitoring of environmental conditions. A successful endpoint would be the integration of multiple sources of information from all three categories to provide immediate and meaningful production guidance and management options, along with pre-emptive mitigation strategies.

Research is proposed in four phases:

- **Phase 1** - Technology audit and evaluation of remote sensing approaches appropriate for offshore/high energy and remote sites (2021-2024). This would consider static and mobile sensing systems, critical environmental measurements and existing / emerging sensor technology. Determine the need for autonomous underwater vehicles (AUV) based sensors and relate to site characteristics including site area and remoteness (number of accessible days). This has been considered in Scoping study *1.20.002 Autonomous Marine Systems at Offshore Aquaculture and Energy Sites*.
- **Phase 2** - Adaption of existing and novel welfare indicators to remote sensing technologies to provide reliable and repeatable data (2021-2024). These data could range across appearance and behaviour of fish to measurement and interpretation of eDNA.
- **Phase 3** - Efficient data management and integration across multiple platforms and to evaluate the need for real-time connectivity and autonomous data flow, rapid data visualisation to inform operations, and ultimately to develop reactive autonomous control in offshore/remote sensing (2024-2028).
- **Phase 4** - Ground-truth remote welfare indicators through validation experiments at different sites and assess technology transfer across species (2025-2029). Monitoring health and welfare of animals in offshore farming operations poses a significant challenge. Traditionally, health and welfare of farmed fish is monitored through regular 'hands-on' procedures, where animals are typically crowded, anesthetised and physically inspected for signs of disease, injury or poor health. The nature of offshore / high energy sites means that access will often be limited, thus making such hands-on procedures operationally prohibitive. This limitation will require a new approach to monitoring that is specific to offshore sites but will also benefit from the general trend to automate and develop artificial intelligence (AI) that is current across the industry.

Several factors can affect health and welfare including infectious and non-infectious diseases, physical and chemical impacts, the presence of predators and other abiotic and biotic environmental stressors.

The success of offshore farming operations will, in part, be determined by the ability of veterinarians and fish health managers to accurately measure the health and welfare of their animals remotely and in near real-time. Such actionable intelligence ensures that timely health interventions can be made and thus ultimately production loss is reduced. Several types of information are available to assist health and welfare assessment including standard production data, such as feeding responses and growth, that are collected for other purposes. As technology advances in line with remote management, integration of data and new possibilities including the use of machine learning new possibilities are opened. For example, the use of sophisticated and very high-quality cameras set up in each pen for remote feed management allows the opportunity to directly assess the fish (see below). Whilst individual measures as indicators can provide valuable information concerning fish health and welfare, they are most useful when integrated into an overall welfare model or index. Examples of this include the SWIM (Salmon Welfare Index Model) and FISHWELL models for welfare assessments. In remote offshore/high energy sites, the challenge will be how to measure welfare indicators remotely, while limiting hands-on procedures.

To be successful the project will connect directly with cross-program activities, including the design of novel offshore aquaculture systems (presented next). There is a clear need identified in the scoping studies to utilise RP1 technology solutions (inc. AUV, ROV) and to incorporate sensor technology development and analytics from RP1, 2 and 4 to provide an integrated approach to autonomous monitoring, inspections and response, which can address monitoring, biosecurity and environmental risks. The information processing will feed into and be fed by the Digital Platform (more details below) for real time connectivity and information flow (for autonomous control and fish welfare management); and the BE Zone provides a test site for further developments and refinements as well as for benchmarking and validation of new or replacement technologies.

2.1.3. Design of novel offshore aquaculture systems

The scoping study project *1.20.005 Review of Fish Pen Designs and Mooring Systems* has provided a comprehensive review of fish pen designs and mooring systems and identified various potential improvements to current fish pen designs.

The scoping study report highlighted that current nearshore fish pens, mooring systems and supporting infrastructure may be damaged and less reliable when deployed in offshore/high energetic sites. Owing to the harsh environmental conditions at offshore sites, offshore fish pen designs must be made either very large and strong or be submerged to move away from the strong surface waves. Although several offshore fish pens have been built recently such as the Ocean Farm 1, Shenlan 1 and Havfarm 1, they involve a large capital expenditure. The recommendation made in the scoping study is to develop more cost effective and durable offshore fish pen designs with their associated infrastructure for the Australian and New Zealand fish farming industry. Below is the roadmap to develop such novel offshore fish pen designs, for specific offshore sites identified in Australia and New Zealand.

The project will be undertaken in four phases as described below:

- **Phase 1** will consider the conceptual designs of novel offshore fish pens (2021-2023). It will include site identification, establishing the environmental and operational conditions that will provide the framework for the design and introduce design concepts. This phase will involve consultation with Blue Economy CRC fish farming companies, working on marine spatial planning and site characterisation (RP4), renewable energy production and storage facilities (RP3) and offshore fish production (RP2). Based on the selected offshore fish pen designs, static and hydrodynamic analyses of the fish pen and mooring system will be performed to ensure that strength, stiffness and stability requirements of all structural elements and entire structural system are met.
- **Phase 2** will consider model-scale testing of the fish pen designs in a wave basin (2024). This phase will allow for calibration/validation of hydrodynamics software (such as the ability to predict wave loading on odd shapes of fish pens) and design refinement and use of hybrid design techniques.
- **Phase 3** will look at testing of prototype system of a reduced size from planned final size (2025-2027). This will include conducting laboratory testing of an integrated/semi-integrated system (involving fish pen, mooring system and multipurpose floating platform) in a relevant environment; followed by verification and demonstration of prototype system(s) in an operational environment, at an integrated pilot system level. This task will be done in consultation with RP2, RP3, RP4, RP5 teams and Blue Economy CRC salmon aquaculture companies. This phase requires significant investment as it involves fabrication of prototype system(s) and demonstration at a selected site (e.g., the BE Zone).
- **Phase 4**, the final phase, is commercial demonstration (2027-2029). This phase may or may not occur within the Blue Economy CRC's 10-year timeframe. In both phases 3 and 4 there are risks associated with the demonstration due to extreme events, loss of fish, and damage to other infrastructure. These risks can be managed with the expertise of the current aquaculture companies given their significant experience with operations.

2.1.4. Offshore Renewable Energy System Demonstration

The Blue Economy CRC has now committed to purchase of Hydrogen infrastructure (electrolyser, hydrogen turbine, and microgrid) due for arrival in early 2022. This constitutes one component of the offshore renewable energy system demonstration project. Further components require integration of offshore renewable electricity generation and use or uptake of energy derived from the system.

There are several phases to this project, that span across all RPs.

Pre-commissioning phase (2021 priority; prior to commissioning of hydrogen infrastructure): Procedures and guidelines for installation, safe operation, maintenance, inspection and monitoring of the ORES need to be established. Hydrogen Council of Australia priorities for 2021 include addressing certification requirements, addressing social license, and building case for net-zero emissions. The Blue Economy CRC has opportunity to deliver to these priorities, with a focus on maritime Hydrogen production and use.

Proposed activities during this phase, delivering to milestone RP3.4.1 include:

i. Assessing social license for hydrogen in blue economy applications (links to RP5);

ii. Reviewing standards for hydrogen production/storage/distribution/consumption in blue economy (links to RP1, RP5)

Pre-commissioning phase (2021 priority): A priority activity is to resolve how the CRC will attend to (potentially competing) OREC demonstration opportunities/proposals, with consideration to how many technologies can be supported given financial considerations. A framework for decisions is required, which may build off the OES 2021 evaluation guidelines report. Near-term research priority for offshore demonstration should focus on establishing design criteria (energy demand profile for target demonstration market – in the Blue Economy CRC context, the focus will be the aquaculture sector (link to RP2), with view to application to other sectors also), site characterisation (with strong connection to RP4), and establishing social and environmental baselines (links to RP4 and RP5).

Phase 1 (2022-2024): The Hydrogen infrastructure is to be deployed on shore during this phase, with electricity to power electrolyser being sourced either from the grid (renewable) or other onshore renewables. During this phase, the emphasis is on de-risking initial configuration, testing the foundational microgrid components in an easily accessible, safe onshore setting, and production of hydrogen (and oxygen), both available for 'export' via off-agreements, or for R&D purposes to develop a hydrogen value chain in the maritime sector. The early-stage development, in an Australian context, will allow opportunity to contribute to broader hydrogen economy priorities relating to certification, building social license, and working towards net-zero. Certification and social license aspects should be prioritised in 2021, to ease deployment of infrastructure when available (with links to RP5).

During this phase, design of offshore renewable energy conversion technology and assessments of their technical (RP1 links), environmental (RP4 links) and social license (RP5 links) viability will be prioritised.

Phase 2 (2023-2026): During this phase, deployment of infrastructure offshore will commence, with a mix of infrastructure deployed onshore and offshore. Production of hydrogen and oxygen will be maintained onshore, and a supply chain into maritime applications will be established. This includes hydrogen storage/containerisation for demonstration (mini) export (onshore to offshore). This phase also introduces demonstration of offshore renewable electricity generation into an offshore microgrid, with hydrogen-generated electricity to firm supply. Prior to commencement of this phase, hydrogen storage scenario research (as recommended from P3.20.001) should occur.

Deployment and demonstration of offshore renewable energy conversion devices, within a diesel-hybrid configuration, prior to this phase may reduce combined risks of the offshore hybrid hydrogen microgrid demonstration.

Phase 3 (2026-2029): involves full offshore demonstration of a hybrid hydrogen microgrid, meeting objectives of milestone 3.4. This requires production of hydrogen offshore, powered with offshore renewable electricity; hydrogen/oxygen will be utilised in the offshore system (to support aquaculture operations, with view to relevance to other blue economy sectors); and excess hydrogen (and oxygen) containerised and exported from the offshore platform. Marinization of the electrolyser, and desalination requirements need to be addressed prior to this phase.

2.1.5. Market Analysis

In RP2 and RP3 the scoping study projects identified a need to understand the market opportunities associated with both the seaweed aquaculture and offshore electricity and hydrogen markets. In collaboration with RP5 the Market Analysis will aim to provide a consistent approach that can be further adapted and adopted as other opportunities require a formalised assessment.

Seaweed Aquaculture. In contrast to the Australian salmonid industry, which is well established and globally competitive, the Australian seaweed industry is very small, with production valued at AU $3 million, with the majority of this value from collection and processing of storm cast kelp in Tasmania. AgriFutures Australia (2020) recently released an Australian Seaweed Industry Blueprint that outlines plans for an AU $1.5 billion Australian seaweed industry that could employ 9,000 people. However, Australia currently has no commercial scale seaweed ocean farms and growth will rely significantly on reformed policy and regulation to allow for ocean cultivation of native seaweeds in offshore zones, and the formation of a dedicated research and development plan.

The recent RP2 scoping study (2.20.001 Seaweed Aquaculture) identified a need to understand the markets, products, value and policy required to support seaweed aquaculture in offshore environments. More specifically:

- Markets for kelp and bull kelp bulk biomass (e.g., alginates, fertiliser), and potential value-added products from all priority seaweeds (e.g., feeds, foods, nutraceuticals).
- Economic analysis of market opportunities and commercialisation as a cost-benefit analysis for offshore production, including potential for attenuation of hydrodynamic forces, use in multispecies aquaculture systems and ultimately integrated multi-trophic aquaculture (IMTA).
- Assessment of commercially viable carbon capture markets and strategies for seaweeds, and how these might align with offshore production models.
- The policy, regulation, and social license necessary for this activity.

In the first instance the opportunity for collaboration with the Australian Seaweed Institute will be explored, at least to ensure that their work is incorporated and not duplicated. The Market Opportunity will support the level and focus for investment by the Blue Economy CRC into options around seaweed propagation, and immediate RP2 priority (see Table 2). Development of seaweed aquaculture could provide at least one if not several species to the RP2 portfolio and contributes to production and seafood marine product orientated milestones (RP2.1, RP2.2, RP2.3) as well as integration orientated milestones (RP2.2). An important opportunity may be the development of floating reefs that will be designed to attach seaweeds for grow out; this addresses further milestones in RP2 and links to RP1. Understanding the multiple values of growing seaweed requires consideration of policy, regulation and social license and links in RP5, RP4 and RP3 (renewable energy and carbon sequestration).

Offshore electricity market. An offshore electricity market value analysis, synthesising feasible options and scenarios (technologies, scales, solutions) for electricity delivery on or from offshore platforms is proposed. The aquaculture energy demand scoping project provided valuable detail on the potential opportunity of powering offshore aquaculture systems from offshore electricity. A clear recommendation is to assess and understand other potential electricity markets for Offshore Renewable Energy Systems (ORES) with similar objectivity.

An initial phase of activity (2021) is focused on market opportunity and value.

- Identify opportunity (electricity consumers/ customers) in offshore/near-coastal settings (inc. aquaculture, coastal defences, communications, defence, island and remote community microgrids, offshore industrial operations (including oil and gas), ocean observations and monitoring, seaports, harbours and marinas, tourism, desalination, decommissioning, and more).
- Establish value (technological, economic, social, environmental) of identified markets.
- Understand market drivers, motivations/social license for renewable energy transition.

Establishing this broad understanding of markets, will ensure CRC technology development focus and supply chain focus are suited to most opportunistic markets; will build sectoral awareness of offshore renewable energy system maturity; and identify pathways to commercialisation for CRC technology partners.

A second phase of technical work (2022-2025) will focus efforts on prioritised market opportunities. This phase is focused on data collection to ensure real data input into energy system models and supports system optimisation for applications. The phase will involve:

- Quantifying the demand profile for various markets. This activity underpins design requirements for ORES technologies and will enable on-going techno-economic assessments of optimal system design for given markets.
- Establish and monitor scale and profile of electricity demand, to support assessment of the size of the market opportunity. This includes continued detailed monitoring of aquaculture sector demand (following *3.20.003 Energy Demand Analysis of Offshore Aquaculture Systems*).

Phase 1 requires strong collaboration of capabilities as identified in Section 2.5 and delivers to milestones within RP3 and RP5. A well-considered research program may link RP2 and RP3 interests in market studies. Real-time energy consumption data, established in phase 2, is a possible data feed for data infrastructure as part of platform management, linked with RP4 milestones.

Offshore hydrogen market. The value chain for hydrogen in the blue economy is not yet established. The CRC bid emphasised the export opportunity for offshore produced hydrogen, however, other potential domestic markets in the blue economy have not yet been well explored. These opportunities include, but likely not limited to, hydrogen powered vessels, including both ship and autonomous vessels and aircraft.

In addition to establishing the potential demand for hydrogen, consideration should be given to demand for oxygen – a co-product of electrolysis – in blue economy applications. The value of oxygen supply to the aquaculture sector has not yet been captured.

A focus for this activity would be the opportunity for hydrogen powered vessels in Australia's blue economy, investigating the market needs for service sized vessels, in industries such as aquaculture, tourism/ferries, and passenger vessels. This requires investigation of the status of hydrogen vessels worldwide, a review of known challenges, supply chain and sea-port requirements, and potential opportunities for Australian shipbuilders.

This activity delivers directly to RP1 and RP3 milestones and offers strong collaboration across existing CRC partners. Third-party involvement of shipbuilders, ship operators and regulators (AMSA) would be important for path to impact. Aquaculture service needs provides link to RP2. RP5 will likely be relevant, with certification and regulatory requirements not yet established in Australia.

Quantifying the maritime demand for hydrogen should be considered a high priority for 2021, given that the Blue Economy CRC anticipates commencing hydrogen production in 2022. Knowledge of market segments is critical information, to ensure technology choices in the hydrogen energy system (storage/distribution options) are fit for purpose.

2.1.6. Digital Platform

Scoping studies from all RPs make it clear that the CRC will collect and create vast amounts of new ocean data, adding to the immense volumes of such information already collected for other applications. Globally, new technology platforms - satellites, AUVs, and emerging data streams (building off traditional ocean monitoring platforms) - collected more data on the oceans in 2018 than was gathered during the entire twentieth Century (Tanhua et al., 2019).

The CRC's data will be multidisciplinary, and span both public and private ownership, which have each presented significant challenges for existing ocean data management. Existing management frameworks are characterised by distributed control, varied formats and data quality, and fragmented work programs, all of which are problems for how ocean data is collected, shared and accessed (Brett et al., 2020).

Opportunity exists for the Blue Economy CRC to make an impact, through appropriate partnerships, to work towards new data architectures that enable flexible access, usage, analysis, visualisation and cooperation. Brett et al. (2020) proposes three fixes: Federated networks; Open data; and Accessibility (the establishment of new business models that can make data more broadly available).

Ultimately, global cooperation is necessary. Australian level cooperation, spanning public and private data, with global engagement, presents a CRC opportunity, through collaboration with other emergent ocean data activities in the national arena (e.g., National Marine Science Committee (NMSC) data sub-committee, IMOS AODN, amongst others).

CRC Milestones require development of a digital platform to deliver CRC outcomes. This platform requires a single 'point of truth' for the CRC community with data sets that are accessible, quality assured and with supporting data layers providing information on confidence/risk associated with derived (modelled) and measured parameters. Consideration and investment in big-picture vision will leave a lasting CRC impact, much larger than captured in it achieving milestones alone.

Thinking beyond data management, procedures and oversight is needed as a matter of urgency and should be a national conversation with key ocean data stakeholders (IMOS/AODN, Geoscience Australia / NationalMap / Data61, Bureau of Meteorology, MNF, CSIRO, industry participants, First Nations people amongst others) and respecting data rights. Public sector data stakeholders are well represented on the NMSC data sub-committee. The Blue Economy CRC presents the opportunity to bring a broader group to the conversation, including strong industry engagement.

Discussions are underway with partner organisations around 'Phase 0' of the digital platform and what that work will look like. Desired functionality should be established from across all CRC domains and partners, and might include, but need not be limited to, aspects such as:

a. Manage and archive data from across programs (observations and models).
b. Real-time data feed and visualization.
c. Manage IP/data protection for industry vs public, open-access, and confidential data.
d. Compatibility with national standards, and systems of commercial infrastructure providers.
e. Developing and testing approaches to address social and cultural license issues, ethics and regulatory/policy considerations.
f. Analytics/alerts.

The digital platform will be central to many activities and contracted milestones, across all programs (RP1.3, RP2.2, RP2.3, RP3.1, RP4.1, RP4.2, RP5.3). There is a requirement for this to be appropriately resourced, balancing CRC data management (in-house data manager), with future-proofing development of digital infrastructure with appropriate collaboration.

However, it likely needs considerable additional funding to undertake it at best practice levels. A partnering relationship with an external provider, willing to contribute in-kind support to cover development or hosting costs long-term, would seem the most viable way forward.

2.1.7. Integrated Multi-Trophic Aquaculture (IMTA) and Artificial Reefs

This "blue sky" concept was an initial motivator for the bid and looks to take offshore production beyond "deep water" versions of nearshore monospecific culture facilities to IMTA; and allows for consideration of, inter alia, biofouling, circular economy, and carbon sequestration.

This body of research requires several enabling research projects. In the first instance, a scoping study is required to understand what research is already underway globally and the current opportunities and challenges. Initially, the scoping study project will address the development of benthic artificial reef systems to enhance productivity and ecosystems (including habitat provision without breaching commercial effectiveness) and to supporting offshore developments through wave attenuation, nutrient recycling, carbon sequestration and, where applicable, provision of marine products (potentially via an IMTA framework). Follow up supporting work includes: scour models; far field effects assessment (what the footprint of these structures are downstream or over broader spatial areas); biofouling and other species interactions with each industry, within a co-located site and with IMTA offshore; understanding of how to leverage the full potential of multispecies production (minimising undesirable aspects of aquaculture footprint); and the cultural preference for species in culture; evaluation of what colocation looks like at different scales.

As a novel ecosystem services approach, artificial reefs have enormous potential and will involve close links across multiple RPs, both in terms of technology development, but also data collection, models for testing designs and concepts. Artificial reefs has potential links across all RPs (RP1 engineering design requirements; RP2 species and system design; RP3 energy use and potential for integrated generation; RP4 environmental footprint and biosecurity, RP5 Legislative requirements, economic viability, social acceptability aspects). The work will also require collaboration with new partners. Those considered include SmartCrete CRC with the development of novel concrete solutions and industry relevant hatchery/growth knowledge and other groups with specific interests in the technologies or IMTA related product potential – such as the Southern Ocean Carbon Company (engineering solutions and commercialisation) and Climate Foundation.

2.1.8. Social Acceptability / Social License to Operate

Developments in offshore areas are likely to have considerable community interest. The initial scoping studies have highlighted the importance of community attitudes and concerns, including the interests of First Nations peoples, communities, and civil society organisations. These factors will influence planning and management of offshore developments.

Cultural licence and respectful and close collaboration with First Nations groups will be shaped around the outcomes of a dedicated project currently under development (which must be shaped jointly with First Nations communities).

Social licence to operate and corporate social responsibility are well recognised by the Blue Economy CRC's industry partners. Research on understanding the elements of social acceptability, including how to develop, maintain and transparently address social license, and cultural licence to operate will be critical to a successful outcome of the CRC's own research efforts (for example in demonstration or trial projects and activities in the BE Zone), but is also an important activity to frame the blue economy more generally.

This activity will require close collaboration with industry partners, including regulatory agencies, but also requires close connections with knowledge brokers and social scientists in participant organisations (i.e., engaging beyond the economists, biophysical scientists and engineers initially attracted to the CRC). Projects centred on science communication and the testing of concepts, frameworks and novel governance approaches under a 'policy laboratory' controlled experimentation process, will be considered. In addition, we will support the Blue Economy CRC's Risk and Opportunities general project underway to assist that team to deliver their research in a way that provides full social benefits.

While social acceptability/social license is addressed in milestones in RP5 (RP5.3.1 to RP5.3.5), it is central to all RPs and a good measure of success of the Blue Economy CRC's activities.

2.2. Research Program Priorities

In addition to the proposed seven cross-program research activities, each Research Program has identified specific priority research. The following section provides a summary of the research activities that can be considered for prioritisation in the short term by the Blue Economy CRC. These are presented by Research Program and demonstrate the links between these activities, those completed or underway, their relationship to the cross-program opportunities identified, and the longer-term plan.

2.2.1. Research Program 1: Offshore Engineering and Technology

Table 2 below provides a summary of the research activities that can be considered for prioritisation in the short term by RP1.

Table 2. Short term (1-3 years) research priorities for RP1 to be considered by the Blue Economy CRC

Research Activity	Description of Activity	Considerations/Implications	Link to Milestone Activities
Offshore autonomous sensing	» Couple remote sensing to in situ static and mobile sensing systems » Sensing focus: Water column profiling and surface sea state. The critical water quality variables of concern for aquaculture are chlorophyll, temperature, salinity, dissolved oxygen, turbidity, nitrate and the metocean parameters are wave period/height/direction and current speed/direction. These parameters have been raised by industry partners as high priority. » Real-time connectivity and autonomous data flow » Rapid data visualisation to inform operations. » Develop reactive autonomous control in offshore sensing.	This is the first phase of a long-term project to deliver a fully integrated monitoring, inspection and response system for BE CRC activities.	Delivers to milestones RP1.4.2 and RP4.3

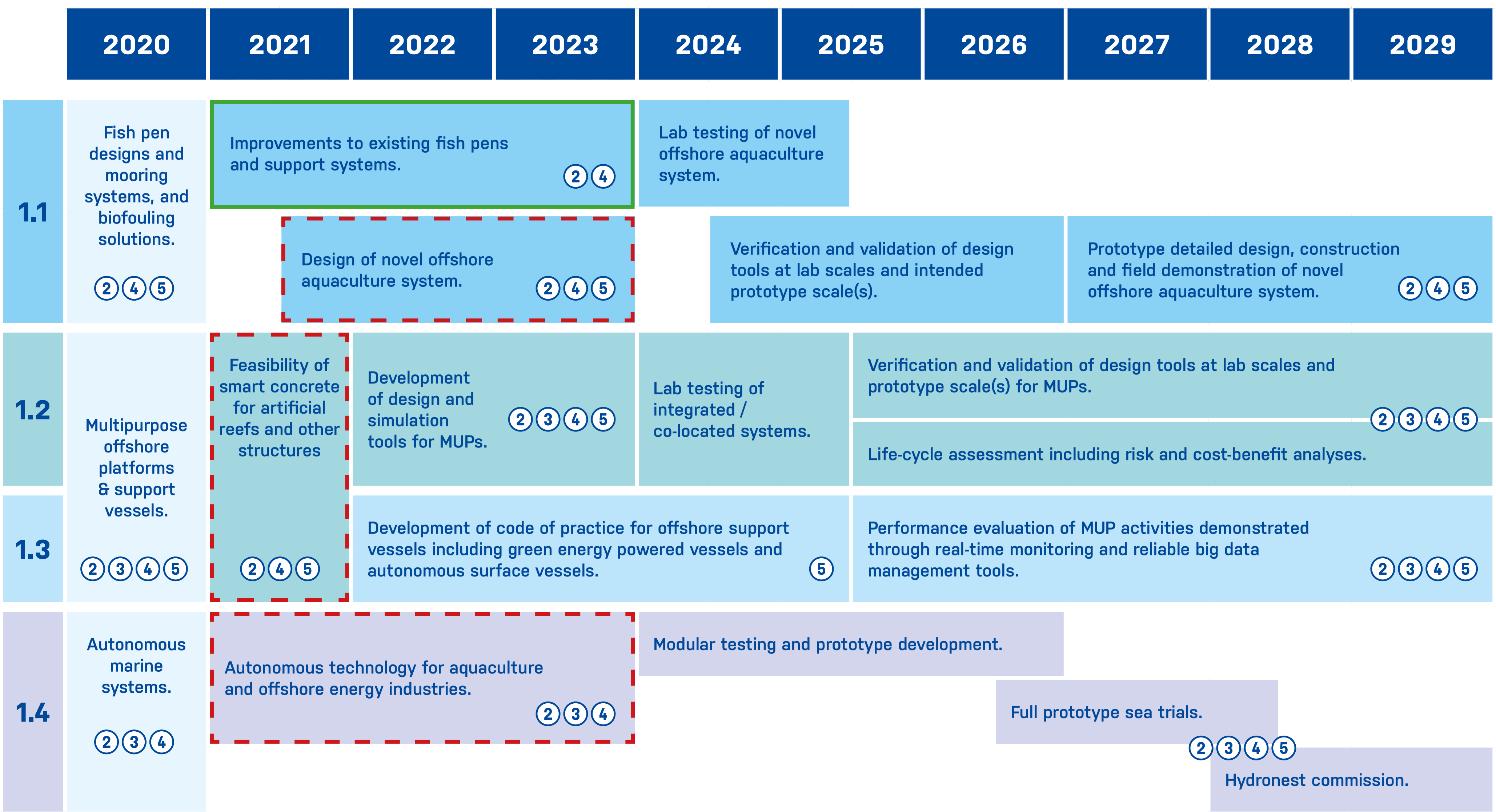
Research Activity	Description of Activity	Considerations/Implications	Link to Milestone Activities
Improvements to Fish Pen: pen-mooring rope connection system	» Assess mooring line loads and strains, local fish pen deflections, and typical failure types where available. Model typical connection geometries and loads. » Propose more robust connections through load spreading / peak load absorption / materials substitution / connection redesign. » Evaluate preferred proposals using simulation and/or scale models (in wave tank if necessary). » Test selected redesign in operating fish pen at full-scale (low-risk testing should be possible)	Damage to fish pens at mooring line connections will be more likely in high energy "offshore" situations. This research area is shortlisted in the Project Report on Scoping Study 1.20.005 WP2.	Delivers to milestone RP1.1.3.
Improvements to Fish Pens: Feed pipe system	» Gather data or monitor fish feed pipe loads and dynamics, fish pen / feed pipe / feed barge movements, typical feed pipe failure scenarios. » Model potential feed pipe connection dynamics. » Propose more robust connections using graded joint dynamics / pipe buckling controls / connection redesign / optimised flexible transitional sections. » Model proposed solutions. » Manufacture selected design at full-scale. » Test selected redesign in operating offshore leases (low-risk testing should be possible).	Damage to feed pipe systems is already common during storms and is costly to replace. Connections will need to be more robust for high energy "offshore" situations. This research area is shortlisted in the Project Report on Scoping Study 1.20.005 WP2.	Delivers to milestone RP1.1.3.
Development of a simple, robust biofouling cleaning and collection system	» Develop new prototype biofouling cleaning and collection system. » Test the prototype at pilot scale in real life conditions	All aquaculture companies indicated this to be an important and urgent priority! The topic is highlighted and explained in detail in the scoping study on biofouling, sections 5.1.2 and 5.1.3 of the final report.	Delivers to milestones RP1.4, RP2.3, RP4.2, RP4.4, RP2.1, RP2.2 and RP1.3.3.

Program Roadmap

The roadmap in Figure 2 highlights RP1 research already underway, what projects should be considered for short- medium- and long- term research activities, connections with research in other RPs and cross cutting research projects.

RP1 ROADMAP

Started | Priority to get started in 2021 | (X) RP Connections



RP1 Roadmap

2.2.2. Research Program 2: Seafood and Marine Products

Table 3 below provides a summary of the research activities that can be considered for prioritisation in the short term by RP2.developments.

Table 3. Short term (1-3 years) research priorities for RP2 to be considered by the Blue Economy CRC

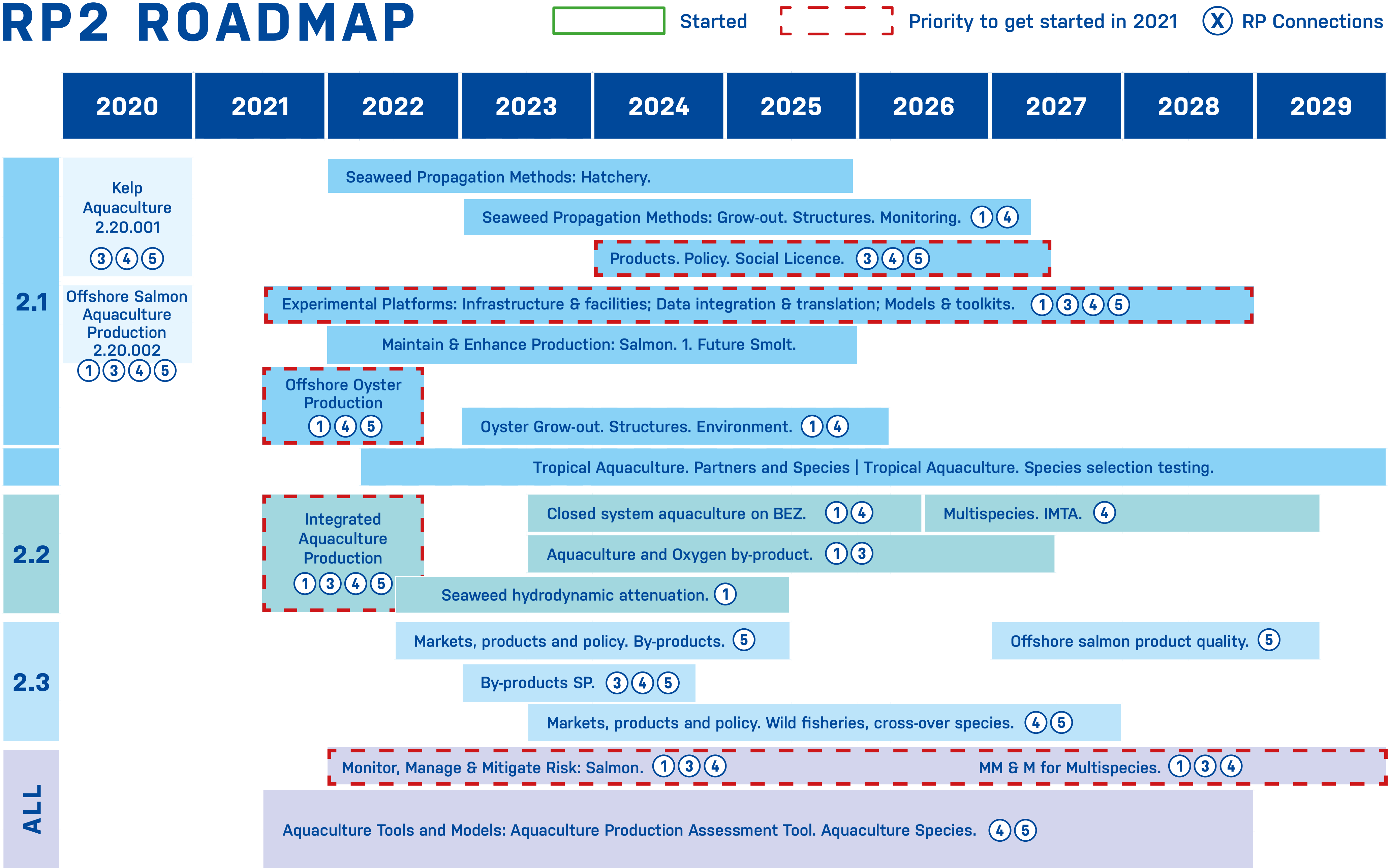
Research Activity	Description of Activity	Considerations/Implications	Link to Milestone Activities
Experimental Platforms for Aquaculture Production	Experimental Platforms that support research and enhance application to commercial situations. Infrastructure and facilities. Data integration and translation. Models and toolkits. Scenario testing, simulations and field experiments. All aquaculture species to be considered. Phase 1. 3 years. Preparing for offshore conditions and experiments using onshore tanks. Testing key variables on selected species: swimming velocity, temperature, oxygen, carbon dioxide. Scenario testing in the field. Incorporation of seaweeds, oysters and other species. Validation of onshore / offshore modelling and predictions.	Linking research and commercial trial facilities with commercial operations. Opportunity to scale research and model translation of data.	Delivers to milestones RP2.1.3, RP2.2.3, and RP2.3.3.
Aquaculture production assessment tool	Aquaculture Production Assessment Tool that uses a production biology assessment model and provides a toolkit. Data collection, collation and comparison to provide benchmarking and underpin decision making. Integrate with Species Selection Tool. All species. Phase 1. 3 years. Develop, test and refine the assessment tool.	The Aquaculture Production Assessment Tool will be used to combine data acquisition and analysis to meet milestones, to plan and interpret experiments and to engage in higher level analysis of production with commercial partners.	Delivers to milestones RP2.1.1, RP2.2.1, RP2.2.2, RP2.3.1, RP2.3.2.
Aquaculture species selection tool	Aquaculture Species Selection Tool Wholistic evidence-based approach to selecting single and multiple species, initially regionally specific but refined to be site specific. Current aquaculture species will be used initially, and the tool will be developed to consider other aquaculture species.	To consider wide range of factors: biological, technological, commercial and environment, value for integration and trade-offs.	Delivers to milestones RP2.1.2, RP2.2.2, RP2.2.3, RP2.3.2. Links to RP4 and RP5. RP4.1.1, RP4.1.3, RP4.4, RP4.5.2
Scoping Project: Pathways to Integrated Aquaculture. Temperate, Tropical and Multispecies.	Pathways to Integrated Aquaculture: Options for the BE CRC, to include temperate, tropical, multispecies, trophic level, natural habitat and integration with renewables.		Delivers to milestones RP2.2.1, RP2.2.2, RP2.2.3, RP2.3.1 and RP2.3.2
Scoping Project: Opportunities and Challenges for the Oyster Industry in Deepwater High Energy Sites	Industry led scoping project to identify opportunities and challenges for the Pacific oyster industry in deepwater and high energy sites. This might include scoping global technology solutions, understanding environmental limitations and site selection, determining selective breeding traits, integration with structures and other species. To consider learnings from mussel aquaculture in deepwater and high energy sites.	Suggested Participants to be involved. Strong need for RP1 and technological solutions, RP4 site selection.	Delivers to milestones RP2.1.1, RP2.1.2, RP2.1.3, RP2.2.1, RP2.2.2, RP2.2.3 RP2.3.1 and RP2.3.2

Research Activity	Description of Activity	Considerations/Implications	Link to Milestone Activities
Maintain and Enhance Salmon Production	Maintain and Enhance Production: This is an industry driven R&D theme that will address immediate industry priorities during the move offshore. Phase 1 Future Smolt (Atlantic salmon). Develop a future smolt strategy to integrate onshore, inshore and offshore sites to ensure cost effective harvest production of optimal quality fish year-round.	May require company specific commercial in confidence elements. Identify short term research goal for early return and consider next salmon research within the theme. Close alignment with MBIE funding proposal for King salmon smolts lead by Cawthorn with AUT, NZKS, IMAS.	Delivers to milestones RP2.1.1, RP2.1.2, RP2.1.3 RP2.2.1, RP2.2.3 RP2.3.1 and RP2.3.2.
Scoping Project: By-products from offshore aquaculture	Scoping project to investigate the potential for by-products from resources that will be associated with offshore aquaculture: this might include biofouling, fish wastes and nutrient re-cycling, wild species from FADs. It could also include recycling and use of structures and components of offshore operations		RP2.3.1, RP2.3.2, R2.3.3., RP2.3.4, RP2.3.5
Propagation, production and harvesting for key seaweed species	Develop Methods » Grow-out and harvest methods and infrastructure for the cultivation of kelps and bull kelp in offshore environments (RP1, RP2) » Life cycle of bull kelp (i.e. both Durvillaea amatheiae and D. potatorum) » Hatchery and grow-out methods for cultivation of Asparagopsis, with appreciation that this is likely to be restricted to sheltered environments or tank-based operations		Delivers to milestones RP2.1.3, RP2.2.3 and RP2.3.1. Links to RP1 and RP4.

Program Roadmap

Figure 3 highlights RP2 research already underway, what projects should be considered for short- medium- and long- term research activities, connections with research in other RPs and cross cutting research projects.

RP2 ROADMAP



RP2 Roadmap

2.2.3. Research Program 3: Offshore Renewable Energy Systems

Table 4 below provides a summary of the research activities that can be considered for prioritisation in the short term by RP3. Note that in the table below OREC and ORES are abbreviations utilised throughout. OREC describes the offshore renewable energy converters (e.g., wave energy device or floating offshore wind device) whereas ORES describes the offshore renewable energy systems (e.g., electrolysers, oxygen, hydrogen storage, FCs, microturbines, and desalination plant).

Table 4. Short term (1-3 years) research priorities for RP3 to be considered by the Blue Economy CRC

Research Activity	Description of Activity	Considerations/Implications	Link to Milestone Activities
Offshore electricity demand assessment, synthesising feasible options and scenarios (technologies, scales, solutions) for electricity delivery on or from offshore platforms	This activity follows identification of priority offshore electricity markets, captured in cross-program market development activity. For priority markets, a technical component of work is required to: (i) Quantify the demand profile for various markets. This activity underpins design requirements for ORES technologies and will enable on-going techno-economic assessments of optimal system design for given markets. (ii) Establish & monitor scale and profile of electricity demand, to support assessment of size of market opportunity. This includes continued detailed monitoring of aquaculture sector demand (following 3.20.003).	3.20.003 built understanding of aquaculture as market for ORE. 3.20.007 assessing opportunity for OSW in Australia's electricity grid. This activity will identify opportunities, and other potential partners for CRC.	Delivers to milestone RP3.1.5. Links to RP5. Supply chain development, social license, market assessment, business development. Links to RP2, with aquaculture sector as identified potential market.
Utilisation of hydrogen (potential future markets) in the blue economy sector	This activity follows identification of priority blue economy hydrogen markets, captured in cross program market development activity. For priority markets, a technical component of work is required to: Assess availability, viability and appropriateness of hydrogen technologies (production, storage, distribution and consumption) for blue economy applications.	Other 3rd parties necessary for success (e.g., shipbuilders). Part of this activity seeks to identify expanded opportunities, and other potential partners for CRC, to build opportunities in offshore hydrogen.	Delivers to milestone RP3.3.4. Link to RP1 on aquaculture support vessels. Link to RP5, re market development, supply chains, decarbonisation targets, regulation/ certification needs.
Develop software models for OREC and other ORES components for analysing the performance/ characteristics (Controlling, fault protection, power quality, offshore electrical standards and regulations) of Hydrogen DC Microgrid design including electrolysers, oxygen, hydrogen storage, other energy storage options, fuel-cells, microturbines, and desalination plant.	Build off recommendations from 3.20.002 Task 3: A focused workshop is proposed to be held during the first half of 2021. This workshop seeks to identify breadth of model systems required to be developed in the program (spanning interests of system simulation, development, optimization, management, prediction, socio-environmental integration), and the existing model systems, capability, supporting data and outstanding requirements identified amongst partners. Discussions will seek to map future project(s), framed arounda common framework across CRC, and identify project and task leads. Should be integrated with requirements of RP3.1.4. This activity has potential links with other RPs that need to be explored.		Delivers to milestone RP3.3.1 and links to RP3.1.4. Potential links to RP1 and RP4 and RP5.

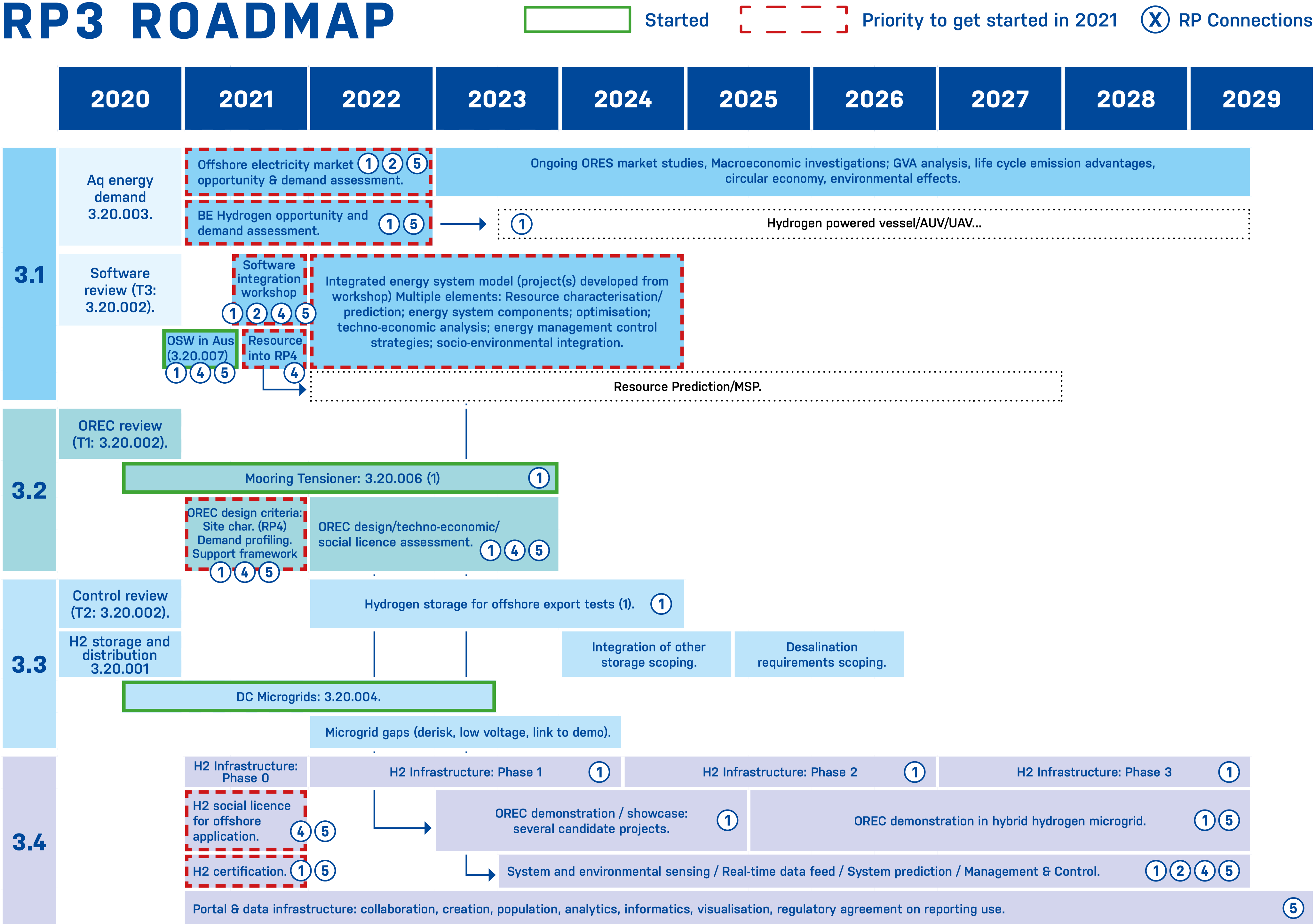
Research Activity	Description of Activity	Considerations/ Implications	Link to Milestone Activities
Procedures for reliable operation of microgrid demonstration	Potential gaps for reliable operation of the microgrid demonstration exist between the funded DC microgrids project, and what is being delivered through the hydrogen infrastructure project. These include: » Control and communication topologies for offshore DC Microgrids » Fault protection of offshore DC Microgrids » Power quality issues of offshore DC Microgrids » Electrical standards/guidelines for offshore DC-grid systems » Other control system risks identified in project 3.20.002. These activities sit beyond the scope of funded projects. Projects to address these issues, potentially through system model development, must be captured in project planning.		Delivers to milestones 3.3 and 3.4

Program Roadmap

The roadmap in Figure 4 highlights RP3 research already underway, what projects should be considered for short- medium- and long- term research activities, connections with research in other RPs and cross cutting research projects.

The roadmap outlines a proposed path to meet the commonwealth milestones to develop and demonstrate an integrated, off-line offshore renewable energy (ORE) system – while simultaneously seeking to build opportunity and market demand for the program outputs (offshore renewable electricity, displacing diesel and hence reducing emissions in off-grid applications; ORE in grid connected scenarios to increase renewable energy penetration in Australia's electricity system; hybrid energy systems for blue economy applications; and hydrogen, for export opportunities and application in blue economy sectors). Program activities work towards successful demonstration over the 10-year timeframe. The latter phase of the roadmap remains less defined, allowing flexibility as the program grows within a rapidly evolving research space.

RP3 ROADMAP



RP3 Roadmap

2.2.4. Research Program 4: Environment and Ecosystems

Table 5 below provides a summary of the research activities that can be considered for prioritisation in the short term by RP4. These do not include those projects already underway.

Table 5. Short term (1-3 years) research priorities for RP4 to be considered by the Blue Economy CRC

Research Activity	Description of Activity	Considerations/Implications	Link to Milestone Activities
Site selection criteria (e.g., Used in Multi Criteria Decision Making methods) need to be developed specifically for offshore sites and multiple use platforms	High priority as foundational to other 4.1 activities and identified as a critical need by stakeholders.	State agencies; indigenous groups and industry representatives within and beyond the CRC (these are extensive so not listed individually here, but does include all CRC participants).	Delivers to milestone RP4.1.1. Links to RP1-3 in terms of design shape and specifications, what is feasible and economic, not just what conditions they have to design to; RP2/3 required conditions; RP5 social license aspect, also insurance, legality and liability aspects.
Marine spatial planning tool development	Identify/collate appropriate data layers, biophysical, socioeconomic, cultural and regulatory (this will involve comparing resolution of what is available vs what is needed, may require modelling to bridge the gap). A co-benefit would be pre-competitive data sharing (facilitated by CRC data repository and digital platform).	Would require links (information flow) across all RPs and collaborations/ links with: State agencies; indigenous groups; IMOS, GeoScience Australia; other research agencies; data holders.	Delivers to milestone RP4.1.3. Links to RP1-3 in terms of what is feasible in terms of engineering, biological tolerances of production species and resource profiles needed for energy generation; RP5 for social, economic and cultural objectives/ values and legislative or regulatory constraints.
Predictive modelling to support site selection	A body of work that generates supporting synthetic datasets, for use in the spatial planning tools, via modelling. This modelling will require a moderate spend to provide synthesised products at suitable scales for habitat defining properties (such as bottom sheer stress, water depth, sediments etc) and species distributions. In terms of energy it will generate downscaled/ finer resolution energy atlas fields (for resource and habitat characterisation) in likely deployment locations.	This will require collaboration across CRC Participants and with rights holders, relevant government agencies, data holding organisations (e.g. Geoscience Australia, IMOS, NESP, state government agencies) or agencies that are also closely involved in marine spatial planning, such as Parks Australia or the Department of Agriculture, Water and the Environment more broadly (e.g. around planning robust to climate and biodiversity considerations). Development of the modelled layers and the resulting tools will need close communication with end-users to make sure the tools are fit for purpose and deliver transparency of content.	Delivers to milestones RP4.1.1, RP4.1.2 and RP4.2.2. Links to RP1-3 in terms of biological tolerances of production species and resource profiles needed for energy generation.

Research Activity	Description of Activity	Considerations/Implications	Link to Milestone Activities
Baseline and monitoring data (for EIA), including consideration of how to use new/ autonomous cost-effective monitoring methods as well as social and cultural aspects	This may require a phased approach to the project, or more likely a series of projects (including a PhD candidate or two). The research will require technology development. and identification of key metrics of environmental performance in offshore waters; and designing cost efficient monitoring strategies for offshore platforms that are suitable to assess environmental impact and satisfy regulatory requirements (based on international bets practice and analogous inshore/ terrestrial policies or circumstances). Supporting/developing emerging monitoring methods, especially those also delivering required data (for compliance reporting) while reducing workplace health and safety risks to operators. If possible (given timing) it would be good to use the MetOcean outputs to help design any field programs (i.e., test the design in silico) to verify useful control and monitoring sites that most effectively capture system state and minimise uncertainty.	This work will involve collaborations with First Nations rights holders; regulatory agencies; social scientists. To minimise industry wastage ($ spent duplicating mapping work company-to-company) agreement for pre-competitive information sharing will be critical. Given the nascent state of existing regulatory requirements/standards in this area (i.e., for offshore sites) there is the potential for the CRC to help in establishing the standards.	Delivers to milestones RP4.3.1, RP4.3.2 and RP4.3.4. Links to all the other RPs - RP 2 and RP3 on characteristics for production; RP1 data collection technology; RP5 baseline in non-stationary environment, social license, policy gaps. This body of work will involve learning from existing AUV work and work in RP1. There will also be strong links to RP5 (around understanding how do define baselines that continue to deliver on regulatory requirements and remain informative despite non-stationary environmental conditions; also, around social license, offshore policies and standards).
Real time data access (web-tools), including model output	Development of digital platform to uptake, run automated QAQC, analytics, informatics, visualisations, dashboard, reporting etc.	The digital platform is discussed further in the above section. It likely needs additional funding to do it to best practice levels or partnering with external partner willing to put in in-kind to cover development or hosting costs long term.	Delivers to milestone RP4.3.3 explicitly, but actually delivers against all milestone areas (4.1-4.5 and also into other RPs across the CRC).
Multi-day to multi-week & probabilistic operational forecasts (of physical environment but also DO, Harmful Algal Blooms, water clarity, etc.)	Develop a Decision Support Service (i) for energy producers to manage and predict generation loads, and (ii) for aquaculture to optimize feed/harvest strategies based on a feeding/fish growth model forced with predicted environmental conditions. Also need data assimilating forecasts (either through combining data across producers or keeping it segregated with tailored forecasts using only own data, depending on partner appetite for mixing information across sources)	Close partnerships required with industry members to ensure the variables and scales of prediction meet planning and operational needs.	Delivers to milestone RP4.3.3. Links with all other RPs in terms of what they (or industry, regulatory bodies) require from the prediction systems.
MetOcean and Forward looking (climate influenced) extreme value analysis (for engineering design)	MetOcean modelling system; Digital twin (relocatable modelling and extreme events modelling and interannual variability). Will need discussion of scales, content, and a firm route to operational uptake as a service (not just a research product). Connectivity modelling and other predictive tools (e.g. for energy systems) will likely come under this umbrella.	There will need to be a solid link with BOM (e.g., for operational uptake). Enabling science will also be required around an analysis to see what set of observations are best placed to reduce uncertainty and ground truth model products.	Links to all other RPs around needs from predictive systems. The MetOcean modelling will be provided as a service to all RPs (thereby avoiding duplication within the CRC).

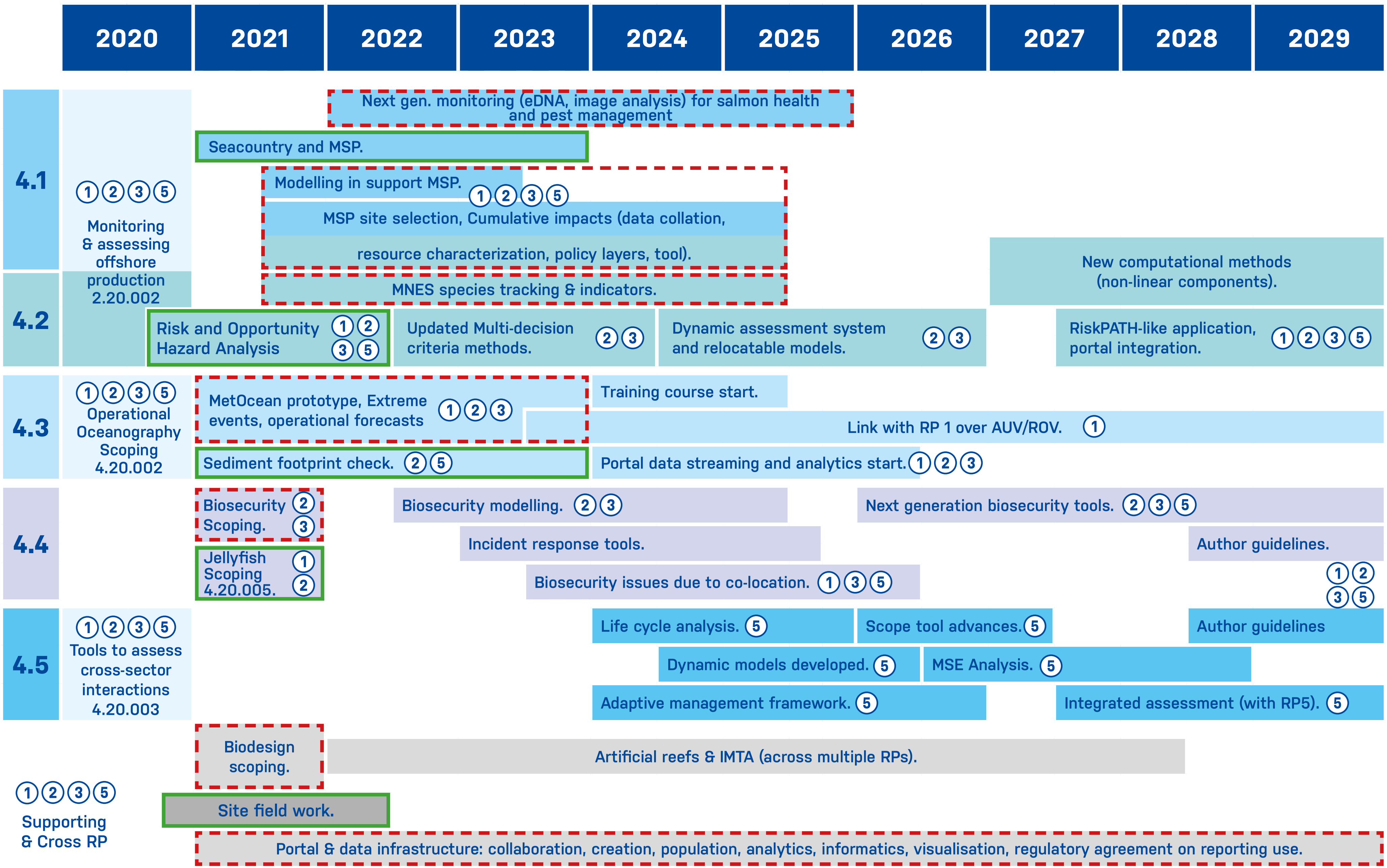
Research Activity	Description of Activity	Considerations/Implications	Link to Milestone Activities
Biosecurity scoping project	Scoping study to see what is feasible, what has been done elsewhere (e.g., with respect to epidemiology, role of eDNA sensing etc) is of primary importance.	This will link with industry members around production considerations and known biosecurity issues, but also requires collaboration with external biosecurity experts (in the same way other scoping projects went beyond CRC participants). Given the potential for IMTA to both minimise some biosecurity issues but also raise new considerations there needs to be a close link to the Artificial Reef and IMTA scoping study (cross-cutting project).	Delivers to milestones in RP4.4. This will have explicit links with RP 2 and 3 who can deliver specific operational information.
Identification of biosecurity (and associated) issues due to colocation (including noise, vibrations, contaminants, interactions with species of conservation concern etc)	This is likely to start as an expert driven piece of work. However, the true form should wait for the output of the scoping study.	The relevant links will be clearer once the project has been specified in more detail but is likely to mirror linkages identified for the biosecurity scoping study.	Delivers to milestones in RP4.4 and RP4.5.2. As this must cover colocation it must link across considerations from all RPs.

Program Roadmap

This roadmap in Figure 5 below indicates the scoping studies that have already completed, general projects underway or in preparation, a PhD project that is currently advertised (on incorporating Sea Country into Marine Spatial Planning; this is strongly linked to RP5 work on First Nation participation in the blue economy but is a separate standalone project), projects to be considered in the short term (2021), as well as medium, and longer, term activities to meet Commonwealth Milestones. Links between these projects and other RPs have also been noted, as have cross cutting research topics.

RP4 ROADMAP

Started | Priority to get started in 2021 | (X) RP Connections



RP4 Roadmap

2.2.5. Research Program 5: Sustainable Offshore Developments

Table 6 below provides a summary of the research activities that can be considered for prioritisation in the short term by RP5.

Table 6. Short term (1-3 year) research priorities for RP5 to be considered by the Blue Economy CRC

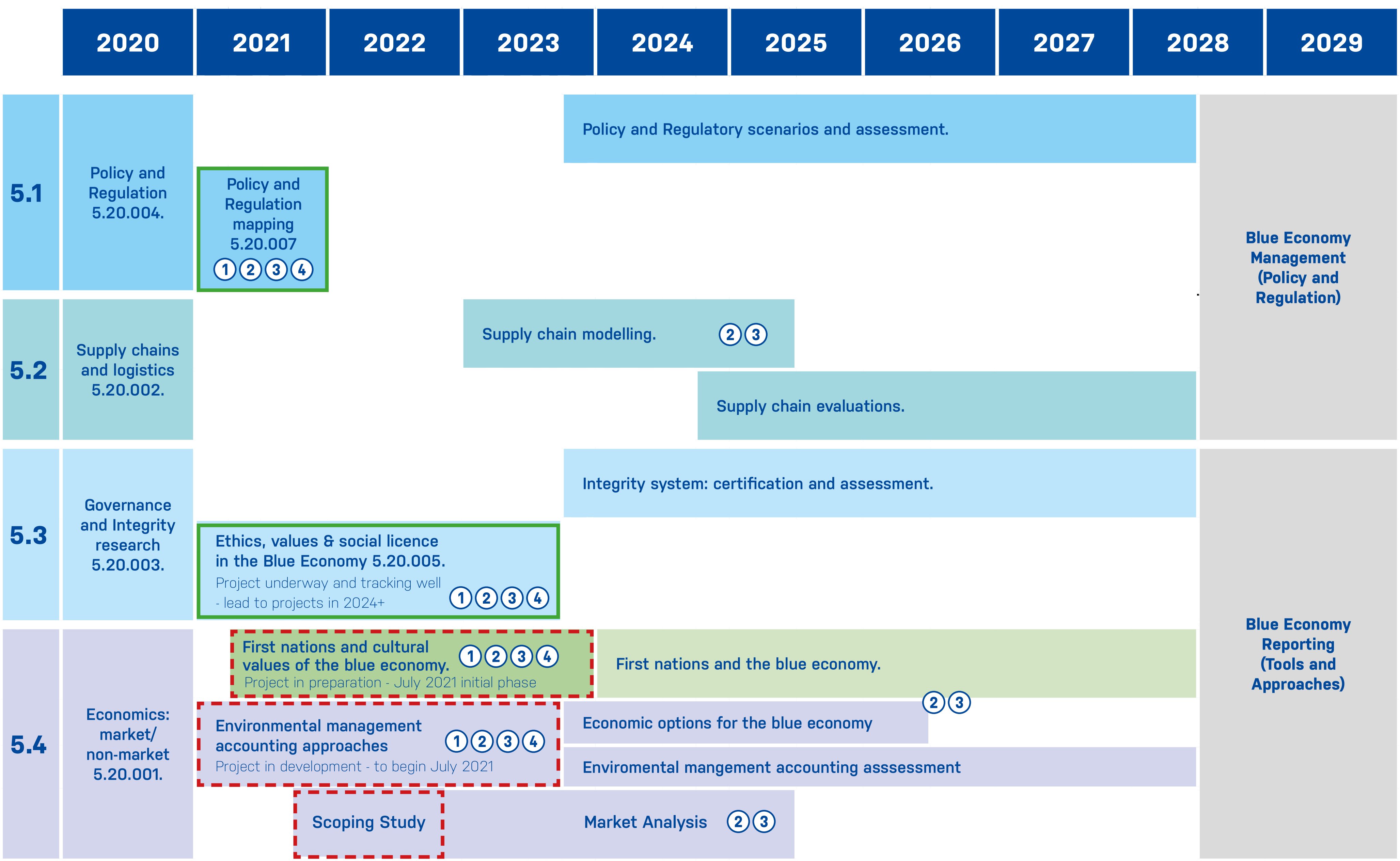
Research Activity	Description of Activity	Considerations/Implications	Link to Milestone Activities
Environmental management accounting	This project will use a 'multi capitals' approach at business, society, and natural ocean scales to measure and report on sustainable value creation through environmental management accounting and ocean accounting applications.	New Participants: Commonwealth Government –DAWE, linking to international initiatives the Global Ocean Accounts Partnership.	Delivers to milestones RP5.4.1. Links to RP2, RP3 and RP4.
First nations and cultural values of the blue economy	This project will address ways in which First Nations Peoples can engage with, participate in, and guide the Blue Economy and foster a trans-Tasman knowledge exchange among First Nations People, researchers, managers and industry. The research will identify the core components of cultural integrity and cultural licence to operate and develop guidelines that will help the BECRC and partners better manage cultural, reputational and industry risks.	Others to consider are Land and Sea Council, Indigenous Land and Sea Corporation.	Links to RP1 RP2, RP3 and RP44.

Program Roadmap

The roadmap shown in Figure 6 highlights RP5's initial research focus and projects currently underway or in preparation. It also identifies project areas for consideration in the short term (2021), as well as medium, and longer, term activities to meet Commonwealth Milestones.

RP5 ROADMAP

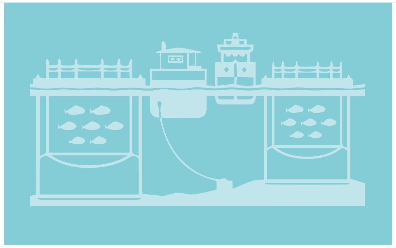
Started | Priority to get started in 2021 | (X) RP Connections



RP5 Roadmap

2.3. Cross-Program Linkages

Several connections have been identified between the Research Programs that has shaped the cross-program and program research activities. These have been captured in Figure 7 below. The detailed description of those cross-program linkages is also provided in Appendix A.2.

	RP1	RP2	RP3	RP4	RP5
RP1		» Seaweed hydrodynamics: attenuation benefits and resistance » Hydrodynamics of farm arrays » Optimising offshore growing infrastructure and farm arrays	» Mooring design » Monitoring system loads, performance, reliability Installation and commissioning » Operations and maintenance » Licensing and standards » Hazard identification, risk management » Integrated system design » Corrosion and biofouling	» Environment site inputs » Environment design constraints » Site selection and zoning » Environment impact from structures » Structures enhancing ecosystems	» Cost effective floating solutions » Supply chains » Logistics » Life cycle analysis » Policy and regulation on vessels, structures and operations » Social acceptability » First nations peoples
RP2	» Optimising aquaculture structure design » Environmental site condition inputs » Environmental design constraints » Fish behaviour in exposed sites » Feeding, bathing & harvesting » Environmental impact		» Increase offshore energy and offset diesel consumption of offshore aquaculture operations » Oxygen application in aquaculture » Biomass for bioenergy generation » Co-location benefits / challenges » Desalination / freshwater needs	» Environment site condition inputs » Environment design constraints » Site selection and zoning » Decision support tools for production and species selection » Minimising environment impact » Monitoring & biological risks offshore » Delivering IMTA	» Policy and regulation on management of integrated aquaculture operations » Social acceptability » First nations peoples » Environmental and carbon accounting
RP3	» Scale, type, capacity of production / storage facilities » Energy demand estimation of farm Infrastructure type (surface, subsea, fixed) » Operations and maintenance » Monitoring Installation and commissioning » Novel materials	» Seaweed hydrodynamic attenuation and renewable energy production » Wave-driven pump for seaweed production » Carbon sequestration » Oxygen for salmon aquaculture		» Environment site inputs » Environment design constraints Marine spatial planning and site selection » Energy resources map » Environment all impact assessment	» Offshore electricity market assessments » Hydrogen utilisation market assessment » Value-Proposition » Market drivers for renewable energy transition » Supply chain and policy requirements » Social acceptability » First nations peoples
RP4	» Site characterisation » Marine Spatial Planning » Extreme events / survivability » Digital infrastructure » Autonomous systems » Biofouling / antibiofouling coatings	» Site characterisation » Marine Spatial Planning » Digital Infrastructure » Decision support tools » Integrated system modelling Integrated sensor networks » Environmental assessment » Biosecurity and incident response » Ecosystem services & IMTA Risk identification & mitigation	» Site characterisation » Marine Spatial Planning » Extreme events / survivability » Digital infrastructure » Resource assessment » Biofouling / antibiofouling coatings » Environmental impact (e.g. striking, noise) » Integrated system modelling » Integrated sensor networks » Decision support tools		» Decision support tools » Regulatory / legislative » Social acceptability » First nations peoples » Environmental and carbon accounting » Life cycle analysis
RP5	» AMSA rules and regulations for aquaculture marine vessels & AUVs » Economic assessment of biofouling mitigation » Emerging / drafted regulations for offshore activities » Social acceptability of emerging technologies	» Decision support tools for production and species selection » Workforce profiling » Social acceptability	» Emerging / drafted regulations for offshore energy activities » Permitting and Licensing » Social acceptability of emerging technologies » Market assessments » Supply chain development » Stakeholder engagement » Workforce profiling » Blue economy metrics	» Decision support tools » Regulatory / legislative » Social acceptability » First nations peoples » Environmental and carbon accounting » Life cycle analysis	

Cross-program linkages identified from scoping study projects

2.4. Key Insights from Scoping Studies

Several connections have been identified between the Research Programs that has shaped the cross-program and program research activities. These have been captured in Figure 7 below. The detailed description of those cross-program linkages is also provided in Appendix A.2.

2.4.1. Overarching Insights

- A number of overarching insights are clear from the scoping studies, as listed below. Marine operational activities will provide the necessary demonstration to gain industry momentum and for the Blue Economy CRC to translate its research into reality. There is also likely to be a long lead time on regulatory approvals; this has been the experience elsewhere in the world given the newness of activities in the offshore and remote environments.
- Multiple use platforms were a key focus of the CRC initial bid description and activities. However, they present many operational and planning challenges (including, for example, capital cost, policy and regulatory arrangements; site selection; deployment; footprint; production and market demand). A phased approach will be required to transition from independent deployment activities, to neighbouring, and then co-located deployments, and to scale from single platforms to arrays. This approach is because while synergistic potential exists, it is not yet well embedded in operations (even internationally, though early examples exist) and stringent operating demands can introduce caution into industry desire to realise the potential.
- There are multiple possible pathways to the CRC achieving sustainable multi-species aquaculture systems that are integrated with other sectors for both temperate and tropical regions. The CRC should determine the most appropriate to pursue. This may require tools to assess production options and species selection and integration. There may also be a requirement for new elements including new partners. Current partners and expertise are for 3 established temperate aquaculture species and one emerging taxa (seaweeds).
- The CRC should understand the industry, economic and social drivers for emerging offshore products (e.g., new offshore aquaculture species including seaweeds, electricity, hydrogen) to ensure meaningful and maximum impact.
- Automated and digital development underlies research opportunities across the CRC portfolio; this fast-moving space will require coordinated collaborations in order to avoid duplication and to facilitate funding in this competitive and capital-intensive space. There may be a requirement for new partners.
- Biofouling is a key operational concern for aquaculture and energy production, as it triggers engineering problems and increases costs. With the move further offshore, there is the potential for biofouling to grow in importance as the biofouling species change and the ability to remove biofouling is reduced due to accessibility. This area of R&D should be explored and tested with our industry partners to ensure that any effort is targeted to areas of importance to the Blue Economy CRC's partners.
- As elaborated further below, there is increased awareness that the blue economy and Sea Country are intimately linked with Australia's and New Zealand's First Nations and respecting the shared values of Aboriginal and Torres Strait Islander Peoples must be central to CRC activities.
- The CRC work requires cross-, inter- and transdisciplinary research programs. Such work is known to be able to leapfrog advances when it succeeds but is also known to have significant obstacles to achieving success and requires dedicated institutional support and program management. This kind of support is a specialist area in its own right and the CRC would benefit from guidance. Fortunately, globally recognised Centres specialising in how to do interdisciplinary and transdisciplinary science well sit within the CRC's research partners (e.g. the Centre for Marine Socioecology which is a collaboration between UTAS, CSIRO and the Australian Antarctic Division) and can be called upon to act on this need.
- It is recognised across all RPs that the vision and potential exceed the current budget envelope and capability pool in certain areas. A targeted and disciplined approach to project development (engaging in co-funding opportunities where applicable or new project partners) will be required to deliver the research program. External collaboration opportunities are discussed in more detail in Section 2.5.
- COVID-19 has created dislocation and disruption and has demanded the reshaping of a number of research activities in the short term. It will continue to do so for some time to come, especially creating hurdles around participatory engagement processes. It will create logistical hurdles in accessing sites and limit direct international participation.

2.4.2. Challenges to offshore developments

The Scoping Studies highlighted a number of challenges to offshore development. Key among those are:

Within Australia there is limited existing policy and regulatory framework for much of the activities that the Blue Economy CRC is looking to do. On one hand this means there is no clear-cut process for CRC Participants to follow in deploying at sea operations, which to date have been dealt with on a case-by-case basis. This is particularly relevant when activities are proposed to be located outside State and Territory waters. Further work is needed to incorporate integrated offshore activities into an appropriate regulatory framework, for example, the Offshore Constitutional Settlement (OCS) framework. This is especially critical where a policy/legislative void limits operation including relevant research demonstration projects. The CRC will work with regulators in the development of certification standards, guidelines, operational rules and regulations across all aspects of the CRC's activities. In addition, CRC activities are proving timely given objectives defined by the High-Level Panel for a Sustainable Ocean Economy, the National Hydrogen Strategy, called for under the EPBC review and the move to new environmental accounting systems at a national level. There is scope for the CRC to provide pre-competitive information synthesis and resource mapping/down-scaling, but the degree to which this can be done is dependent on Participant data-sharing.

Availability of existing solutions is limited. Many of the topic areas are at the margin (or beyond) of what has been achieved previously in the individual domains. This is not only in the sense of being in a remote and challenging/unforgiving physical environment, but also about the science (e.g., in terms of the computational analyses required at notoriously difficult scales or the variation in technology readiness, ranging from emerging to commercialised). It may also be constrained by access to sufficient capability of the type needed for the individual research activities – many of the skill sets are globally in short supply.

The infancy of the production concepts being considered whether for aquaculture or for some of the less mature offshore renewable energy (ORE) technologies, means the CRC must consider carefully whether adapting "off the shelf" solutions from elsewhere is an appropriate solution.

While some offshore renewable energy conversion technologies operate commercially internationally (particularly offshore wind in the northern hemisphere), Australian environmental conditions (e.g., swell exposure and continental shelf depth profile) mean that simple translation is not necessarily straightforward. This does present Australia with the opportunity to be globally influential, finding new solutions and tackling common problems in a new way (opening up opportunities for nations who do not match the investment and physical environment prevalent in the USA or Europe), but it also means a fast moving space – as many nations look to get a competitive advantage and in the context of COVID-19, oceans have been put forward as a central part of schemes to "build back better".

Social acceptability will likely be a key determinant of the success of proposed offshore activities, as ocean systems are considered by many to be communal areas that simultaneously are core to long held traditional belief systems (both formalized and tacit) and seen as amongst the final frontiers of human use. Thus, despite the "out of sight" nature of offshore activities that lend themselves to being of less interest to general society or to community trusting in regulatory processes, activities in offshore waters can garner considerable and critical interest. Social acceptability (also known as social license) will be a key topic area for the CRC – in terms of its research activities, but also for industry activities and the potential to realise the blue economy vision into the future. This is appreciated by many of the industry partners but is differentially appreciated across the research domains and may not have been fully appreciated during the initial bid budget specifications.

Commercialization of offshore technologies face a number of well recognized hurdles. In each of the research domains, development of the required technologies/tools/capabilities is achievable but matching these with immediate industry need and seeing the research outputs through to commercial/operational use will need active management. This will involve identifying the technical, commercial and legislative gaps hindering uptake.

Barriers to commercialisation of offshore activities include:

- Pre-competitive and specialist information services can struggle to find a home. It has long been the experience of modellers that once developed it can be hard to find a skilled set of hands to continue supporting the model. Once a product does not have a single home institute/company, legacy support and maintenance can flounder.
- The lack of suitable baseline information for offshore deployments means informed decision making with regard to deployments is difficult, but perhaps more importantly regulatory bodies can be overly precautionary, requiring monitoring far in excess of what might be asked for more well-developed technologies and locations.
- Availability of capital for prototype development and in-water demonstration projects. Given the perception of the offshore environment being high cost and high risk, traditional sources of capital are either wary or potentially demand even stronger proof of potential before investing.
- The lack of integrated policy for offshore activities is a barrier as it increases transactional costs and perceived investment risk. Where there is a multi-step onshore-offshore network needed in the supply and value chain, the need to deal with all three levels of government in Australia, can act as a deterrent to commercial initiatives.
- Access to market, this is especially acute for energy as they try to enter markets where existing energy sources, at potentially cheaper prices, already meet demand and there is path dependency in existing agreements and infrastructure.
- Sufficiently skilled workforce may be difficult to access, especially if new skill sets are required and/or due to the remote nature of the work.

2.5. Collaborations and other Opportunities

Several external collaborations were identified when mapping out the research opportunities; some are collaborations which would simply be beneficial, while others are critical to the research going ahead (either due to critical data, capability or co-funding needs). These are discussed below.

2.5.1. Regulatory agencies

A range of Commonwealth and state government regulatory agencies have responsibilities and mandates impacting on, and influencing, a range of activities proposed by the Blue Economy CRC's ongoing research program. The Blue Economy CRC's research program also provides important opportunities for these agencies, as noted in their interest in continuing to develop linkages. The breadth of the Blue Economy CRC's activities poses both opportunities and challenges for engagement with the Commonwealth government, as there is no single point of contact. Each program is developing contact points with key agencies:

Commonwealth Government

- Department of Agriculture, Water and Environment (DAWE) – Environmental management accounting, oceans management and policy
- Australian Fisheries Management Authority (AFMA) – regulatory responsibility for fisheries legislation
- Department of Industry Science, Energy and Resources (DISER) Clean Technology Branch, Global Innovation Linkages – offshore renewable energy, hydrogen
- Australian Maritime Safety Authority (AMSA) – definition of code of practice for offshore aquaculture vessels
- ARENA – potential co-funding for demonstration projects but challenges due to the BE CRC's Commonwealth Government funding
- NOPSEMA – Offshore oil and gas developments regulator; proposed regulator for future offshore clean energy technology.

Other agencies such as the Department of Foreign Affairs and Trade (DFAT) have interests in blue economy research and development with respect to their oceans, small island development, and aid program.

State Government

The Blue Economy CRC has strong linkages with the Tasmania government as a partner, with the Department of Primary Industries, Parks, Water and Environment (DPIPWE) and Department of State Growth (DSG) actively involved in the CRC's research program. Strengthened engagement with other state governments is required: for example, Victoria as the Star of the South offshore wind project develops, Western Australia with offshore renewable energy and aquaculture projects; South Australia with offshore aquaculture and the Queensland government, leveraging off relationships with CSIRO, the University of Queensland and Griffith University as research partners in the CRC, in several areas.

2.5.2. First Nations People

The Blue Economy and Sea country are intimately linked with Australia's and New Zealand's First Nations and are central to achieving positive outcomes for all Australians. The importance of Sea country means that respecting the shared values of Aboriginal and Torres Strait Islander Peoples will be central to CRC activities.

Supporting the growth of the Blue Economy can strongly contribute to the Australian Commonwealth government 'Closing the Gap' strategy, in particular "Improving the employment opportunities for, and income levels of, our people, and through this enable them to play a direct part in achieving their goals". For the Blue Economy CRC 'Closing the Gap' means that we acknowledge the strong contributions of First Nations People to society and the need to work together to understand and align needs, values, objectives, and intent to co-develop solutions towards equitable and sustainable futures (KPMG, 2016; Cohen et al., 2019).

Over the past decade it has been recognized that not all research has been delivered in such a way that benefits First Nations. Front and centre of ethical guidelines on inclusive research activities highlights the need for spirit and integrity, cultural continuity, equity, reciprocity, respect, and responsibility (Cohen et al., 2019). This requires developing truly collaborative, ethical, and respectful partnerships and relationships among researchers and First Nations groups, to the mutual benefit of the priorities, needs and aspirations of all involved. Such an approach will support strengthening indigenous knowledge, and the development of strong partnerships that will help create and share knowledge for caring for Country (Cohen et al., 2019).

This involves recognition of Indigenous interests, ownership and sovereignty; benefit sharing; genuine Indigenous leadership and involvement in R&D development and production; tangible recognition of traditional knowledge in planning operational processes (including data management considerations to protect the rights of First Nations people); provision for influential Indigenous participation at each phase of activity; capacity building and provision of sufficient and timely information to ensure effective Indigenous participation (including Indigenous commercial activities); consideration of indigenous decision-making processes; and the creation of spaces to facilitate partnerships and knowledge sharing in caring for Country (Cohen et al., 2019).

These considerations are a key motivation behind the proposed general project being shaped by Indigenous researchers around pathways to Indigenous Blue Growth and the CRC funded PhD project working with the Quandimooka – Yoolooburrabee peoples to investigate options for embedding traditional owner's rights and customs in future management approaches. This collaborative approach is required to co-define what this research pathway looks like. While not explicitly mentioned in each project scope detailed above respectful inclusion and consideration of First nations is the intent behind every research project. Formalizing in detail what that looks like must however wait until of the general project and inaugural meetings of the CRC's Indigenous Reference Committee. Allowing for full expression of the R&D pathway in a way that meets the standards requires both healthy and respectful partnerships with interested First Nations groups, but also a stable funding stream. Making the correct connections to deliver the former while also helping guarantee the later most likely comes from partnering with Indigenous researchers (or other experienced and trusted researchers who are well known to First Nations groups) across an array of research agencies around Australia and New Zealand, but also engaging with specific First Nations representative bodies and industry. To this end discussions should be begun with Land and Sea Councils in relevant areas and the Indigenous Land and Sea Corporation, who have a trusted position in guiding investments in Indigenous agribusinesses to realise the potential of new opportunities (including in the marine estate) to achieve economic, environmental, social, and cultural benefits for Indigenous Australians.

There is a general project under development that will address ways in which First Nations Peoples can engage with, participate in, and guide the Blue Economy and foster a trans-Tasman knowledge exchange among First Nations People, researchers, managers and industry. The research will develop a framework to explore the core factors driving the rubrics of cultural integrity and fairness for cultural licence to operate in the context of the marine industry sector.

This is critical to all milestones at a base level, but particularly important for RP4 and RP5 milestones where social license, cultural licence, ethics and ethical responsibilities are a research focus.

2.5.3. Data Provision

Access to data is critical for the development of the Blue Economy. The extent of the marine estate means data gathering is well beyond any one organization and for the CRC to meet its purpose it must partner both with primary data holders (including First Nations), but also organization(s) experienced in data infrastructure and operational visualization. To make such partnerships long lasting and attractive, mutual benefit must be found; the CRC's goals to deploy sensors and generate new data streams will likely make it an attractive proposition for many potential partnerships.

The suite of partners will evolve through time, as new data streams come on line and as the CRC's needs evolve. However, in the first instance the following organisations have been identified as data holders/providers to engage with:

- SmartSat CRC (and other satellite data sources) – for development/refinement of remotely sensed data streams, which will be an important part of the use of autonomous technology for data gathering.
- Firetail Robotics and Blue Zone Group – for further development of sensors and autonomous technology for aquaculture and offshore energy industries.
- Geoscience Australia/AusSeabed – data for site selection and marine spatial planning.
- Integrated Marine Observing System (IMOS) – data collection, storage and data management, and sensor relevance.
- Commonwealth Government (e.g., DAWE) – relevant public data sets (or specific regulatory data subsets under specific sharing provisions), such as information used in marine spatial planning or environmental management accounting.
- Bureau of Meteorology (BOM) – Energy resource prediction (where there is co-funding interests).
- GA/Data61 - NationalMap development.
- International – US DoE appetite for shared energy innovation activities; UK ORE Supergen. Interest for shared innovation activities.
- Private sector – Demonstrate effective management of commercial data streams, protecting IP where necessary, but exploiting value of private sector data where not. Data of existing CRC partners could be used for demonstration, to build confidence for contributions from further private sector data custodians (marine and coastal industry service providers).
- First Nations groups. These relationships are still forming, but respectful handling of data and rights of First Nations people will be central to the CRC data related activities, with the number of groups growing as the CRC engages in new locations.

An external partner will also very likely be required to help share costs for the digital platform which is identified as critical to the delivery of numerous R&D outputs across the CRC. Potential partnership may be possible with one of the large cyber-tech companies (e.g., Microsoft, Amazon, Google) around provision of in-kind to cover development or hosting costs long term for digital platform and real time data access (web-tools). Careful attention would need to be paid to retention of data provenance and Australian data laws in this instance.

2.5.4. Other Opportunities

In drawing together the information available in the scoping studies and the additional information synthesised to form the research plan it was clear that a number of other opportunities exist, including:

- Firetail Robotics – for development of autonomous technology for aquaculture and offshore energy industries.
- Kedge, Subcon, SmartCrete CRC and Southern Ocean Carbon Company – for floating artificial reefs.
- MBIE, NZ (Ministry of Business Innovation Enterprise) is funding several large multi-million dollar grants on aquaculture with strategic intent to develop NZ industry and involving many of the BECRC partners. Opportunity is for formal discussion about what opportunity this presents.
- For Pacific oysters ASI (Australian Seafood Industries) is looking to incorporate offshore traits into the selective breeding program. There may be opportunity for leverage other funding sources including the FRDC to support this.
- Climate Foundation – on the production of seaweeds including, grow-out and harvesting.
- PSP Soluciones – water aeration and air microbubbles curtain technology which can have positive impacts on the sea environment and at the same time, operation benefits such as cost savings on biofouling mitigation and biosecurity, and applications to water desalination plants.

- Innovasea – integrated aquaculture sensor technology.
- AKVA Group (Norway) or similar commercial suppliers to partner development and or refinement of Aquaculture Production Assessment Tool.
- Austral Fisheries – on the development and trialling of hydrogen-fuelled vessels for fisheries and aquaculture.
- Other Energy & Hydrogen Focused CRC's (Future Fuels CRC, FenEx CRC, RACE for 2030).
- NERA – Growth Centre supporting relationship growth with oil and gas (O&G) sector. NERA have a number of clusters they support include the Subsea Innovation Cluster Australia (SICA).
- Unions (Maritime Union of Australia, Australian Manufacturing Workers' Union, Electrical Trades Union) – for workforce profiling of the blue economy. Currently supporting interests in the development of offshore wind in Australia but will be valuable in other maritime sectors.
- International – Federal Ministry of Education and Research (BMBF) Germany – international labs for green hydrogen.
- International – US Department of Energy appetite for shared energy innovation activities.
- International – UK ORE Supergen. Interest for shared innovation activities.
- International Energy Agency – Ocean Energy Systems, small strategic projects (e.g., Aquaculture demand study).

3. Acknowledgements

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5. Appendices

A.1. Scoping Study Projects Engagement Strategy

In order to achieve their aims, the Scoping Studies were undertaken with a heavy emphasis on the active engagement of Participants, particularly those with specialised policy and operational knowledge of the research topics in question. A range of engagement activities were employed by the Project Leaders to gather the essential information from Participants. These activities included:

- Surveys and interviews
- Field visits
- Workshops
- Planning meetings

The completion of each Final Report required a review of the document by all Participants in each Scoping Study. In many cases, industry Participants had provided detailed documentation and verbal advice to the lead Study researchers, which was extremely valuable in informing the findings of those Studies. As some of this information was of a confidential nature (due to commercial considerations), that information was not distributed to other Participants as part of the Report review process.

Owing to the unanticipated challenges presented by COVID-19 (which impacted on every Study, to varying degrees), it was necessary for Project Leaders to find alternatives to certain planned engagement tasks and events.

The Blue Economy CRC provided advice and mechanisms of support to Participants regarding hosting stakeholder engagement activities and finding good alternatives to face to face meetings that still allowed for in depth information exchange.

The integration of the offshore aquaculture, renewable energy, and maritime engineering research sectors is deliberate; they are naturally synergistic and the Blue Economy CRC provides the opportunity for them to share critical knowledge and infrastructure, delivering productivity and operational cost benefits. All 40 Participants in the Blue Economy CRC have collaborated extensively in the 17 Scoping Projects, in addition, five third-party organisations were formally involved as project partners. A significant number of other organisations made contributions to the scoping projects (primarily through responding to surveys), as external parties not formally listed as project partners. While there was significant (and expected) variation in the direct involvement of each Blue Economy CRC Participant in the Scoping Studies, every Participant was formally engaged in at least one Study. This was primarily attributable to the range of specific topics that were covered in the initial 17 Studies.

A.2. Key insights from Scoping Study Projects, relationship to Commonwealth milestones and medium to long term research priorities

The following sections summarise the process the individual research programs took in pulling together information from scoping studies and creating research programs for their areas. While each individual program touches on scoping project findings, within research program syntheses and formulation of their overall plans the process followed in each case did differ. This is consistent with the different focus, disciplinary backgrounds and individual leadership styles of each program. We have not attempted to shoehorn them into a uniform format as the core information for comparing across programs has been summarised and presented in the main body of the document and these sections are provided for those interested in looking more deeply into the details.

1.1. Research Program 1: Offshore Engineering & Technology (RP1)

Several external collaborations were identified when mapping out the research opportunities; some are collaborations which would simply be beneficial, while others are critical to the research going ahead (either due to critical data, capability or co-funding needs). These are discussed below.

1.1.1. Key Insights

Scoping Project P.1.20.001 Aquaculture Vessel Requirements: There is a possibility of regulating offshore aquaculture vessels and platforms through current AMSA NSCV rules and regulations. An opportunity exists for Blue Economy CRC to jointly develop a new set of regulations specific for offshore aquaculture platforms and vessels with AMSA. Human Factor (HF) principles are beneficial for the design of future offshore aquaculture vessels and platforms and they should be applied for the comfort and safety of workers in vessels and platforms. Together with RP3, it is essential to develop green vessels and platforms to support the development, operation and decarbonisation of the aquaculture industry and the offshore renewable energy industry.

Scoping Project P.1.20.002 Autonomous Marine Systems at Offshore Aquaculture and Energy Sites: As aquaculture and renewable energy moves offshore there is a need to develop technologies that perform inspection and maintenance tasks. A survey of industry partners reveals operational needs that are not currently met in sensing, command, and control systems as well as localisation and navigation. The report describes the challenges of bridging the “Valley of Death” in research commercialisation and proposes a focus for Blue Economy CRC on mid-stage technology development to accelerate the development of academic research through to scalable solutions. The need to focus on specific aspects of offshore autonomous systems means that it will be important to consider building development platforms that can then be translated into solutions.

Scoping Project P.1.20.003 Biofouling Challenges and Possible Solutions: Biofouling poses serious challenges in aquaculture, sensing and monitoring, and marine renewable energy sectors of the Blue Economy. The increased labour requirements in managing biofouling in offshore areas will increase financial burdens and production inefficiencies across these major industries. Developing a targeted and interdisciplinary R&D roadmap is essential to tackle biofouling. An immediate need is to develop a simple, robust, and fast biofouling cleaning and collection system and find possible usages for the collected biofouling organisms.

Scoping Project P.1.20.004 Multi-Purpose Offshore/ High Energy Platform s: Concepts and Applications: Multi-Purpose Offshore Platforms (MPOPs), whether they are integrated or co-located, can be a viable option for future developments in Australia. However, they must be cost-effective, reliable and have a minimal impact on the ecosystem. Currently, there is a strong interest in floating offshore wind development, and hence it opens opportunities to future MPOP projects for both offshore renewable energy and aquaculture industries. The effects of floating offshore wind turbines, in both normal and idle modes, on aquaculture operations are still unknown. The offshore oil and gas industry provides lots of lessons to learn, data to use, and design engineering standards and tools to adapt for designing reliable MPOPs.

Scoping Project P.1.20.005 Review of Fish Pen Designs and Mooring Systems: This scoping project has 2 work packages. In Work Package #1, a definition for offshore fish farming was presented. Challenges for offshore fish farming were identified. Fish pen designs were reviewed, categorised and their advantages and disadvantages were discussed. Types of mooring system and anchor foundation for fish pens were reviewed. Fish pen designs and future of offshore fish farming were discussed. Knowledge gaps and future research topics are identified (e.g., making aquaculture systems storm proof, co-location of aquaculture and renewable energy farms, developing analysis tools for offshore fish pens and developing closed containment systems for fish farming in exposed sites). From studying the advantageous features of various offshore fish pen designs, a novel fish pen design is proposed for further research and development. In Work Package #2, key areas for improvement in the existing fish pens and mooring systems were identified (e.g., pen-mooring rope connection system and the feed pipe system).

Relationship to Milestones

The completion of Scoping Studies P.1.20.002, P.20.004 and P.1.20.005 met the milestones RP1.4.1, RP1.2.1, RP1.1.1 and RP1.1.2. However, the scoping projects have not entirely addressed the key Blue Economy industry-focused research questions and short-term industry needs, but they have provided lots of valuable information and more importantly a clear direction towards developing future research projects in the medium- and long-term.

Milestone 1.1: There is a high priority to meet RP1.1.3 (Dec 2023) which requires at least one report to be completed on the selection of appropriate materials and analysis methods based on optimised simulation and analysis for new or improved fish cage design. The current general project on collar tie (P.1.20.006) and future projects on improvements of fish pens are expected to address this milestone. The outcomes of RP1.1.3 should inform and provide insight into RP1.1.4 (June 2026).

Milestone 1.2: There is a high priority to meet RP1.2.2 (June 2021) and RP1.2.3 (June 2023). Currently. there is no research activity to address these milestones. These can be achieved through a small work package on modular design of floating structures/platforms over a 12-month period.

Milestone 1.3: There is a medium to high priority to meet RP1.3.1 (June 2021) and RP1.3.2 (June 2023). The former can be achieved through a collaboration across the RPs to provide information about existing and potential sites for the production. This should be done through collaboration through RP1 and RP3, in particular, though contributions will also be need from the other RPs around additional constraints/requirements to be considered. A few of the scoping studies conducted within RP3 have already provided some useful information.

Milestone 1.4: There is a high priority to meet RP1.4.2 (June 2024) which requires the development of novel autonomous and remote sensing concepts for offshore risk mitigation and management. Deliver at least two reports on the activities. This can be met through a General Project + PhD Projects. Currently, there is a PhD being funded for AUT, and the outcome of this project once executed is expected to contribute to this milestone.

Table 7. Summary of RP1 milestones due in 2021-2026.

Research Topic	Milestone	Due date	Priority for 2021-2025	Recommendations
Fish (aquaculture) Pens	RP1.1.3	31 Dec 2023	High priority	This can be met through a General Project + PhD Projects
	RP1.1.4	30 Jun 2026	High priority	This can be met through a General Project + PhD Projects
Multi-Use platforms	RP1.2.2	30 Jun 2021	High priority	This can be achieved through a small project for < 12 months
	RP1.2.3	30 Jun 2023	High priority	This can be achieved through a linkage with the project of RP1.2.2
	RP1.2.5	30 Jun 2026	Very low priority	This can be linked to RP1.1.3 & RP1.1.4
	RP1.3.1	30 Jun 2021	Medium priority	This can be achieved by providing info about existing & potential sites for the BE.
	RP1.3.2	30 Jun 2022	High priority	This should be done through collaboration through RP1 and RP3. Some of the scoping studies conducted within RP3 have already provided some useful information.
	RP1.3.4	30 Jun 2025	Low priority	Some of RP5 scoping studies has provided some information. However, gaps still exist which can be filled through future "Demo" projects.
Mooring Systems	RP1.2.4	1 Jan 2022	Medium priority	This can be linked to the fish pen project and the project of RP1.2.2
Risk and safety	RP1.3.3	30 Jun 2025	Low priority	This can be achieved through a PhD being funded for MQ University. The outcomes of P.1.20.004 have also provided information.
Support Systems: remote sensors, ROVs, AUVs, drones, vessels, barges	RP1.4.2	30 Jun 2024	High priority	This can be met through a General Project + PhD Projects. There is a PhD being funded for AUT.
	RP1.4.3	30 Jun 2026	Low priority	The outcomes of RP1.4.2 should inform and provide insight "whether the HydroNest is feasible or not". Note that Hydronest is a term coined to describe an integrated system that is capable of aerial, surface, subsurface monitoring and mitigation tasks in offshore environment.

1.1.2. Future Research Priorities

Table 8 below provides a summary of the future opportunities that can be explored by RP1.

Table 8. RP1 medium to long term research priorities identified.

Research Activity	Description of Activity	Considerations/Implications	Link to Milestone Activities
Code of practice for offshore aquaculture vessels	1. Develop a code of practice for offshore aquaculture vessels in Australian jurisdiction, as such a code does not currently exist. 2. Code would seek to reference existing AMSA rules where available, and where not available provide directions on particular issues. Some known issues include categorization of staff/manning, training requirements.		Relevant research programs: » RP1 » RP5

Research Activity	Description of Activity	Considerations/Implications	Link to Milestone Activities
Hydrogen powered aquaculture support vessels and platforms	1. Feasibility and conceptual design of a new generation of hydrogen powered aquaculture vessels, feeding barges and platforms. 2. Study the hydrogen infrastructure (fuelling, loading, and offloading) for Australian ports/terminals.		Relevant research programs: » RP3 » RP4 » RP5
Gasification of waste and biofouling to generate value added products	1. Demonstrate proof-of-concept at lab scale. 2. Optimization of concept at lab-scale 3. Pilot scale testing under real life conditions	All aquaculture companies have expressed great interest to explore novel approaches to create direct commercial, operational or ecological benefits from the innovative use of waste products. The topic is highlighted and explained in detail in the Biofouling R&D Roadmap in Section 5.1.4 Resource Recovery of the Final Report.	Relevant research programs: » RP2.2 » RP4.2
Floating Artificial Reefs	2021-2022 **Phase 1 – 2021-2023** Conduct a feasibility study and conceptual design of a floating artificial reef to grow seaweed (e.g., giant kelp) and other marine organisms for food production. **Phase 2 – 2024-2026** Validation and prototype testing of floating reef	This is a multidisciplinary project.	This research project is to be done in collaboration with the other four RPs. RP1 has initiated discussions with the SmartCrete CRC for potential developing a joint research project on floating concrete reefs. This is a great opportunity to collaborate with another CRC.
Waste reduction and circular economy in Aquaculture	1. Comprehensively review the waste produced in the aquaculture industry and establish a detailed value/waste chain for each participant. 2. Identify key opportunities and perform techno/economic feasibility study. 3. Select 1-3 (TBC) identified opportunities and develop/ implement solution in collaboration with the industry partners	All aquaculture companies have expressed great interest to explore novel approaches to create direct commercial, operational or ecological benefits from the innovative use of waste products. Due to the magnitude of the problem, a comprehensive review is necessary to ensure effort is appropriately targeted and delivers the economic and ecologic impact. The issue was highlighted in both the biofouling and cage design scooping studies as a major area of interest.	Major Milestones in bold: » RP2.2 » RP4.2
Beneficial Biofouling – from Myth to Reality	1. Identify major environmental drivers of biofouling communities in SE Tasmania. 2. Explore methods to manipulate farm (micro) environments to encourage settlement of desirable species. 3. Test novel concepts in real life conditions	The topic is highlighted and explained in great detail in the Biofouling R&D Roadmap in Section 5.1.5 Farm Manipulation and Other Biological Studies of the Final Report	Major Milestones in bold: » RP2.2 » RP4.4 » RP2.3

1.1.3. Cross-Program Linkages

There are strong links that exist with RP1 surrounding engineering requirements for offshore aquaculture and renewable energy production. These include:

- Zoning and site selection: Engineers need to know what conditions they need to design for. Similarly, there are close connections around monitoring platforms (autonomous and embedded in built infrastructure, both for monitoring in water aspects and monitoring the infrastructure itself for maintenance purposes) (RP4).
- Offshore structures: Multi-purpose structure design within the CRC should consider the needs for energy system integration (RP3) and implications for the environmental footprint (RP4). At present RP1 considers the other RPs as a wealthy source of problems they can engineer solutions for (with RP4 and RP5 in particular defining constraints on what is allowable).
- Artificial reefs: RP1 is particularly interested in looking at cost effective floating breakwater options (RP5), whether such infrastructure can be a useful production base/enhancer (via providing substrate and smoothed water conditions) or what needs to be done to minimise undesirable establishment of bio-invaders (RP4).
- Operations and Maintenance: O&M procedures and guidelines for each activity of the energy system, should be developed in partnership with requirements of RP1, in developing logistic plans for build, installation and commissioning (M3.4.1) (RP3).
- Monitoring systems: Monitoring of system loads, performance, reliability, potentially using innovative monitoring systems (UAV/AUV), should be developed in partnership with RP1 (RP3.4.2)
- Licensing/Standards: License agreements and adherence to Standards should be shared activity with RP1 (RP3).
- OHS: OHS procedures developed in partnership in RP1 (RP3).
- Vessel requirements (H2/Electric): RP1 and RP3 carry shared interests in development of sustainable shipping (RP3).
- Hazard identification: HAZOP procedures should be developed in partnership with RP1 (RP3).
- Risk management/mitigation: Risk identification, management and mitigation spans all programs. RP3 contains many engineering risks, for which associated activities will benefit from shared activity with RP1 (RP3).
- Commissioning/Logistics: Logistics surrounding commissioning of energy systems on the offshore demonstration should be developed in conjunction with RP1 (RP3).
- Integrated offshore platforms (co-benefits): integration of energy systems should be factored into integrated system designs (RP3).
- Corrosion and other marinization challenges: corrosion and other challenges face deployment of energy systems in offshore environment, that are a common challenge with RP1 activities (RP3).
- Biofouling: Biofouling is an issue common to all offshore deployed infrastructure for the CRC and blue economy. Biofouling can substantially affect performance of offshore energy converters (RP3).
- Moorings: Energy systems will require innovative mooring solutions, which RP1 will also be considering for platforms (RP3).
- Policy and regulatory analysis in response to the design and operation of offshore structures (including fish cages, artificial reefs), vessels, and operations (RP5).

There are opportunistic links (and in some cases knowledge gaps) important for RP1 to consider where seaweed aquaculture is concerned. These are:

- Fundamental hydrodynamics of priority seaweed species and of potential farm arrays for offshore cultivation. Seaweed hydrodynamic attenuation benefits (RP1 and RP2).
- Seaweed biomechanics to understand seaweed response / resistance to hydrodynamic forces (RP1 and RP2).
- Optimising offshore growing infrastructure and configurations for seaweeds (RP1 and RP2).

1.2. **Research Program 2:** Seafood and Marine Products (RP2)

1.2.1. Key Insights

The Seafood and Marine Products Program aims to develop innovative aquaculture systems to provide solutions in animal and plant husbandry and feed design. Its Legacy goals reflect strongly the two Scoping Projects carried out to date:

- Salmon aquaculture in offshore / high energy sites that is sustainable and allows industry a choice about where to farm salmon and a pathway for industry expansion and diversification.
- Sustainable and integrated seafood and marine products that come from multiple species and maximise the efficient capture, use and recycling of energy and key nutrients.

The two RP2 scoping study projects consolidated thinking around overarching support required to support ongoing R&D and achieve the Commonwealth milestones and at a higher level than would be done within individual projects. Three projects (see Table 9) are dependent on interactions and support from all the other Research Programs but particularly RP4 and RP5: Experimental Platforms (Milestone 2.1); Aquaculture Production Assessment Tool (Milestone 2.2); Aquaculture Species Selection Tool (Milestone 2.3). The Seaweed Aquaculture scoping study provided a comprehensive research plan in two phases and clearly identified numerous potential links with other RPs. There was a particular focus on experimental platforms; translation of experimental findings, scenario planning and field work. One major area of research proposed the use of seaweeds to attenuate hydrodynamic forces and even channel them to increase options for renewable energy generation. This research is encouraging being multilayered and integrated across Blue Economy CRC activity and RPs. Seaweed aquaculture has the potential to provide at least one major production species and contribute directly to multiple milestones. However, there are some challenges before it can achieve this status including the need for at least one financially viable commercial partner and around ensuring effective collaborations that maximise reportable outcomes for the Blue Economy CRC, due to ongoing or planned research outside of the Blue Economy CRC, and in relation to investment, given other funding sources.

The challenges around Salmon Production biology research relate to the Blue Economy CRC identifying unique research and include; commercial advantage for single companies and their own in-house ability to solve problems; decision making around using the considerable amount of overseas R&D vs. need to have local R&D due to differences in stock and environments; on-going R&D and overlaps with Blue Economy CRC and non-Blue Economy CRC organisations. The scoping project identified 59 potential research questions that were placed into 5 large integrated research themes. Current industry interest suggests Blue Economy CRC should start developing the “Monitoring and Mitigation” general project, this aims to integrate new technologies to make real-time assessments of health and welfare of salmon and predict threats to provide time for management options. Immediate challenges and opportunity for research projects relate to the ongoing experiences of Australian industry at their high energy sites as well as the timeline around NZKS putting fish in the water, R&D needs are extremely dynamic and priorities subject to change.

Both scoping study projects indicated there are opportunities and challenges around achieving integrated aquaculture systems in a 1–3-year timeframe starting in 2021. For example, salmon – seaweed duoculture was not prioritised in either scoping project. This is partly due to established salmon industry focus on immediate issues around high energy sites, as well as the need for new investment for any integrated multi-species systems and or integration with renewable energy. The proposed Blue Economy CRC offshore facility presents an outstanding opportunity to test more innovative approaches.

Relationship to Milestones

There are three types of projects that need to be at least started in the next three years: Overarching Support; Scoping Projects and General Projects. The first two Overarching Support elements are initially specific to the development of salmon and seaweed aquaculture, respectively, and can then be evolved to support other species. A number of general projects are identified for immediate development by PR2. The development of the three Overarching Support elements is identified as critical for completing the Commonwealth milestones. These elements require collaboration, and perhaps leadership, with other RPs. They are vital and underpin many RP2 milestones, but will require specific research projects to provide the data and knowledge inputs (OS2 and OS3), or they drive the direction of the research by setting the research paradigm and providing the relevant physical and analytical infrastructure (OS1).

Table 9. Overarching critical support elements required to achieve RP2 outcomes and proposed as General Projects.

Experimental Platforms	Aquaculture Production Assessment Tool	Aquaculture Species Selection Tool
Experimental Platforms. Infrastructure and facilities. Data integration and translation. Models and toolkits. Scenario testing, simulations and field experiments. All species.	Production Biology Assessment Tool (Model) and Toolkit. Data collection, collation and comparison to provide benchmarking and underpin decision making. Integrate with Species Selection Tool. All species.	Species Selection Tool. Wholistic evidence-based approach to selecting single and multiple species, initially regionally specific but refined to be site specific. All species.
RP1. RP3. RP4. RP5	RP4. RP5	RP4. RP5
RP2.1.3, RP2.2.3, RP2.3.3	RP2.1.1, RP2.2.1, RP2.2.2, RP2.3.1, RP2.3.2,	RP2.1.2, RP2.2.2, RP2.2.3, RP2.3.2,

Most of the Commonwealth Milestones require outputs are done for “2 or more” species or address “2 or more” production biology R&D questions, this means single species milestones can be met by Atlantic and Chinook salmon and either or both salmon can be used to meet production biology linked milestones for established aquaculture species. Oyster aquaculture is established and is an important extractive species to consider for milestones concerning multispecies systems. Seaweed aquaculture provides emerging extractive species that potentially contribute to multispecies systems. The scoping projects did not address multi-species systems or knowledge gaps in production biology for species that might be used in this way (including tropical systems): extractive filter feeding invertebrates; extractive deposit feeding invertebrates; tropical nutrient generating fish species; the role of very high value species (urchins, rock lobsters, abalone). Inclusion of these topics is recommended as part of a Scoping Study Project on integration:

- Scoping Project: Pathways to integrated aquaculture options for the Blue Economy CRC: to include temperate, tropical, multispecies and integration with renewables.

The scoping study on salmon presented a relatively diverse discussion about seafood and non-seafood from salmon, this aspect was not prioritised. Product quality of offshore salmon can be incorporated into production biology research that involves large harvest size salmon or uses farm stock.

At this time, industry was not interested in exploring salmon product development or considering niche markets. R&D around non-seafood marine products potentially has a very wide range of opportunity since it might include anything from feed ingredients from seaweed, to using by-products from salmon processing, or even value-adding to biofouling removed from cages. Two milestones relate to non-seafood marine products and require “2 or more” for each. Project Seaweed 1 will explore options that relate to these milestones and at least identify if there are opportunities to pursue. The oyster industry is focused on a future using deep water high-energy sites and proposes a Scoping Study, there is considerable expertise and ongoing research in NZ, including at the Cawthron Institute. Otherwise, it is recommended that RP2:

- Ensure Seafood product quality and links to human nutrition and marketplace are embedded or provide a pathway for project development.
- Map a pathway to novel products from offshore aquaculture and associated structures (e.g., biofouling, FAD fisheries, etc.)
- PhD topics: The scoping projects identified the importance of PhD student projects and nine projects on salmon production were linked to the research themes.

1.2.2. Future Research Priorities

Table 10 below provides a summary of the future research activities that should be prioritized in RP2.

Table 10. RP2 medium to long term research priorities identified.

Research Activity	Description of Activity	Considerations/Implications	Link to Milestone Activities
Salmon	Maintain and Enhance Production: growth performance. Encompasses potential drivers including feeds and feeding technology; smolt quality; early maturation; critical abiotic factors (temperature, DO, current velocity); critical biotic factors (feed-days, growth depensation, submergence); feed formulation and nutrient requirements. Include seafood quality. Developing research tools.		RP2.1.1,3 RP2.2.1,3 RP2.3.1,2,3
Salmon, oysters, seaweeds and others	Breeding animals for offshore: assess GxE of pedigreed animals in offshore / high energy sites to re-evaluate the overall breeding goal. Species may include Atlantic salmon, Chinook salmon, Pacific oysters and seaweeds.	Partner with industry Selective Breeding Programs.	RP2.1.3 RP2.2.3 RP2.3.2,3
Seaweed	Hydrodynamic fundamentals » Fundamental hydrodynamics of priority seaweed species and of potential farm arrays proposed for offshore cultivation. » Seaweed biomechanics (ability of the seaweeds to withstand the hydrodynamic forces) » Species-level risk-opportunity matrix	RP1	RP2.1.1 RP2.2.1
Seaweed	Improved scenario-testing and capacity to conduct trials » Modelling/simulations » Tank/flume experiments » Small-scale field measurements	RP1, RP4	RP2.2.3
Seaweed	Trade-offs and values » Understanding the economics of hydrodynamic applications of seaweed » Examine infrastructure benefits of attenuation by seaweed » Are hydrodynamics/ renewables the key co-benefits?	RP1, PR2, RP3	RP2.1.1 RP2.1.2 RP2.2.1 RP2.2.2
Seaweed	Infrastructure » Cultivation infrastructure will be driven largely by the species' biology » Associated biodiversity of seaweed arrays » Engineering solutions – align with existing engineering options for wave breaks/ renewables » Cost effective substrates	RP1	

The following have been identified as other research opportunities for RP2:

- Use of hydrogen production by-products: Opportunity and requirements for oxygen to support different aquaculture systems and species.
- Site selection – determine and input relevant species characteristics.
- Pens / grow-out structures – determine and input relevant species characteristics.
- Potential of biofouling as a feed ingredient, feed or by-product that supplies one or more high-value product. Potential to expand from nets to other structures.
- Product quality in relation to integrated offshore platforms with particular focus on food safety and managing risks of chemical contamination (e.g. lubricating oils).
- Closed system aquaculture to be developed on the CRC Facility as an experimental tool to: to examine nutrient fluxes and benchmark models; test different multi-species groupings; investigate impacts of offshore commercial environments (e.g. noise, disturbance, water quality, marine debris including plastics) on animal performance.

1.2.3. Cross-Program Linkages

The connections (and in some cases knowledge gaps) important for RP2 to consider are:

- Design inputs on the environmental conditions suitable for aquaculture farming (e.g., wave height, wave period, current speed, water depth); fish behaviour under storm, noise, high stock density, long term submergence and pen shape; fish production processes (e.g., feeding, bathing, harvesting); and biological risks in open sea (pathogen, harmful algae, jelly fish, predators) (RP1, RP4).
- Defining suitable conditions, monitoring and delivering IMTA with minimal broader environmental footprint (RP4). However, the flow of information to the digital platform and from decision support tools is also a key CRC cross connection that underpins many operational aspects.
- Policy and regulatory factors affecting management of integrated aquaculture operations (IMTA); including species selection and social acceptability of such operations (RP5).
- Development of the aquaculture production assessment tool and aquaculture species selection tool (RP4, RP5). and support to identify sites and species that would be best to culture (RP4).

Opportunistic links exist with RP2, that exist include:

- Energy for offshore operations: An aspiration of RP3 is to offset diesel consumption of offshore aquaculture operations with renewable energy solutions; this requires strong engagement with RP2 partners.
- Oxygen application in aquaculture: Oxygen is a co-product of electrolysis and has application in aquaculture. The value of this co-benefit should be explored (RP3).
- Kelp aquaculture/other biomass: Kelp aquaculture offers an additional mechanism to offset emissions of offshore aquaculture and can also provide biomass for bioenergy generation. The value of this as a renewable energy solution in blue economy context should be considered (RP3).
- Bioenergy/Negative Emissions: as above (RP3).
- Multi-use platforms: There are potential benefits/or challenges in co-locating energy and aquaculture that need to be more fully understood. For example, understanding whether near or colocation undermines operations of the other sector and what is needed to mitigate/avoid this (RP3).
- Freshwater needs: Freshwater requirements of salmon aquaculture potentially drives a strong energy demand. Establishing these requirements and exploring benefits/challenges associated with provision of this offshore should be explored (RP3).

Table 11. RP2 research outcomes over the short, medium and long term.

Experimental Platforms		
Short	**Medium**	**Long**
Horizon 1	**Horizon 2**	**Horizon 3**
Maintain & Enhance Production: Salmon	Sustainable High Energy Salmon Aquaculture	Sustainable Offshore Tropical Fish Aquaculture
Monitor, Manage & Mitigate Risk: Salmon Health and Welfare	Selection of Temperate Aquaculture Species	Multi-species Temperate Aquaculture
Tropical Aquaculture Species: Partners and species	Selection of Tropical Aquaculture Species	Multi-species Tropical Aquaculture
Propagation Methods for Seaweeds	Offshore Tropical Seaweed Aquaculture	Integrated Platforms including Aquaculture
Offshore Temperate Seaweed Aquaculture	Floating Reefs, FADs and Wild-Catch Potential	Marine Products: New High Value
Marine Products: Seafood	Offshore Tropical Seaweed Aquaculture	Value proposition for offshore aquaculture: optimised mix of species for sustainable production
Marine Products: Feed Ingredients	Infrastructure for Tropical Aquaculture Species	

1.3. Research Program 3: Offshore Renewable Energy Systems (RP3)

1.3.1. Key Insights

The three RP3 scoping studies provide some key insights to assist in framing the future research program, and potential opportunities for integration with other CRC programs.

- Stationary offshore energy demand for 10,000 HOG tonne aquaculture facility is about 6 MWh/day (~1 MW installed capacity demo project). Further monitoring of electricity use by aquaculture and other blue economy sectors is recommended, to identify market opportunities for ORES.
- Vessel energy demand for aquaculture comprises a further 8 MWh/day demand. This provides a potential market for Hydrogen in the maritime sector and provides a significant opportunity for the CRC to build off current national priorities. To capitalise on this opportunity, further partners and resources would be required. More detailed assessment of vessel requirements is required.
- Australian aquaculture market alone is not large (above facility represents ~1/10th of 2030 salmon production). It is critical that the CRC/RP3 be seen as independent of the aquaculture focus in the CRC, and be seeking to build electricity and hydrogen markets within an all-encompassing view of the blue economy. These other opportunities need to be more thoroughly explored, identifying size of markets, appropriate collaborators and partners. Technology design should be general enough to meet multiple market opportunities.
- Gas or Liquid Hydrogen are primary storage/distribution options that could achieve $2/kg delivery. Excludes chemical conversion from CRC priorities. Absorption technologies are also cost-effective and have advantages for storage on medium length time-frames (6-12 months).
- Significant technical and commercial risk surrounds development of ORES. Several mitigation recommendations were provided. Technology investments should carefully consider risks and target technology considered best able to meet end-use requirements (with economic, social and environmental considerations).
- Program research to be industry focussed – strong engagement critical and should be expanded beyond current CRC partners, including across value chain (supply and demand). Modelling of components an important risk mitigation component.

- Coordination across CRC community needs to be addressed, along with integration with other programs where sensible.
- Market opportunities in Australia need to be better understood. Work to identify technical, commercial and legislative gaps hindering ORES development. Support to establish ORES value chain (supply and demand chains) for offshore generated electricity and hydrogen is required.
- $2/kg Hydrogen is significant challenge for offshore hydrogen. The value proposition for offshore produced hydrogen needs to be established.
- CRC opportunities exist to support OREC development around mooring system and survivability, and colocation/integration with other blue economy sectors.
- Demonstration project is opportunity to showcase and draw together CRC capability to develop and demonstrate solutions for ORES in Australia.
- CRC commitment to hydrogen infrastructure, for delivery within next 12 months, dictates several short term priorities.
- Off the back of Star of the South and other Offshore Wind developments, and national Hydrogen priorities, the landscape for RP3 in Australian context is rapidly evolving. Internationally, the integration of offshore renewables with offshore hydrogen production, and associated transition of marine vessels to sustainable fuels, is also developing rapidly. This provides immense opportunities for the CRC/ RP3, however provides challenges for maximising program impact. Commonwealth milestones are potentially a constraint in this environment.

Relationship to Milestones

The three completed RP3 scoping studies have provided broad perspective on current status of some aspects the research program. Further perspective on potential priority activities have been gained through program workshops, and conversations with key program partners. Beyond the three complete scoping studies, a further scoping study to identify opportunities for offshore wind in Australia has just commenced, two general projects are underway (development of a wave energy converting mooring tensioner; and development of DC microgrids for offshore industry); and the CRC has invested in hydrogen microgrid infrastructure, including a 700kW ITM Power Electrolyser, a 65kW Capstone C65 Hydrogen Microturbine, and a DC microgrid network, anticipated to be delivered in early 2022, that will frame future research activities.

Here, we outline key priorities for the program, by program milestone/output.

Milestone 3.1: An energy demand and optimisation model for offshore industry operations. A primary outcome from the scoping projects is recognition of the critical need to better understand the market opportunities for offshore renewable energy technologies and hydrogen in the blue economy, and identifying the technical, commercial and legislative gaps that presently hinder development of those opportunities (3.20.002 – Recommendation 1-1).

Scoping project 3.20.003 identified that aquaculture represents only a relatively small sector/market for these technologies. Within the CRC, this sector represents an industrial offshore energy demand whereby the program can support gradual transition of their offshore operations (presently diesel dependent) towards lower emission (e.g., diesel hybrid) solutions. This step-wise application (e.g., diesel displacement with renewable conversion) is an established pathway for terrestrial microgrids, and will enable ‘real-world impact’ for the CRC, and may be used to build momentum towards the ultimate CRC program vision of zero-emission hybrid hydrogen microgrids for offshore industry. Demand from the sector for this transition is low, but not nil.

To maximise impact however, the CRC must broaden engagement beyond aquaculture with other potential blue economy market opportunities, including for example the oil and gas sector, tourism, ports, shipping, amongst others.

Modelling provides a cost-effective mechanism to identify and optimise distinct elements of the offshore renewable energy system, and mitigate risks associate with system development. These elements span across scales from physics associated with technical components of the system, environmental resource models (with links to RP4), through to macro-economic models of various market sectors (with links to RP5). CRC emphasis will be less on development of these models, and more towards integration across scales, sectors and CRC capabilities.

***Milestone 3.2:* Offshore Renewable Energy Converter design and improvement.** The milestone spans many emerging technologies, with potential competing interests. Thus, a potentially significant financial risk is associated with this milestone should development of multiple technologies be supported, Mitigation options include development of a clear framework for technology support by the CRC, and strong partnership with other technology development funders (domestic and/or international). The International Energy Agency Ocean Energy Systems Working Group have recently (Feb 2020) released a guidance framework for ocean energy technologies, which can be adapted for use.

Scoping project 3.20.002 reviewed many technologies, identifying potential advantages for particular applications, proposing a multi-criteria site selection tool exploiting application specific advantages. Such a tool aligns with site selection objectives in RP4, and can support program objectives (milestone 3.1) to understand market size opportunities for given technologies. Such a tool will be dependent on an appropriate CRC data repository capable of integration across sources.

Strong collaborations with other ORE related industries, research centres, organisations and Governments can strengthen impact of this milestone. Potential partners include Domestic organisations, such as AOEG, Wave Energy Research Centre, Aus-China Joint Research Centre for Offshore Wind and Wave Harvesting, Star of the South, ARENA, NERA, along with seeking stronger ties with related International activities (e.g. UK ORE Supergen, DOE WPTO, IEA-OES).

Given risks of high investment with low impact, establishment of framework for targeted support should be considered priority. General Project 3.20.006 Mooring tensioner project precedes establishment of this framework. Lower risk is associated with research capable of supporting a range of ORE technologies, as well as other offshore industries. These include: mooring systems and offshore platform survivability; colocation, integration and related benefits between ORE resource technologies and other offshore industries; and Microgrids and their control for integration of multiple energy sources and storage systems linked to demands.

***Milestone 3.3:* Bench scale test system for Offshore Renewable Energy System components.** The focus of this milestone is on the development of the hybrid hydrogen microgrid, encompassing a wide range of components (electrolysers, oxygen, hydrogen and battery storage and distribution, hydrogen turbine &/or turbine and desalination). The milestone spans component modelling, development and demonstration of DC microgrids, system control, and maritime sector hydrogen applications. The development of a hydrogen economy is an identified low emission technology priority of the Commonwealth, to which the program can align. Equally, hydrogen is a rapidly evolving, and crowded domain both nationally and internationally, and the program must play to its niche opportunity in this landscape – opportunity in maritime or blue economy contexts, and partner appropriately to deliver outcomes.

Many significant technical and commercial risks were identified in development of the offshore microgrid. These should be considered at each stage of development of the microgrid demonstrator.

Several activities should be prioritised in the next 1-2 years. The DC microgrid general project (3.20.004) addresses near-term priorities of system architecture. Other priority activities include: development of system component models, with strong collaboration across several CRC partners (representing system components), and consideration of how these integrate with each other, and with other elements of the CRC program; and linking with activities identified under Milestone 3.1, there is need to understand the demand for hydrogen for blue economy applications, including within vessels, UAVs, ROVs and AUVs, amongst others. This presents a significant opportunity for the CRC, aligning with key national priorities. While this presents significant opportunity, this field is not a capability strength of the current CRC partnership, and additional partners and investment would be necessary to have influence in this area, given rate of development internationally.

Further scoping of integration of other energy storage technologies, exploring low and medium voltage standards for offshore microgrids, and desalination requirements for offshore deployments should be addressed.

***Milestone 3.4:* Field demonstration of a novel Offshore Renewable Energy System.** The focus of this milestone is on the deployment, operation and monitoring of an offshore microgrid. The CRC has committed investment towards delivery of hydrogen infrastructure as a component towards this milestone. This infrastructure includes a 700kW ITM Power electrolyser, a 65kW Capstone Hydrogen Microturbine, and a DC microgrid.

A three-phase plan has been proposed for deployment of this infrastructure. Anticipated delivery of infrastructure is within the next 12 months.

Phase 1: All infrastructure to be deployed on shore, with electricity to power electrolyser being sourced either from the grid (renewable) or other onshore renewables. During this phase, the emphasis is on de-risking initial configuration, testing the foundational microgrid components in an easily accessible, safe onshore setting, and production of hydrogen (and oxygen), both available for 'export' via off-agreements, or for R&D purposes to develop a hydrogen value chain in the maritime sector. The early-stage development, in an Australian context, will allow opportunity to contribute to broader hydrogen economy priorities relating to certification, building social license, and working towards net-zero. Certification and social license aspects should be prioritised in 2021, to ease deployment of infrastructure when available (with links to RP5).

Phase 2: involves a combination of infrastructure deployed onshore and offshore. This configuration introduces other program objectives. Production of hydrogen and oxygen will be maintained onshore, and a supply chain into maritime applications will be established. This includes hydrogen storage/ containerisation for demonstration (mini) export (onshore to offshore). This phase also introduces demonstration of offshore renewable electricity generation into and offshore microgrid, with hydrogen-generated electricity to firm supply.

Prior to commencement of this phase, hydrogen storage scenario research (as recommended from P3.20.001) should occur.

Deployment and demonstration of offshore renewable energy conversion devices, within a diesel-hybrid configuration, prior to this phase may reduce combined risks of the offshore hybrid hydrogen microgrid demonstration.

Phase 3: involves full offshore demonstration of a hybrid hydrogen microgrid, meeting objectives of milestone 3.4. This requires production of hydrogen offshore, hydrogen/oxygen utilised in the offshore system, and excess hydrogen (and oxygen) containerised and exported from the offshore platform.

Marinization of the electrolyser, and desalination requirements need to be addressed prior to this phase.

1.3.2. Future Research Priorities

Table 12 provides a summary of the medium-term research activities that need considerations in RP3.

Table 12. RP3 medium-term research priorities.

Research Activity	Description of Activity	Considerations/ Implications	Link to Milestone Activities
Characterisation of offshore renewable resource and Met-Ocean conditions for offshore renewable energy systems.	Coarse scale resource information mostly available via AREMI. Detailed in P3.20.002 Task 1 report. Prelim offshore wind resource assessment being completed in P3.20.007. Future downscaled resource characterisation (modelling and monitoring) is required, and aligns with RP4 activities.		RP3.1.1 Will link to RP4 site selection and metoc modelling. Links to RP1 design requirements.
Offshore renewable energy prediction system for energy management	Establish a working ORE prediction system, for energy management. Links with operational modelling needs in RP4 Links with design requirements (extremes) in RP1 This activity should be explored within prioritized modelling workshop outlined in Table 4.	Partner with industry Selective Breeding Programs. Use / contribute facilities.	RP3.1.3 And RP4 and RP1

Research Activity	Description of Activity	Considerations/ Implications	Link to Milestone Activities
Offshore energy system model (including life cycle analysis and electricity, storage, oxygen, freshwater, transport demands), which accounts for co-optimised operation of co-located offshore activities	Scoping study (P3.20.002 Task 3) did not address these aspects of model review. This activity should be explored within prioritized modelling workshop outlined in Table 4, to map path forward. Link with RP3.3.1, to build system model. Link with other programs, ensure seamlessness into other sectors.		RP3.1.4 Notable Links to RP4 and RP5. Associated with blue economy metrics, digital framework. Potential links to other program.
Determination of recommended optimal hydrogen storage options for offshore applications and optimal desalination techniques for offshore applications.	Bench scale test of DC microgrid is being addressed by P3.20.004. P3.20.001 provided recommendations for hydrogen storage tests. These should be undertaken, prior to implementation of Phase 2 of the Hydrogen Infrastructure deployments (2023-2024). Desalination requirements are not well captured in scoping studies. P3.20.003 has reported challenges from the aquaculture sector for offshore storage of freshwater. A scoping study investigating requirements and challenges for desalination to support offshore electrolysis should be carried out. This is required to clarify phase 3 plans for infrastructure.		RP3.3.3 Potential link to RP1 regarding engineering requirements.

1.3.3. Cross-Program Linkages

The connections (and in some cases knowledge gaps) important for RP3 to consider are:

- Renewable energy production and storage facilities (scale, type, capacity, etc.) required to be co-located or integrated (i.e., multipurpose offshore platforms) with the aquaculture systems (RP1).
- Energy demand estimation of an aquaculture farm (based on tonnes of production). The capacity and size of such energy production and storage facilities to be co-located or integrated with the aquaculture systems (RP1).
- Type of infrastructure (e.g., surface, subsea, fixed, etc.) needed to support and protect these energy production and storage facilities (RP1).
- Support systems required to safely operate and maintain these offshore energy production facilities (RP1).
- Seaweed hydrodynamic attenuation and renewable energy production (RP2).
- Carbon sequestration from seaweed aquaculture (RP2).
- Use and value of local oxygen supply, by-product from hydrogen production, for aquaculture production (RP2).
- Marine spatial planning and site selection: Deployments will rely on a map of energy resources and load at selected sites especially extreme conditions (RP4), baseline survey including metocean and seabed conditions (RP4).
- Environmental impact assessment from structures on surrounding physical conditions and ecological communities (e.g., collision risk, acoustics/noise, changes in benthic/pelagic food webs/habitats) (RP4). Much of the current understanding of the footprint of energy production is from the northern hemisphere, with little information available from southern hemisphere species or ecosystems. Nevertheless, there is the desire (where possible) to leverage that existing data and employ the risk retirement ideas put forward by the International Energy Agency (IEA) OES-Environmental program (this would require coordination with RP5 to make sure this would meet social license sensitives and be in-line with regulatory and legislative expectations) (RP4, RP5).
- Offshore electricity and hydrogen utilisation market assessments. Provide a market analysis to identify opportunities, establish value proposition (including economic, environmental, and societal benefits), market drivers for renewable energy transition, supply chain opportunities and policy requirements (RP5).

1.4. Research Program 4: Environment and Ecosystems (RP4)

1.4.1. Key Insights

To date three scoping studies have been completed for RP4 – Environment and Ecosystems. These studies have focused on milestones 4.1-4.3, with some aspects of 4.5 also addressed around marine spatial planning, site selection, oceanographic modelling and integrated assessment needs. The findings of these scoping studies are briefly summarised in the short science summaries found in Appendix 9. The following sections outline milestone progress before presenting an RP4 level set of research directions (per milestone) and a roadmap of prioritised research projects.

Key high-level insights flagged in the RP4 scoping studies include:

1. For many countries the marine estate (as represented by the Exclusive Economic Zone) is vastly greater than the land area and so provides opportunities for sustainable economic growth. In Australia, coastal seas and EEZs are already used by a wide variety of stakeholders and have cultural and historic significance. This means that multiple ocean sectors already compete for space and resources, creating potential conflicts but also opportunities to plan for synergistic outcomes and benefits. Consequently, new developments will require careful planning if it is to minimise the chance of conflict while ensuring environmental, social and economic sustainability.
2. The marine environment is a particularly physically challenging environment and levels of knowledge are much lower than for terrestrial and nearshore systems. All aspects of RP4 work will require key data and understanding that is currently missing. This is particularly frustrating as inshore analogues cannot be simply transported offshore due to fundamentally different ecological communities, environmental conditions and high natural variability.
3. Industry feedback has made it clear that there is a pressing need for a suite of modelling/forecast tools (that vary in focus and complexity) to support different stages of the planning process and during operations through to decommissioning. This includes models to: support planning and marine spatial site selection for new infrastructure; the management of cross-sector interactions; fine scale multi-week, probabilistic forecasts that capture both the mean and extreme conditions, or warn of biosecurity or other production risks.

Relationship to Milestones

With respect to specific milestones, the key insights from the RP4 Scoping studies were:

Milestone 4.1 and 4.2: Stakeholders recognise the immediate requirement for a consistent and definitive regulatory framework which extends beyond State territorial boundaries. This should include the development of comprehensive assessment and monitoring guidelines to reduce regulatory uncertainty.

Milestone 4.1 and 4.2: There remains a lack of data for comprehensively assessing offshore site suitability, particularly in respect of benthic environments. The long-term goal should be to link all physical, environmental, cultural and heritage, resource potential, operational logistics and risks into a comprehensive decision support tool (or small suite of tools). Site selection should also consider the specifics around multi-use platforms (which can alter the requirements of offshore structures and therefore the site selection criteria), as well as other users and how offshore projects may impact them. These risks may be mitigated through developing marine spatial planning tools and improved accessibility to geospatial databases. Cross disciplinary research is recommended to update site selection parameters and model inputs.

Milestone 4.1 and 4.2: Site selection criteria commonly used in Multi Criteria Decision Making methods need to be developed specifically for offshore sites. Furthermore, consideration should be given to multi-use platforms (Aquaculture and Renewable Energy). New emerging technologies can alter the requirements of offshore structures and therefore the site selection criteria.

Milestone 4.1 and 4.2: The participation, acceptance and support of all stakeholders – including other industry sectors, community members and First Nation rights holders - is necessary to ensure sustainable offshore expansion. Processes to engage all parties during the marine spatial planning process need to be addressed.

Milestone 4.2 and 4.5: Research is required to address the cumulative impacts linked to large scale offshore development and co-located activities, including but not limited to renewable energy and aquaculture operations.

Milestone 4.3 and 4.4: Stakeholders identified the need for research data in order to improve modelling that can accurately predict offshore impacts and risks including occurrences of algal and jellyfish blooms, spread of pathogens, noise pollution and dispersion of nutrients. Stakeholders also identified the need for further work on preventive measures to avoid marine megafauna entanglements.

Milestone 4.3: There is a need to standardise assessment and monitoring practices (to ensure comparability between related projects/industries) and develop government endorsed guidelines (ideally be linked to clear management responses and trigger values). There is a critical need to identify appropriate sentinel indicators for offshore environments and to provide guidance on correct use of statistical models. The requirements of environmental monitoring will differ depending on the type of aquaculture and energy system deployed. Environmental monitoring can reduce the risk of adverse effects, operational costs and maintain public confidence in the associated industries. To ensure workforce health and safety, the focus for offshore sites should be automated and remote sensor technology ideally supported by AI systems.

Milestone 4.3: Multi-week probabilistic forecasts at scales relevant to farm/device operations, this will increase the lead times available for planning to be onsite (this includes predictions of environmental properties, such as Water Clarity predictions to understand when AUV/ROV and diver led operations can take place, but also extreme events, harmful algal blooms, jellyfish etc).

Milestones 4.1-4.5: Data needs to be easily accessible with methods to interface with Decision Support systems. This data infrastructure must be of a form that operational modelling systems can interrogate and deliver into. Information generated by CRC tools (e.g. planning and model-based tools) must be easily accessible, as stakeholders identified the need for integrated and accessible online tools for assessing multi-sector impacts and planning.

Milestone 4.3: Rapidly Deployable Model Systems need to be developed/used to make regional/global forecasts relevant to a facility site.

Milestone 4.2, 4.2, 4.5: Multi-sector studies generally approach the assessment of cross-sector interactions using a range of tools that fall within spatial modelling and prioritization frameworks (with many well-developed packages already extant for use in site selection). Dynamic ecosystem and oceanographic models (often used for operational tasks) are well developed for single sectors, particularly commercial fisheries, but have been less commonly applied in multi-sector studies. Furthermore, methods to assess trade-offs and simulate change in ecosystems over time are underutilised, and there is room to develop and utilise more sophisticated approaches to assess cross-sector interactions, particularly dynamic and non-additive feedbacks among sectors, and tools that support direct scenario comparisons. This must be done with care to ensure that tools remain useful rather than being overwhelmed by complexity, especially in dimensions where there is little available data for validation.

Milestone 4.2, 4.4 and 4.5: The CRC should investigate implementing overarching frameworks such as Structured Decision Making or Management Strategy Evaluation to analyse complex interactions between sectors and benefits of offshore production. This approach would incorporate adaptive management considerations, dynamic feedbacks, account for uncertainty (potentially through multiple-model ensembles) and can make explicit and transparent the trade-offs in triple bottom line performance.

1.4.2. Future Research Priorities

Representatives of each of the scoping project teams met with the RP4 leadership team for a half day workshop to consider the gaps and opportunities highlighted by the scoping studies and to map out research ideas to build off that understanding and deliver to the RP's milestones. Another half day workshop was held with leads from each of RP1,2,3 and 5 to discuss cross connections and collaborative research ideas. All of this was brought together to create a prioritised work plan, with extra detail put into near term projects, as medium-term projects will need to be subject to CRC, national and international advances in the interim. The list of research activities identified for RP4 are shown in Table 13 (for the medium term).

Table 13. RP4 medium-term research priorities.

Research Activity	Description of Activity	Considerations/ Implications	Link to Milestone Activities
Address cross-sector interactions and feedbacks for dynamic assessments (without being overly complicated)	This work needs to be done as supporting work for integrated/cumulative assessments (so either as an early phase of that work or moderate standalone project). This is a high priority area. This work will require enabling research on understanding what the interactions/feedbacks are of colocation (as well as effect on environment, FAD role, large animal behaviour change etc).	Lessons may be gained from Star of South development (and OES-Environmental and EU internationally).	Delivers to RP4.2.3, RP4.2.4, RP4.2.5 and RP4.5 This work will require a close link with RP5, which has strong overlap in assessments it has to deliver.
Cumulative (or integrated) effects assessment framework/tool development – including linking all physical, environmental, cultural and heritage, resource potential, operational logistics and risks into a comprehensive decision support tool. And address cumulative impacts linked to large scale offshore development and co-located activities	Cumulative effects work is top priority (with the hazards analysis step of this work already underway). If/when go further to quantified risk there will be a need to think on how to bring in different dimensions (socioeconomic and biophysical; first nations lessons). Dynamic systems models might be an option, but given development costs perhaps not a good investment and should look to more easily deployable tools (and/or link with other modelling activities).	Going beyond hazard analysis may not be an absolute CRC requirement depending on what MULTIFRAME does in EU.	Delivers to RP4.2.3, RP4.2.4, RP4.2.5 and RP4.5 There is a strong link with RP5, which has overlap in assessments it has to deliver.
New computational and analytic methods for working up field data and model output (especially non-linear interactions and prediction cross scales)	This is a longer-term research area. This will be required for making sure the final deliver of 4.3 remains relevant as new technology comes online by 2027 (rough start date for such work).		
'RISKPATH' application to help users identify what risk/portal (or other CRC) tools deliver to their needs given available data	Create a tool to help users see what is feasible in terms of prediction, monitoring, analytics given available data streams. The FISHPATH tool (https://www.fishpath.org/the-tool), which looks at options for fisheries stock assessment, provides an example of the kind of concept this tool is trying to capture.		Delivers to RP4.2 and RP4.3 and longevity of CRC outputs. Links across all RPs (in terms of user needs).
Biosecurity modelling	This will be medium term activity and is a fast moving field and the CRC should adapt its research program accordingly as new methods/products become available beyond the CRC.	May require partnering with groups beyond CRC to access best in field expertise.	Delivers on RP4.4.1 and RP4.4.2 This will have explicit links with RP2 and RP3 who can deliver specific operational information.
Incident response tools	This will be medium term activity and may require the use of machine learning and AI based methods to further develop the tools (though this is a fast-moving field and the CRC should adapt its research program accordingly as new methods/products become available beyond the CRC).	May require partnering with groups beyond CRC to access best in field expertise.	Delivers on RP4.4.2 As this must cover colocation it must link across considerations from all RPs.

Research Activity	Description of Activity	Considerations/ Implications	Link to Milestone Activities
Next generation biosecurity tools	This is a medium to long-term body of work and will be shaped by scoping study output. One possibility is use of eDNA flag presence of pathogen (this would need to link to source and connectivity modelling and require barcodes of specific species being scanned for).		Delivers on RP4.4.1 and RP4.4.2 As this must cover colocation it must link across considerations from all RPs.
New biosecurity guidelines for use on co-located platforms			Delivers on RP4.4.3
Life-cycle analysis			Delivers on RP4.5.3 Explicit links with Rp5, which has similar activities.
Adaptive management framework for co-located platforms	Create a tool to help users see what is feasible in terms of prediction, monitoring, analytics given available data streams. The FISHPATH tool (https://www.fishpath.org/the-tool), which looks at options for fisheries stock assessment, provides an example of the kind of concept this tool is trying to capture.		Delivers to RP4.2 and RP4.3 and longevity of CRC outputs. Links across all RPs (in terms of user needs).
Management strategy evaluation of deployment, operations and decommissioning of co-located offshore production platforms	This is a medium to long-term type of work and may need to align with functions and operations of co-located multi-use platforms. This should cover risks and opportunities of co-located offshore platforms and a co-located production environment, supply chain information and integrated networks, and business model.		Delivers to RP4.5 Explicit links with RP5, which has similar activities.
Integrated assessment of benefit of offshore production	This should cover both (i) the assessment of colocation potential beyond aquaculture and energy and (ii) the benefits of offshore production vs onshore/nearshore production. This work could be done as a single overarching piece of work or two separate smaller projects.	This will require working with relevant agencies and industries.	Delivers to RP4.5.4 and RP4.5.5 This should be done in conjunction with RP5.

1.4.3. Cross-Program Linkages

The connections (and in some cases knowledge gaps) important for RP4 to consider are below. Many of these linkages relevant to RP5 as well are captured here.

- Experimental Platforms. Infrastructure and facilities. Data integration and translation. Models and toolkits. Scenario testing, simulations and field experiments. All species (RP2).
- Environmental and biosecurity assessment and incident response with a focus on early identification of disease vectors and of biological and environmental risks for species production and in the development of autonomous systems (RP2, RP1).
- The potential to leverage off ecosystem approaches in shaping any IMTA focused research (RP2).
- Identifying risks to production from local fauna and flora and how changes in operations (and potential design) mitigate those risk (RP2).
- Biofouling. Environmental concerns in using antibiofouling coatings/materials for fish (or other species) pens and offshore renewable energy extraction devices (RP1, RP3). Understanding how ecological communities and processes respond to physical shape and materials so that the physical structure of the platforms can be tailored to minimise the ecological footprint (throughout the life of the platform, including decommissioning) without undermining production capacity (RP1, RP3).
- Environmental effects: the environmental effects of ocean energy technologies vary by technology. These include issues associated with conversion technologies, such as striking,

noise and electromagnetic radiation effects. Current knowledge is predominantly gained from north-hemisphere ecosystems. Additionally, consideration of potential environmental issues associated with electrolysis (e.g., contaminants if electrolysing seawater) (RP3).

- Site selection and site suitability: Resource assessment, site characteristics are common challenges for many RPs (RP1, RP2, RP3, RP4). The deployment of offshore fish (or other species) structures and multipurpose offshore platforms (RP1). Sites suitable for energy production (RP3), Interaction between biological capability of aquaculture species and site characteristics (average and extremes) (RP2).
- Marine Spatial Planning: Emerging RE industry should be recognised as a user of ocean space in MSP activities (RP3).
- Integrated system modelling: Energy system models developed in RP3 have potential to link with broader system simulations (RP3).
- Integrated sensor networks: Environmental variables to be monitored are critical to effective control and management of the energy system (RP3).
- Decision support tools: Shared interests in decision support tools (RP3).
- Digital frameworks and data repositories: Shared interests in appropriate data frameworks that capture the needs of RP3 (RP3 RP4, RP5). Accessible and reliable data are a key requirement of evidence based development of a Blue Economy. A common data platform holding quality assured data sets is a key issue for all RPs.

1.5. Research Program 5: Sustainable Offshore Developments (RP5)

1.5.1. Key Insights

Four Scoping projects were commissioned through RP5 addressing core elements of the broad-based research program; economic (market and non-market) assessment; integrity systems and values (including social license and certification issues); supply chain and logistics issues; policy and regulatory frameworks. The projects, while impacted by some dislocation and disruption caused by COVID-19, were completed effectively and involved a number of partners and included progress report workshop presented to Blue Economy CRC community.

Relationship to Milestones

Each of the four projects contributed to key initial milestones of the program due in June 2021. In two areas – policy and regulatory analysis and values, ethics, and social license the scoping studies led directly into General Projects commenced in late 2020, which will meet milestones due in 2021-2023. The scoping studies provided strong intra-program linkages and provide support for cross-program activities, as well as helping to prioritise RP5 activities in 2021-2022.

The key insights from the RP5 Scoping studies were:

Milestone 5.1: The Scoping studies identified need to address clarity/certainty in policy commitments with respect to broad Blue Economy objectives (RP5 milestone outputs RP5.1.2), and recognized the need for a practical trial (e.g. an offshore platform/activity) to further investigate and analyse jurisdictional and legal arrangements with respect to activities outside state waters (RP5 milestone outputs RP5.1.2). The Scoping Studies identified ethics and values as a key frame and need to integrate values across economic assessments, supply chains and within the BECRC and projects (RP5 milestone outputs RP5.1.2. RP5.3.1).

Milestone 5.2.1: The research undertaken in the Scoping studies identified the importance of supply chain mapping and analysis, highlighted future activities (RP5 milestone outputs RP5.2.2), and outlined the utility of supply chain operations reference (SCOR) model (RP5 milestone outputs RP5.2.2); link to policy and regulation, economic modelling and social license.

Milestone 5.3.1: The Scoping studies identified the key elements of and justification for an integrity system approach to assessment of blue economy activities and operations, outlined future work plan to address these topics and outlined the base of certification processes and governance of certification of blue economy activities and operations (RP5 milestone outputs RP5.3.4).

Milestone 5.4.2: The research undertaken in the Scoping studies examined the basis and development of appropriate economic indicators for Blue Economy activities (RP5 milestone outputs RP5.4.2). This research noted the utility of non-market valuation tools providing insights into activities that cannot be 'measured' by traditional economic indicators. This work has direct linkages to work on policy options, social and cultural values and identified future direction for this work (RP5 milestone outputs RP5.4.2).

Table 14. Summary of RP5 milestones due in 2021-2026.

Research Topic	Milestone	Due date	Priority for 2021-2025	Recommendations
Legislative, economic and policy frameworks	5.1.1 Undertake and report on the mapping of existing normative, legislative, policy and economic frameworks (including native title issues).	31 December 2021	High	Scoping study and Milestone being addressed with GP led by Fidelman.
	5.1.1 Report on the assessment of current frameworks and gaps identified, assessing fit and risk management with integrity systems standards and criteria	31 December 2023	High	Scoping study complete. Milestone being addressed with GP led by Sampford.
	5.1.3 Identify and report on key elements of reform.	31 December 2026	Moderate	Build on data from GP Fidelman – new project.
Supply Chain and Logistics	5.2.1 Report on the mapping of marine and offshore energy and aquaculture supply chains	31 December 2021	Moderate	Scoping study completed by Chen.
	5.2.2 Identify and report on challenges and potential for an integrated colocation approach.	31 December 2023	Moderate	New project; build on Scoping study by Chen.
	5.2.3 Report on the protocols, strategies and tools for coordination and cooperation across the supply chains.	31 December 2026	Low	New project; build on Scoping study by Chen.
Ethical Basis to Blue Economy	5.3.1 Report on the proposed standards and criteria for integrity and accountability systems, including values identification, interpretation and application as shaping blue economy operations.	2023	Moderate	Milestone being addressed with GP Sampford
Cost and benefits Offshore colocation	5.4.1 Establish and assess an environmental management accounting system to strengthen integrity of the blue economy. Deliver at least one report on the findings.	31 December 2024	High	Build on Scoping studies from Ngyuen and Chen. New General Project being developed (Lee) to begin 2021.
	5.4.2 Development and modelling of economic options for sustainable blue economy operations. Deliver at least two reports on the activities and findings.	31 December 2025	Moderate	Build on project being developed (Lee) beginning 2021.
Communication and Engagement	5.5.1 Establish, monitor and revise evaluation framework for Program 5	2022	Moderate	Build on data and information provided by Scoping Studies and Scoping Studies Research Synthesis Report (whole CRC).

Below are the targeted research activities for RP5 that are currently in progress.

- Policy and regulatory mapping - RP5 milestone outputs (RP5.1.1; 5.1.3.) – addressed by General Project 5.20.007.
- Ethics, values and social license (RP5.3.5) – addressed by General Project (5.20.005).
- Environmental Management Accounting General project – **a priority needed in 2021** to address current milestone (RP5.4.1).
- First nations and cultural values of the blue economy - integrated research across all RPs, being addressed by General Project in development (RP5.20.006) – **a priority needed in 2021.**
- Artificial Reefs project – integrated research across RPs 5, 4, 2 and being addressed by scoping project in development – **a priority needed in 2021.**

The short-term priorities have been described and captured in Table 6.

1.5.2. Future Research Priorities

Targeted research activities that should be prioritised in the medium to long-term are provided in Table 15 below.

Table 15. RP5 future research priorities

Research Activity	Description of Activity	Considerations/ Implications	Link to Milestone Activities
Development of a framework including standards and criteria for integrity and accountability system	This project will extend work on ethics and values underpinning a social license to operate in the blue economy. It will identify integrity mechanisms, standards and criteria by which those values are delivered, and by which social license is developed, strengthened and retained.		RP 5.3.1
Supply chain analysis non-market valuation tools	This project will explore application of tools and approaches to assess supply chains development and provide robust assessment and valuation of non -market goods and services in the Blue Economy.		Delivers to RP2.2.2; RP5.4.2. Links to RP2, RP3 and RP4

1.5.3. Cross-Program Linkages

The connections (and in some cases knowledge gaps) important for RP5 to consider are below. There are strong and direct linkages in terms of specific deliverables in relation regulatory/legislative, economic (environmental and carbon accounting and life cycle analysis) and social acceptability across all RPs.

- AMSA rules and regulations for aquaculture marine vessels (including electric vessels, autonomous surface vessels, etc.) and AUVs (RP1).
- Economic assessment of biofouling mitigation approaches including externalities: Important to fully understand the cost of implementing new management solutions. At the moment, industries are 'turned off' by the high CAPEX of new antifouling technologies but the overall ownership cost may be lower (RP1).
- Standards for assessing antifouling technologies: Any Australian guidelines for screening antifouling technologies for offshore aquaculture/ renewable energy / structures. This is important because biofouling patterns are unique depending on the site (RP1).
- Emerging/ drafted regulations for the following: materials that are "banned" or restricted (e.g., concentration restrictions for seabed or water column) for offshore fish pens and mooring systems by state or commonwealth legislations; mechanical-based underwater cleaning. Current net cleaning practice just leave biofouling waste in the ocean; activities in multi-use sites when co-located with aquaculture farms (e.g., tourism, energy, etc.); multipurpose offshore platforms. Defining what is driven by strictly operational requirements and what is statutory. (RP1).
- Production Biology Assessment Tool (Model) and Toolkit. Data collection, collation and comparison to provide benchmarking and underpin decision making. Integrate with Species Selection Tool (RP2).
- Species Selection Tool. Wholistic evidence-based approach to selecting single and multiple species, initially regionally specific but refined to be site specific (RP2).
- Regulatory framework: The regulatory framework at State and Commonwealth level for offshore energy projects is immature; reviews and recommendations of international best practice present value (RP3).
- Permitting and Licensing: permitting and licensing requirements of multiple components of the energy systems requires consideration (RP3).
- Social acceptance: Social acceptability of emerging technologies. Social acceptability of novel multi-use or expansive offshore structures or offshore renewable energy is an unknown (RP1, RP3), and could vary by industry and technology (ORES conversion technologies and use of hydrogen in blue economy) (RP3). This is with the critical aim to avoid inadvertently undermining an industry's or regulator's social license.

- Market assessments: Investigation of market opportunities and potential value of ORE development, including Gross Value Add assessments required to assess cost-benefit ratio of ORE in Australia (RP3). Seaweed market analysis has also identified for RP2. Value and trade-offs for seaweeds. Improved benefit-cost analysis, eco-techno-economic analysis, etc: specific to different aquaculture systems (local biodiversity, biofouling, disease, hydrodynamic-attenuation) (RP2).
- Supply chain development: ORES supply chain is immature in Australia. Identifying challenges and gaps can be key to supporting industry growth. Supply chains disruptions in offshore environment is a foreseeable risk factor in blue economy. Supply chain opportunities for offshore aquaculture systems and renewable energy are also relevant. (RP2, RP3).
- Life cycle analysis: Life cycle analysis in targeted aquaculture operations and a co-located offshore platform will identify environmental and economic impacts to support decision makings at policy and corporate management in offshore aquaculture (RP1, RP2, RP4)
- Management strategy evaluation and business development: In the operational and strategic level, there is a strong need to investigate the risks and opportunities for offshore productions in a co-located environment. Strategies and strategy renewal, cost and benefit analysis, business model development of multi-use platforms and/or the associated applications need to be developed (RP3, RP4).
- Stakeholder engagement: ORE is emerging industry. Stakeholder engagement critical to leave no-one behind (RP3).
- Workforce profiling: Gross value added (GVA) analysis in cost-benefit assessments of ORES and offshore aquaculture (RP2, RP3).
- Blue economy metrics, including carbon accounting: Accounting GHG emissions in blue economy. If seeking to decarbonise blue economy, this is key metric to establish (RP3).

A.3. Relationship to Commonwealth Milestones

Below are the Commonwealth Milestones as stipulated in Schedule 2 of the Blue Economy CRC's Participants Agreement.

Research Program No. 1 - Offshore Engineering and Technology			
Milestones		**Start Date**	**End Date**
Output.1.1 Commercial-ready designs and sub-systems for offshore aquaculture cages in a high-energy environment. Outputs include; propriety IP for materials, cage design, floating breakwaters, mooring systems and manufacturing methods as well as in-depth performance data from deployment tests. This output also includes the designated design and operational frameworks covering engineering principles, economic models and operational guidelines as well as dynamic risk models for life cycle assessment of offshore structures.			
RP1.1.1	Deliver a report identifying the range of site conditions applicable to offshore fish cage design, and the criteria for commercial application in an offshore environment.	1 June 2020	31 December 2020
RP1.1.2	Deliver a report on evaluation of existing conventional nearshore and emerging offshore fish cage designs under offshore conditions (as identified in M1.1.1) to ascertain the operating envelope and identify failure modes.	1 July 2020	30 June 2021
RP1.1.3	Deliver at least one report on the selection of appropriate materials and analysis methods based on optimised simulation and analysis for new or improved fish cage design completed.	1 July 2021	31 December 2023
RP1.1.4	Deliver a report summarising experiments on new cage designs conducted and designs refined.	1 January 2024	30 June 2026
RP1.1.5	Deliver two reports summarising the verification and validation of cage designs carried out through field demonstration and further optimisation.	1 July 2026	30 June 2029
Output 1.2 First standardised modular multi-use platform system in a state appropriate for commercial development and/or implementation. IP covering the design, fabrication, deployment and decommission of the entire system. This output includes the business case for the system, validated performance data from field tests and design and operation guidelines. Other outputs include new mooring and station keeping systems, design and simulation tools and guidelines and standards applicable to a broad range floating offshore platform.			
RP1.2.1	Deliver a report on potential applications for standardised modular multi-use platforms identified.	1 June 2020	31 December 2020
RP1.2.2	Develop and populate an offshore application portfolio that includes, (i) sub-division of basic modules, (ii) requirements to external station keeping system, and (iii) requirements to internal connectors (strength and flexibility).	1 July 2020	30 June 2021
RP1.2.3	Deliver at least one report on the determination and definition of optimal shapes and sizes of floating modules and required structural solutions.	1 July 2021	30 June 2023
RP1.2.4	Deliver a report on station keeping systems and designs (including foundations, moorings, and active floating systems) for a range of identified modular platforms.	1 January 2022	31 December 2023
RP1.2.5	Conduct and deliver numerical simulations and experimental tests on an optimal design of an integrated fish farm and renewable energy production farm concept and deliver at least one report on the activities.	1 January 2024	30 June 2026
RP1.2.6	Develop draft design guidelines that include life-cycle analysis and cost-benefit analysis for modular designed assembled fish farm and renewable energy farm. Identify in those guidelines all potential challenges, consequences and risks, and develop a plan to address these aspects. Provide final guideline report.	1 July 2026	30 June 2029

Output 1.3 A demonstrator multi-use offshore platform will be deployed as part of this activity. For the first time, this will allow the realistic investigation of system integration aspects of multi-use platforms and the quantification of synergistic benefits of multi-use platform operation. For the last 5 years of the project the platform will serve as live testbed for the real-world testing and colocation of the participant's systems and CRC outputs.			
RP1.3.1	Provide a report on the assessment and verification of site suitability for multi-use platform demonstration using a desktop study analysis, existing met-ocean resource data and field site characterisation data.	1 July 2020	30 June 2021
RP1.3.2	Deliver a report on the final selection of the types of ocean renewable energy systems, aquaculture and offshore industry operations to demonstrate colocation activity.	1 July 2020	30 June 2022
RP1.3.3	Develop procedures and guidelines for hazard identification, risk management and mitigation for installation, safe operation, maintenance, inspection and monitoring and decommissioning of ORES. Deliver final guideline report.	1 July 2020	30 June 2025
RP1.3.4	Develop and produce at least two reports on planning for logistics, installation and commissioning of systems (cages, ORES, platform) and necessary infrastructure/vessel support.	1 July 2020	30 June 2025
RP1.3.5	Evaluate the performance of the multi-use platform activities through real-time monitoring. Develop tools to support data management and analysis of data taken from the platforms activities (cages, ORES, platform). Deliver at least two iterative reports on the activities.	1 July 2023	30 June 2029
Output 1.4 Development of remote sensors and autonomous platform that uses some combination of aerial, surface and underwater systems to reduce the operational risks for aquaculture and renewable energy. A strong emphasis will be on sensor integration and cross-platform communication to allow predictive decision making.			
RP1.4.1	Review risks associated with manual operations; » in offshore environments, » on offshore structures, and identify remote sensing and autonomous operations that could be implemented to reduce risks (and costs) for operations.	1 June 2020	31 December 2020
RP1.4.2	Develop novel autonomous and remote sensing concepts for offshore risk mitigation and management. Deliver at least two reports on the activities.	1 July 2020	30 June 2024
RP1.4.3	Deliver an initial report outlining the key design features for a HydroNest (an offshore landing platform that integrates the airborne, surface and underwater systems and provides for extended endurance/power for continuous offshore operations).	1 July 2024	30 June 2026
RP1.4.4	Commission, test and analyse the performance of the HydroNest in relation to its use in integrated offshore aquaculture and renewable energy operations. Delivery two iterative reports summarising the activity and findings.	1 July 2026	30 June 2029

Research Program No. 2 - Seafood and Marine Products			
Milestones		**Start Date**	**End Date**
Output.2.1 Advanced understanding of, and industry-ready knowledge to- improve production biology in offshore environments. This will include operational guidelines and protocols, tools (models) to compare production, policy recommendations, environment and food safety across multiple species and tailored to offshore sites. This knowledge will be translated in the form of an online tool that lists suitable species and the likely production benefits from the adoption of advanced production approaches.			
RP2.1.1	Deliver production assessment reports to compare and contrast production biology and growth performance in offshore environments. Assess measured production performance against expected performance. Determine key factors, propose technical improvements and experimental testing. Ongoing activity will be undertaken on different species and aquaculture systems. Deliver at least two iterative reports on the activities and findings.	1 January 2020	31 December 2028
RP2.1.2	Develop and populate a portfolio of preferred offshore species. Define relevant characteristics, determine likely candidates, consolidate existing knowledge and determine knowledge gaps for CRC activity. Deliver at least two reports on the activities and findings.	1 January 2020	31 December 2028
RP2.1.3	Conduct of laboratory and/or field experiments to answer defined research questions on selected key production biology variables. Ongoing activity will be undertaken across different variables and aquaculture systems. Deliver at least two reports on the activities and findings.	1 January 2020	30 June 2028
Output 2.2 A framework for integrating production and engineering technologies that advances overall productivity of seafood marine products. This will be in the form of a matrix that trades off the complexity of physical platforms and maximises the recovery of nutrients and nutritional material. The development of operational guidelines and protocols, policy recommendations and a suite of information material.			
RP2.2.1	Progressively document the refinement of the best-practice production and productivity for different (individual) species and aquaculture systems. Deliver at least two iterative reports on the activities and findings.	1 January 2020	31 December 2028
RP2.2.2	Undertake a production performance-based assessment on integrated production (across multiple species), and report on the findings. Assess measured production performance against expected performance. Determine most likely causes, technical solutions and experimental testing. Ongoing activity will be undertaken on different species and aquaculture systems Deliver at least two iterative reports on the activities and findings.	1 January 2021	30 June 2028
RP2.2.3	Conduct laboratory and or field experiments to fill knowledge gaps for selected species. Incorporate new knowledge into ongoing activity and across different species and aquaculture systems. Deliver at least two iterative reports on the activities and findings.	1 January 2020	31 December 2028
Output 2.3 Platform to underpin the value and promotion of seafood from new aquaculture systems. This will be based on providing evidence to support operational arrangements. New species will achieve high value in the marketplace, based on attributes such as sustainability, animal welfare improvements and nutritional value. Consumer confidence will be enhanced through certification schemes.			
RP2.3.1	Determine and refine standardised approach that compares production and productivity to include quality criteria for seafood products and provide a minimum of two reports on findings. Ongoing activity will be undertaken across different species and aquaculture systems.	1 January 2020	31 December 2028
RP2.3.2	Consolidate new knowledge about quality of seafood from commercial offshore operations and define knowledge gaps to develop an evolving set of operational guidelines and protocols across different species and aquaculture systems. Deliver at least two iterative reports on the activities and findings.	1 January 2020	30 June 2028

RP2.3.3	Conduct laboratory and/or field experiments to understand the influence of offshore environmental factors on product quality of seafood. Ongoing activity will be undertaken across different species and aquaculture systems. Deliver at least two reports on the activities and findings.	1 January 2020	31 December 2028
RP2.3.4	Assess the opportunity to develop animal feed products from offshore aquaculture. In a minimum of two reports summarise the laboratory and/or field experiments on animal feed products from concept to proto-type. Ongoing activity will be undertaken across different animal feed products.	1 January 2020	30 June 2028
RP2.3.5	Assess the opportunity to develop non-feed products from offshore aquaculture. In a minimum of two reports summarise the laboratory and/or field experiments to progress development of products from concept to proto-type. Ongoing activity will be undertaken across different non-food products.	1 January 2020	30 June 2028

Research Program No. 3 - Offshore Renewable Energy Systems			
Milestones		**Start Date**	**End Date**
Output.3.1 An energy demand and optimisation model for offshore industry operations (for proposed co-located aquaculture platform, and other future scenarios).			
RP3.1.1	Report on the characterisation of offshore renewable resource and Met-Ocean conditions for Australia (solar, wind, wave, tidal, OTEC, ocean-current with climate consideration) and site suitability of proposed ORES demonstration reported.	1 January 2020	30 June 2022
RP3.1.2	Establish a working database of technical-economic performance of OREC technology options, suited for Australian resource conditions.	1 January 2020	31 December 2021
RP3.1.3	Establish a working ORE resource prediction system, for energy management.	1 January 2020	31 December 2027
RP3.1.4	Develop a working offshore energy system model (including life cycle analysis and electricity, storage, oxygen, freshwater, transport demands), which accounts for co-optimised operation of co-located offshore activities (intelligent scheduling) for future alternate scenarios.	1 January 2020	31 December 2026
RP3.1.5	Undertake an energy market analysis, synthesising feasible options and scenarios (technologies, scales, solutions) for energy delivery on or from offshore platforms, and market penetration pathways. Deliver at least two reports on the activities and findings.	1 January 2020	31 December 2028
Output.3.2 Offshore Renewable Energy Converter (OREC) designs, patents, improvement in existing technologies with increased survivability and decreased environmental impact, capital and operating costs.			
RP3.2.1	Produce a review to examine existing and state-of-the-art ORES concepts to identify suitable options for Australian offshore conditions and end user suitability, and pathway mapped for advancing ORESs (desktop study).	1 January 2020	31 December 2020
RP3.2.2	Deliver at least two reports which summarise technical and economic feasibility and for ORECs arrays/farms including understanding the hydrodynamics interactions between ORECs, array layout, resource analysis, grid connection, permitting, feed in tariffs, regulations and standards, and supply chain.	1 January 2020	31 December 2029
RP3.2.3	Report on the design, develop and demonstrate ORECs/OREC components to improve existing technologies with increased survivability and decreased environmental impact, capital and operating costs.	1 January 2020	31 December 2029

Output.3.3 Designs, patents, energy management strategies, new and integrated technologies, suitable for the offshore environment, leading to a bench-scale test system and products such as micro-grid architecture, desalination, oxygen, hydrogen, ammonia and other storage solutions, derived from Offshore Renewable Energy Systems (ORES).			
RP3.3.1	Develop software models for ORECs and other ORES components; electrolysers, oxygen, hydrogen storage, FCs, microturbines, and desalination plant.	1 January 2020	31 December 2024
RP3.3.2	Conduct a feasibility study for DC microgrids in a marine environment and preliminary design including architecture and control system, and at least one report on findings.	1 January 2020	31 December 2023
RP3.3.3	Demonstrate and test a bench scale DC microgrid system that includes battery energy storage, fuel cell, hydrogen production, oxygen and desalination. Determine recommended optimal hydrogen storage options for offshore applications and optimal desalination techniques for offshore applications. Deliver at least two reports on the activities and findings.	1 July 2020	31 December 2024
RP3.3.4	Undertake and report on a feasibility study on the utilisation of hydrogen fuel cells for replacing diesel generators on any combinations of; vessels, UAV, ROV and AUV's. Deliver at least two reports on the activities and findings.	1 January 2020	31 December 2026
RP3.3.5	Deliver at least two reports that summarise the evaluation and optimisation of grid and storage performance relative to models and the ORES subsystems for outputs (such as fresh water, power, oxygen, hydrogen, etc.). Report on the assessment of the relative scale of production of these outputs for any given demand at the site.	1 July 2024	30 June 2029
Output.3.4 Successful proof of concept through field demonstration of the operation of novel ORES, reporting findings and learnings (e.g., performance, system-scaling, installation, monitoring systems, licensing, risk management and mitigation, maintenance, end-user demands, CAPEX and OPEX reductions).			
RP3.4.1	Develop procedures and guidelines for each activity that includes hazard identification, risk management and mitigation for installation, safe operation, maintenance, inspection and monitoring and decommissioning of ORES. Develop logistics plans for the build, installation and commissioning of ORES, including consideration given to the necessary infrastructure/vessel support required. Provide final guidelines report.	1 July 2020	31 December 2025
RP3.4.2	Develop a real-time monitoring tool to support data management and analysis of environmental conditions, environmental impact and ORES. Deliver a report on the activities and findings.	1 January 2020	31 December 2027
RP3.4.3	Demonstrate a "live" and /or publish on Blue Economy CRC website real-time monitoring of ORES installed at the demonstration site (this is aimed at supporting stakeholder and community engagement and improving social acceptability of practices and technologies).	1 January 2020	31 December 2027
RP3.4.4	Complete two assessments of the project's impacts and uptake associated with user's investments in ORES and resultant outputs (such as power, water, oxygen, hydrogen) for current and future offshore aquaculture operations and co-located activity. Deliver at least one report on the findings.	1 July 2024	30 June 2029

Research Program No. 4 - Environment and Ecosystems			
Milestones		**Start Date**	**End Date**
Output.4.1 Multi-criteria regional marine spatial planning tool for the identification of regional areas that would be feasible (technically and economically) for integrated multiple-use platforms. Including consideration for other users (and associated trade-offs), identification of desired environmental conditions, and a suite of potential indicators and reference points to be used to track operational performance and predicted impacts.			
RP4.1.1	Develop an integrated offshore structure resource characterisation and prediction system, in consultation with appropriate experts to develop appropriate selection criteria, suitable indicators and reference points for evaluating the performance of the platform. Deliver at least one report on the findings.	1 January 2020	31 December 2024
RP4.1.2	Undertake predictive modelling to support site selection for colocation of activities (and resulting growth and nutritional profiles) for multispecies assemblages based on dynamic environmental conditions. At least one report on the findings.	1 January 2020	31 December 2023
RP4.1.3	Develop a decision support system (based on RP4.1.2) for finding suitable sites for offshore activities that balances cumulative impacts on the environment and cross-industry synergies including blue tourism and trade-offs. Refinement through application to case study demonstration(s).	1 January 2020	31 December 2024
Output.4.2 Framework for assessing proposed offshore activities & supporting specific site selection. Constituent products include: Systematic risk assessment process (hazard analysis, risk assessment, contingency & response identification); indicator identification & benchmarking; characterisation of site properties; creation of reference cases & requirements for subsequent developments & assessments.			
RP4.2.1	Undertake and report on a systematic hazard analysis for threats to offshore production systems, together with the threats they pose, in multi-use offshore environments. Provide recommendations on risk factors and levels for further evaluation.	1 January 2020	31 December 2022
RP4.2.2	Undertake resource and habitat characterisation and mapping of potential production and / or control sites to support an ongoing monitoring design. Deliver at least one report on the findings.	1 January 2020	31 December 2025
RP4.2.3	Deliver a report to assess potential risk levels of various industries and production models including assessment of technical (e.g. species) requirements, economic and environmental feasibility and implications for matters of national environment significance (MNES).	1 January 2020	31 December 2027
RP4.2.4	Development and transfer of multiple environmental decision support tools. These will include both risk assessment and risk-based monitoring and management strategies for site selection and installation performance/footprint assessment. The tools will be developed recognising the need to respond to future technological development arising from within the CRC and externally. They will therefore consist of a series of sub-models/ tools that can be substituted/revised. This modular structure will also provide the potential to link these ecosystem focused evaluations with similar decision support tools developed in RP5 focused on business/ social expectations (i.e. growth/ expansion strategies).	1 January 2023	31 December 2028
RP4.2.5	Develop and demonstrate a probabilistic cumulative risk assessment for specified hazards (particularly to do with design, situation, operation and decommissioning of offshore production systems), aligning risk endpoints with observable changes in social, economic and environmental indicators, thereby defining acceptable operational boundaries and pre-defined set of adverse (beyond acceptable limits) circumstances and incidents. Deliver at least two reports on the activities and findings.	1 January 2023	31 December 2028

Output.4.3 Smart monitoring and information platforms, maximising probability of correctly attributing cause of observed changes and enables responsive operations. Automated data workflows feeding forecasting systems with resulting model and data products coordinated in centralised information platforms featuring in-built visualisation and processing, and a design focus on easing access and interoperability. Underlies a risk alert system and incident response platform.			
RP4.3.1	Design and implementation of an integrated observing system that (in)validates risk and impact predictions, and evaluates the effectiveness of environmental management actions, based on periodic and real-time observations taken from (autonomous and remotely operated) aerial, surface and sub-surface monitoring platforms, with specific focus on attribution of effects within multi-use environments and identification of tolerable operational limits. Indicate how design allows for inclusion of new data-types (e.g. eDNA), transparency and accountable monitoring system that is accepted by Government, Community and Industry. Deliver at least two reports on the activities and findings.	1 January 2020	31 December 2028
RP4.3.2	Conduct a trial of a multi-sensor AUVs to work as autonomous marine platforms for the health inspection of the seafood (and seafood production facilities), inspection of renewable energy production facilities, environmental monitoring for impacts evaluation and tracking of offshore ocean environment (using Adaptive sampling and Multi-vehicle networking techniques).	I January 2023	31 December 2025
RP4.3.3	Development and operation of a Metocean forecasting system (wind, waves, circulation and water quality) with additional biogeochemical modules. Built with advanced data assimilation and coupling capability delivering outputs suitable for site design, and operational support. Deliver at least one report on the activities and findings.	1 July 2020	30 June 2024
RP4.3.4	Report on the evaluation of the environmental footprint of multiple-use platforms with particular consideration of interactions with MNES (e.g. threatened, endangered and protected species) and indicators identified in RP4.1-RP4.2. Deliver at least one report on the findings.	1 January 2025	31 December 2027
Output.4.4 New understanding and prioritisation of environmental interactions with production in the novel offshore environment. This will include biosecurity (exposure and treatments) with regard to emerging and extant disease and parasite vectors, as well as interactions with wild flora and fauna – how they influence and are influenced by offshore production. New biosecurity protocols will leverage off the new understanding and new data types (accessed via RP4.3) to prioritise risk responses and operational procedures for stocks on production sites and in the immediate vicinity of platforms.			
RP4.4.1	Assess the biosecurity interaction risks of offshore co-production platforms (on and alongside platforms and due to external sources) & the practical implications for disease management. Deliver at least two reports on the activities and findings.	1 January 2020	31 December 2027
RP4.4.2	Report on the use of new data streams in biosecurity monitoring and incident prediction and response (in response to pathogen prioritisation process and hazard analysis).	1 July 2023	31 December 2026
RP4.4.3	Develop guidelines for biosecurity for management (both for operations, planning and management).	1 January 2027	31 December 2028
Output.4.5 Understanding, tools and guidelines pertaining to the benefits, drawbacks and trade-offs associated with colocation of operations on multiple use platforms. Including: social, economic, environmental footprint of platforms and their interaction with surrounding socio-ecological systems; life cycle, economic and systems analysis procedures; reporting; analyses of feasibility, returns on investment and public good comparison of offshore activities vs terrestrial or coastal industries.			
RP4.5.1	Deliver at least one report on the development of life cycle and systems analysis for integration of multiple use platforms.	1 January 2020	30 June 2026
RP4.5.2	Deliver at least one report on the understanding of interactions between classes of infrastructure, food and energy production and the implications for social, economic, environmental footprint.	1 July 2024	31 December 2028
RP4.5.3	Address assessment and report against adaptive management of multiple use offshore platforms, including explicit consideration of trade-offs and synergies. Report to include feedback of new understanding and inclusion in planning stages and on data streams that input into existing national environmental reporting initiatives, national accounts and international initiatives.	1 July 2024	31 December 2028

RP4.5.4	Assess and report on colocation potential for additional sectors (e.g. eco-tourism, biodiversity conservation, accommodation, shipping waypoint, fishing ports, offshore processing) and potential impacts and responses to future stressors on multiple-use platforms (e.g. global change impacts, crowding, and potential new platform uses such as carbon sequestration). Deliver at least two iterative reports on the activities and findings.	1 July 2025	30 June 2029
RP4.5.5	Deliver at least one report to assess the nested net benefit of individual activities within regional/national scale activities mix; including (i) evaluation of benefits to regional and national economy (fully integrated cost-benefit assessment of potential influences on skill levels, training, employment in regional communities, offsets, royalties, social infrastructure requirements and benefits) (ii) comparison of offshore platforms versus traditional terrestrial or coastal sites (ii) consideration of implications for food and energy security in remote locations (accounting for social acceptance and technical/economic feasibility). Utilise results to shape guidelines on the benefits and pitfalls associated with colocation of activities on multiple use platforms.	1 July 2025	30 June 2029

Research Program No. 5 - Sustainable Offshore Developments

Milestones		Start Date	End Date
Output.5.1 Assessment of the fit of current legislative and policy frameworks for blue economy activities. An evaluation of mechanisms in relation to management of risks (in implementation of integrated management and development) and application of policy tools to assess effectiveness in meeting policy objectives.			
RP5.1.1	Undertake and report on the mapping of existing normative, legislative, policy and economic frameworks (including native title issues).	1 January 2020	31 December 2021
RP5.1.2	Report on the assessment of current frameworks and gaps identified, assessing fit and risk management with integrity systems standards and criteria (per RP5.3.1).	1 January 2022	31 December 2023
RP5.1.3	Identify and report on key elements of reform.	1 January 2024	31 December 2026
RP5.1.4	Develop a legislative design model/options report.	1 January 2027	31 December 2028
RP5.1.5	Evaluate model/options (from RP5.1.4), including fit and risk management with integrity systems standards/criteria (per RP5.3.1).	1 January 2028	30 June 2029
Output.5.2 An integrated and planned approach to managing supply chains that includes the identification of potential synergies between marine and offshore energy and aquaculture systems that results in cost effectiveness.			
RP5.2.1	Report on the mapping of marine and offshore energy and aquaculture supply chains.	1 January 2020	31 December 2021
RP5.2.2	Identify and report on challenges and potential for an integrated colocation approach.	1 January 2022	31 December 2023
RP5.2.3	Report on the protocols, strategies and tools for coordination and cooperation across the supply chains.	1 January 2024	31 December 2026
RP5.2.4	Evaluate and report on the supply chain protocols required for proposed co-located activities.	1 January 2027	31 December 2028
RP5.2.5	Develop and report on best practice supply chain protocols for blue economy operations.	1 January 2028	30 June 2029

Output.5.3 Framework for reporting the state of the blue economy. The framework will be developed through the undertaking of mapping and assessing of existing frameworks and providing recommendations for improvement to blue economy integrity systems.			
RP5.3.1	Report on the proposed standards and criteria for integrity and accountability systems, including values identification, interpretation and application as shaping blue economy operations.	1 January 2020	31 December 2022
RP5.3.2	Identify and report on the current data management arrangements for multiple sectors in the blue economy.	1 January 2022	31 December 2023
RP5.3.3	Develop and report on a best practice data management system and security for the integrated management of the blue economy focusing on improved transparency and accessibility.	1 January 2024	31 December 2026
RP5.3.4	Assess and report on model/options standards and criteria certification processes supporting legitimacy and social license to operate.	1 January 2027	31 December 2028
RP5.3.5	Develop guidelines for a blue economy integrity system that considers laws, incentives, standards, institutions, and ethical norms.	1 January 2028	30 June 2029
RP5.3.6	Report on the proposed standards and criteria for integrity and accountability systems, including values identification, interpretation and application as shaping blue economy operations.	1 January 2020	31 December 2022
Output.5.4 Establishment of cost effective and robust economic assessments and environmental management accounting systems for blue economy activities.			
RP5.4.1	Establish and assess an environmental management accounting system to strengthen integrity of the blue economy. Deliver at least one report on the findings.	1 January 2021	31 December 2025
RP5.4.2	Development and modelling of economic options for sustainable blue economy operations. Deliver at least two reports on the activities and findings.	1 January 2022	31 December 2027
RP5.4.3	Identify and report on the risks associated with different parts of the integrated business and commercialisation stages.	1 January 2025	31 December 2025
RP5.4.4	A final report on the identification and development of potential solutions to reduce or manage risks.	1 January 2027	31 December 2028
Output.5.5 Establishment of internal CRC research engagement and extension process. Establishment of research user forums and industry workshop to enhance capacity.			
RP5.5.1	Assess and report on public acceptance of alternative models/ options for sustainable blue economy operations. Deliver at least two reports on the activities and findings.	1 July 2024	30 June 2029
RP5.5.2	Develop and deliver user forums workshops, master classes and training initiatives biennially including continuing professional development and micro-credentialled activities.	1 January 2020	30 June 2029

A.4.

Scoping Study Projects Short Science Summaries

1.20.001 Aquaculture Vessel Requirement Scoping Study

Research Program

RP1 Offshore Engineering & Technology

Introduction

This project conducted a comprehensive review of the existing Australian and international maritime classification standards and Human Factors (HF) guidelines from the design, building, construction, and survey perspective of the offshore aquaculture platforms and vessels.

Key Points

- There is a possibility of regulating offshore aquaculture vessels and platforms through current AMSA National Standard for Commercial Vessels (NSCV) rules and regulations.
- An opportunity exists for BE CRC to jointly develop a new set of regulations specific for offshore aquaculture platforms and vessels with AMSA.
- Human Factor (HF) principles are beneficial for the design of future offshore aquaculture vessels and platforms and they should be applied for the comfort and safety of workers in vessels and platforms.
- It is essential to develop green vessels and platforms to support the development and operation of the aquaculture industry and the offshore renewable energy industry.

The Challenge

Some of the international offshore aquaculture projects took many years to obtain regulatory approvals for their vessels. It is important for Australia also to have a clear regulatory system in hand before proceeding with offshore aquaculture vessel and platform designs, building and acquisition process. Thus, it is timely to explore the current Australian regulatory system with the view to formulate rules and regulations for offshore aquaculture platforms and vessels for design, construction, operation, monitoring and maintenance during their life cycles.

The Opportunity

The scoping study project provided a platform to discuss with the major aquaculture companies, regulatory authorities, and research organisations involved in offshore aquaculture and identify the problems they would face while operating future offshore aquaculture vessels that are larger, armed with advanced equipment and powered by green energy. Also, it identified the possibility of utilising the existing regulatory framework and the opportunity to develop a code of conduct for future offshore aquaculture vessel operations.

Research

Core Of The Study

This project conducted a comprehensive review of the existing Australian and international maritime classification standards and Human Factors guidelines from design, building, and survey perspectives of the offshore aquaculture platforms and vessels. The study identified the gaps to be addressed within the existing regulations and infrastructure requirements for future offshore aquaculture platforms and vessels in Australian waters.

Categories Of Vessels In Operation

The scoping study analysed the regulations required for various types of offshore aquaculture vessels, as shown in Figure 1.

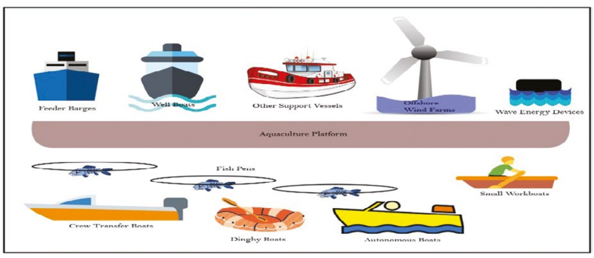

Figure 1. Vessels operating in offshore aquaculture sites.

Major Areas Of Study

The following subjects were discussed: design and construction standards of offshore aquaculture vessels; human factor design guidelines; survey regimes of vessels; emerging trends in vessel designs; and the availability of infrastructure facilities to maintain the vessels. Online interviews were conducted with industry partners, research organisations, and regulatory authorities to identify problems at the ground level and to find avenues for solutions.

Outcomes

The scoping study confirms that the existing NSCV rules and regulations of AMSA for fishing vessel and non-passenger vessel can be adopted for regulating offshore aquaculture vessels and platforms. In addition, guidance documents related to HF (beneficial for the design of future offshore aquaculture vessels and platforms) are presented.

The study also assessed the infrastructure facilities in Tasmania and Victoria for the refit and repair of large aquaculture vessels. It was concluded that it may be essential to develop infrastructure facilities commensurate with the development of offshore aquaculture industry. Further, a list of national and international organisations working in the research area of offshore aquaculture vessels and platforms are presented.

Next Steps

- There is ambiguity in defining the word “offshore” as it identifies differently within the aquaculture community and the NSCV rules. Therefore, it is recommended that a common definition for the word “offshore” be used within the aquaculture industry.
- An opportunity exists for BE CRC to propose a new set of regulations specific for the offshore aquaculture platforms and vessels together with AMSA. Therefore, it is recommended to continue this initiative through future BE CRC general projects.
- The use of specially tailored vessels would be beneficial for offshore aquaculture. Therefore, vessel types suitable for specific operations such as harvesting, fish and crew transportation, and cargo movements should be further investigated.
- A general project can be initiated to investigate and report on the status of hydrogen for use as a fuel for vessel propulsion. It would then investigate the market needs for using hydrogen to power vessel fleets in Australia, in such industries as aquaculture, ferries, and passenger’s vessels. Also, the port infrastructure for fuelling hydrogen vessels would be investigated.

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Project Reports/Publications

Amarawardhana, A., Shearer, C., Jayarathne, N., Jayasinghe, S., Abeysiriwardhane, A., Abdussamie, N., Chin, C., Bjelland, H., Abraham, J., Dove, T., Tomlinson, N., & Corden-McKinley, B. (2020). Aquaculture Vessel Requirement Scoping Study, P.1.20.001 – Final Project Report. Launceston, Australia: Blue Economy Cooperative Research Centre.

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1.20.002 Autonomous Marine Systems at Offshore Aquaculture and Energy Sites

Research Program

RP1 Offshore Engineering & Technology

Introduction

This scoping study finds a clear demand among surveyed industry partners for increased use of AMS in their operations. The breadth of AMS technologies and applications is significant. As such, there is unevenness both in the readiness of platforms to meet industry needs, and in the understanding of partners as to the specific roles that AMS will play in the future.

Key Points

- As aquaculture and renewable energy moves offshore there is a need to find technologies that perform inspection and maintenance tasks.
- A survey of industry partners reveals operational needs that are not currently met in sensing, command and control systems, as well as localisation and navigation.
- The report describes the challenges of bridging the “Valley of Death” in research commercialisation and proposes a focus for BE CRC on mid-stage technology development to accelerate the development of academic research through to scalable solutions.
- The need to focus on specific aspects of offshore autonomous systems means that it will be important to consider building development platforms that can then be translated into solutions.

The Challenge

Making offshore/high energy fish farms and tidal energy systems safe and financially viable means a step-change in the adoption of technologies Autonomous Marine Systems (AMS). AMS have seen rapid development over the past 20 years, with advances in battery, computer, sensing and communication technology enabling vehicles that are capable of multi-role survey and on-the-fly mission adaptation. In spite of these developments, there are currently no solutions on the market that can completely replace human staff at offshore/high energy sites.

The potential uses for AMS in the offshore environment vary widely, including the continuous monitoring of the marine environment, undertaking maintenance tasks, and inspecting key infrastructure. The areas of offshore sites where AMS might be deployed (Figure 1) directly impacts the current readiness of commercially available solutions to operate safely and reliably.

For example, surface craft in open water can rely on satellite navigation and communications with relatively few hazards with which to contend. Conversely robots that operate underwater in or around fish pens must avoid lines and moving nets, all while trying to calculate their position without the benefit of systems such as GPS.

Scientists and engineers are developing autonomous capabilities but matching promising systems with industry need and driving them through to commercial use remains a challenge.

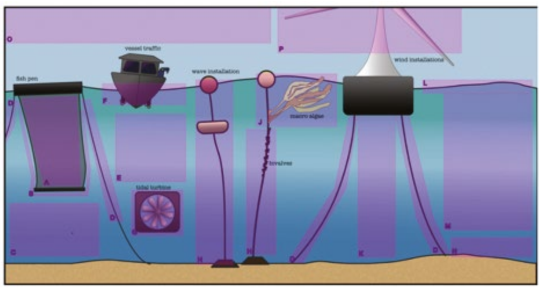

Figure 1. Segmentation of domains of operation for offshore autonomous marine systems.

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The Opportunity

The Blue Economy CRC brings together a diverse group of industry stakeholders and researchers, which presents an opportunity to bridge the gap that exists between industry need and academic research. By meeting with industrial partners and understanding their goals, specific technology gaps can be identified.

Once described, these gaps become a roadmap for development. The gaps themselves require the engagement by researchers across multiple disciplines, from robotics, to control theory and communications, as well as specialists in industry operations, and data analysis. The BE CRC is thus an opportunity to bring these researchers together to collaborate and build and test concepts and prototypes that address targeted problems, with end-user involvement throughout.

Research

Step 1. Ask the audience

The key to identifying relevant technology gaps is to start with the question on what industry needs. A survey was sent to industry partners of the BE CRC with questions that probed the current use of autonomous technology, problems faced in adopting technology, limitations for power and communications at offshore sites, the work done by humans that might be too dangerous or difficult to conduct when operations move offshore and the frequency and urgency of different tasks. The survey responses built a picture of work currently undertaken and the expectations of how it will change in the future.

Step 2. Decompose

The survey responses were laid out and described. From the answers, which came from both aquaculture and renewable energy partners, three specific user cases became clear. Partners need solutions for monitoring the environment around sites, visually inspecting infrastructure and performing maintenance and repair. These three requirements were then described according to their locations, centres of control (Figure 2), precision, sensors etc., by using a Decomposition Tool that asks a series of questions about the requirements.

Step 3. Map

Once the individual components of the problem were described they were mapped to technologies, both commercially available and in development. Knowing the profile of technological readiness across a potential solution helped to identify areas of weakness that need support before a platform can advance to being a viable, fully featured answer to an industry problem.

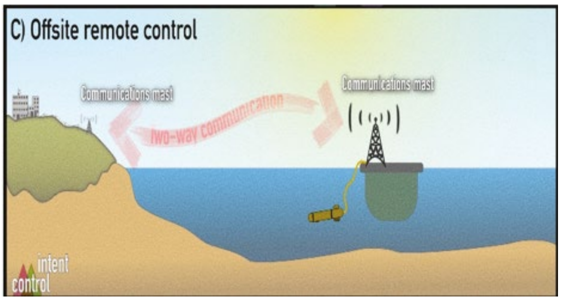

Figure 2. An example of a control scheme that might be employed, where humans stay onshore and communicate directly with offshore robots.

Step 4. Prioritise

Understanding the readiness of potential solution allowed for the categorisation of the research needed to make it mature. Some elements exist at a low level of readiness, as primary research within academic institutions. These may take a long time to mature and carry the inherent risks of all early-stage development; they may not work, and costs are hard to predict. Elements at a high level of readiness may need a push to commercialisation but in general they have undergone significant development and now need final reliability testing and scaling. These are nearly ready for deployment and need manufacturer attention, more than academic. The prioritisation step classifies the mapped technologies by both their readiness and relevance. Innovations that fall in the middle of the readiness scale, and those that are highly sought after by industry partners are those that are most highly recommended by the report.

Outcomes

Industry partners reported a significant need for innovation in remote and autonomous systems to make their offshore operations safe and efficient. Reduction of risk to people and business was identified as a key concern. There is a mix of solutions needed to achieve industry goals, both remotely control and autonomous.

The mapping of detailed requirements highlighted gaps that exist in the sensing of the marine environment, the safe and autonomous control of vehicles that operate around offshore sites, and the technologies that underpin precise navigation underwater. In all cases there are exciting opportunities that fall within the readiness ranges most likely to see a benefit from BE CRC support.

Next Steps

The report produced as part of this project recommends that the technology gaps in meeting industry requirements are relevant for research support by the BE CRC. It also recommends that intermediate platforms be considered, where technologies can be trialled and shown to be reliable, as steppingstones to prototype commercial systems. The tools developed for interpreting the responses to the industry survey (Decomposition, Mapping & Prioritisation) may be useful in interpreting industry needs as they emerge in the future, and can be used for assessing the relevance of proposed solution and likely impact of Blue Economy CRC support.

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Project Reports/Publications

Guihen, D. et al. (2020). Autonomous Marine Systems at Offshore Aquaculture and Energy Sites, 1.20.002 – Final Project Report. Launceston, Australia: Blue Economy Cooperative Research Centre.

1.20.003 Biofouling Challenges and Possible Solutions

Research Program

RP1 Offshore Engineering & Technology

Introduction

This scoping study developed an R&D roadmap that includes near-, medium-, and long-term projects to investigate and contribute to solutions of biofouling challenges in the BE CRC.

Key Points

- Biofouling poses serious challenges in aquaculture, sensing and monitoring, and marine renewable energy sectors of the Blue Economy.
- The increased labour requirements in managing biofouling in offshore areas will increase financial burdens and production inefficiencies across these major industries.
- Developing a targeted and interdisciplinary R&D roadmap is essential to tackle biofouling.

The Challenge

Biofouling is the growth of unwanted organisms on the surfaces of man-made structures immersed in the sea. It poses several challenges in the aquaculture, sensing and monitoring, and marine renewable energy sectors (Figure 1).

Biofouling is considered one of the key challenges of the Blue Economy in transitioning to a sustainable, efficient, and economic offshore seafood and renewable energy production system. The increased labour requirements in managing biofouling in offshore areas will increase financial burdens and production inefficiencies across these major industries. The financial burdens include both the direct costs, such as loss of productivity in aquaculture and increased energy consumption for the marine renewable industry, damage to sensors, as well as the costs associated with prevention and biofouling mitigation. In addition, the externalities related to biofouling such as fish health impacts are substantial yet largely unassessed.

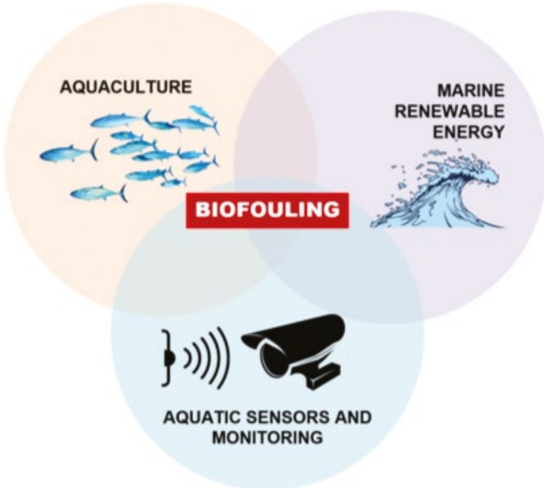

Figure 1. Biofouling in the Blue Economy.

The Opportunity

This scoping study (1.20.003) developed an R&D roadmap that identifies near-, medium-, and long-term opportunities, field studies, and demonstration trials to tackle biofouling in the Blue Economy. Some activities include the evaluation of existing and emerging antifouling technologies from various literature (i.e. grey literature, patent search, and scientific literature) and industry interviews and workshops. Active engagement with research and industry partners is an essential part of the project to understand the operations, management practices, and constraints within each sector and to develop R&D solutions that can be achieved within the duration of the CRC.

The R&D roadmap will be highly interdisciplinary, covering structural, chemical and mechanical engineering, marine biology, and materials science. This is essential to effectively integrate combinations of antifouling solutions in the Blue Economy. The R&D roadmap will include opportunities to adopt more sustainable and environmentally safe antifouling practices to protect the marine environment.

Research

BIOFOULING IN THE BLUE ECONOMY

Biofouling is already a major problem in many sectors in near-shore environments and it is foreseen to pose more technical challenges and economic burdens when the operations are moved offshore.

Biofouling colonisation brings serious problems to aquaculture farms worldwide. The extra weight caused by biofouling growth causes structural damage to farm infrastructures. The growth on nets closes their aperture leading to reduced dissolved oxygen in the fish pens. Biofouling organisms also serve as vectors for pathogens and other diseases thus creating a non-ideal environment for fish growth.

Aggressive biofouling prevents long-term deployment of monitoring equipment and water quality sensors. The accumulation of biofouling decreases data accuracy as the organisms disturb the biological and chemical properties of the studied site. This increases maintenance costs associated with sensor replacement, cleaning, and sensor re-calibration. Biofouling also affects marine renewable energy structures as it can impair the system performance and increase the risk of structural damage.

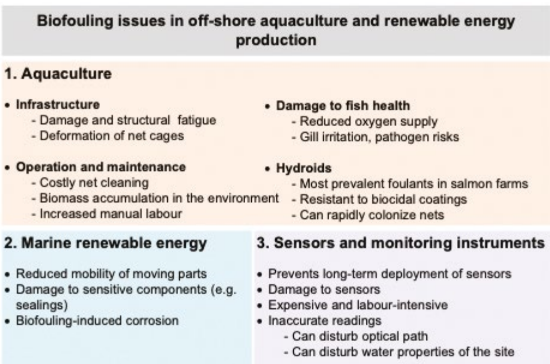

Figure 2. Summary of biofouling issues in key sectors of Blue Economy.

EMERGING BIOFOULING TECHNOLOGIES

The majority of biofouling management strategies are aimed at:

(i) preventing the settlement of organisms;

(ii) mitigating the growth of the settled organisms;

(iii) removing biofouling growth.

Ideally, prevention is the most effective strategy against biofouling, albeit the most challenging approach given the complexity of biofouling patterns and harsh conditions in the sea.

Prevention is commonly done in the form of coatings. Coatings are highly desired as a long-term surface protection against biofouling.

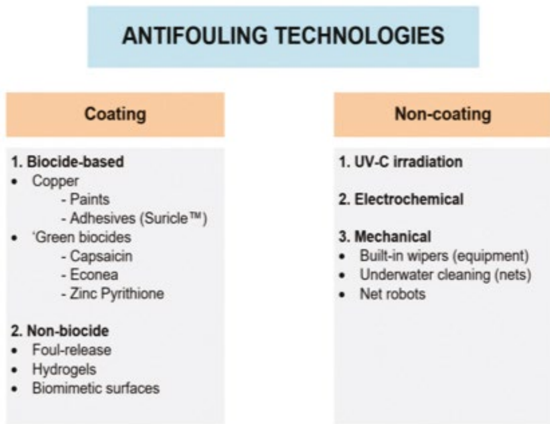

Figure 3. Emerging antifouling technologies from scientific and grey literature.

Effective coatings allow for passive antifouling protection that allows for minimal human intervention for cleaning and maintenance. Coatings however suffer from several issues ranging from short service life, environmental safety, and overall poor efficacy.

Non-coating technologies are mostly mechanical. These strategies are more practical to implement and relatively have shorter R&D timeframe in comparison to coatings. They are generally 'environmentally benign' as they do not release chemicals to the ocean hence being the preferred option in aquaculture operations.

Outcomes

Aquaculture

- It is very challenging to adopt coatings in Australian aquaculture, especially on nets due to stringent requirements on fish production safety and environmental impact.
- Mechanical net cleaning is an essential biofouling management practice in fish farms.
- Net cleaning should be considered in designing new fish cages.

Sensors and monitoring instruments

- Coatings can be well utilised in this sector given the low surface area of the instruments which poses a relatively lower risk to the surrounding marine environment.
- Continuous coating R&D is important to meet the growing sophistication of sensor technologies (i.e. 100% optical clarity, extended service life, more robust mechanical properties).
- Design integration is important.

Marine renewable energy

- Coatings can decrease maintenance requirements and prolong cleaning intervals.
- Given the relatively short service life of coatings (<5 yrs), maintenance is important in the latter stages, when the coatings are no longer functional.
- Understanding the site-specific seasonal and temporal patterns and life-cycle characteristics of important fouling species could help optimise deployment and inform maintenance planning.

Next Steps

An ideal antifouling technology must possess a broad-spectrum effect against many fouling species, exhibit superior efficacy even in static conditions, cost-effectiveness, and ease of integration in existing infrastructure. The technology must meet the requirements imposed by Australian regulatory boards especially when implementing solutions with active chemical components. We found that it is very challenging, and in reality nearly impossible, to develop one "silver bullet" antifouling technology that meets these criteria of all stakeholders of the Blue Economy. Hence, a tailored approach must be taken to manage this problem.

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Project Reports/Publications

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1.20.004 Multi-Purpose Offshore/High Energy Platforms: Concepts and Applications

Research Program

RP1 Offshore Engineering & Technology

Introduction

This project focused on identifying potential opportunities and challenges between the energy and aquaculture sectors through reporting on novel multi-purpose offshore platform (MPOP) concepts and pilot projects recently developed worldwide to address the challenges of offshore seafood and energy production, and enable leveraging the benefits of co-location, vertical integration, infrastructure, and shared services.

This project also sought to shed light on the limitations structural reliability analysis methods employed for assessing the structural safety of novel MPOPs. It addressed the current status and future directions for structural reliability analysis of a novel MPOP considering Australia's unique environment.

Key Points

- Current marine renewable energy and aquaculture practices would require large structures to be installed offshore.
- Included in these prospects for blue economy growth is the co-location and/or integration of both seafood and renewable energy production systems.
- MPOPs, whether they are integrated or co-located, can be a viable option for future developments in Australia. However, they must be cost-effective, reliable and have a minimal impact on the ecosystem.
- Currently, there is a strong interest in floating offshore wind development, and hence it opens opportunities to future MPOP projects for both offshore renewable energy and aquaculture industries. However, the effects of floating offshore wind turbines, in both normal and idle modes, on aquaculture operations are still unknown.
- The offshore oil and gas industry provide lots of lessons to learn, data to use, and design engineering standards and tools to adapt for designing reliable MPOPs.

The Challenge

The realisation of MPOPs requires different actors to co-operate which could slow down the development and making implementation difficult. The different technologies and sectors are of differing maturity level, which could be a barrier for development. Likewise, the governance issues that arises when combining operations from different industrial sectors adds to uncertainty and could potentially slow down implementation.

The Opportunity

Multi-purpose offshore platforms can decrease the impact on the environment compared to several single-use platforms by reducing the footprint of the operations and thereby optimising maritime spatial planning and by sharing infrastructure, resources and services which could offer significant benefits in terms of economic performance.

Research

RESEARCH OBJECTIVES

This scoping study project focused on identifying potential opportunities and challenges between the energy and aquaculture sectors, by reporting on novel MPOP concepts and pilot projects recently developed worldwide. All such initiatives seek to address the challenges of offshore seafood and energy production, and enable leveraging the benefits of co-location, vertical integration, infrastructure, and shared services. This study also aimed at shedding light on the limitations of structural reliability analysis methods employed for assessing the structural safety of novel MPOPs. It discussed the current status and future directions for structural reliability analysis of a novel MPOP, considering Australia's unique environment.

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OUR APPROACH

The project multidisciplinary research team specialised in offshore engineering, risk and reliability and marine biology conducted a systematic literature review of the state-of-the-art challenges and opportunities of offshore aquaculture farms and renewable energy systems to assess their feasibility in Australia as a case study.

A comprehensive review of the past and existing pilot projects of multi-use concepts was conducted to identify technological research gaps in terms of integrated/co-located marine renewable energy and aquaculture farming, and survey perspective of such offshore aquaculture platforms and their associate facilities and support systems, critical components and their potential failure modes.

MULTI-USE CONCEPTS

Multi-purpose offshore platforms can be defined as compatible applications combining multiple functions within the same infrastructure, share the same space, or occur at the same time. Multi-purpose offshore platforms can be realised via two approaches, namely co-location, and integration. Co-location mainly involves moving two or more platforms close together without physically connecting them to share benefits such as logistics, sea space, etc. Integration, on the other hand, is defined as hybrid use of a single structure for different purposes, e.g., aquaculture, wind, and wave.

REVIEW OF MULTI-USE PILOT PROJECTS

Multi-use concepts with integrated energy and aquaculture have been studied by several EU projects such as TROPOS, MERMAID, H2Ocean, Aqua Wind Power and OOMU projects. The available experience and knowledge gained through these projects can be of significant help for developing MPOP concepts in Australia.

RISK AND RELIABILITY

An integrated system such as a MPOP would operate in an extremely uncertain offshore or nearshore environment. The uncertainty of the influencing parameters such as wave and wind models must be considered in deriving the stress distribution caused by the environmental forces over the structural components. As an example, Figure 1 shows some of the influencing random parameters in reliability assessment of offshore wind turbines and aquaculture structures.

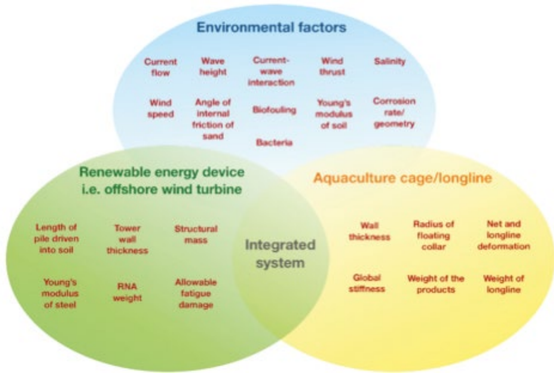

Figure 1. Examples of random parameters affecting reliability of an integrated floating aqua-wind system.

Outcomes

Innovative integration methods on a commercial basis for marine renewable and aquaculture sectors are still in their infancy, as there are many unknown aspects and limitations regarding the operational and technical issues which may threaten human safety, the environment, and assets.

Even though site selections of a multi-use ocean space have been extensively studied in the literature, only a few studies have focused on different frameworks for integrating the structural limitations of specific design concepts into the geographic information system (GIS)-based site selection tools.

It should also be considered that the transition of aquaculture systems from sheltered to more exposed culture environments is in a relatively nascent stage of development – much is still to be learned about how animal welfare and system suitability are affected by these increasingly challenging environments, and novel approaches are continuously being developed e.g., a submersible aquaculture system.

Accurate reliability assessment of MPOPs would not be possible without dealing with challenges regarding flexibility of structural components, unique structural features of renewable energy and aquaculture systems, high level of non-linearity, multi-scale features, etc. that make load analysis of the intended system difficult.

Next Steps

Failure modes specific to the novel design of MPOPs must be identified, formulated, and studied considering the dependencies among the corresponding failure mechanisms. Uncertainties which exist within the models, environmental and design parameters, deterioration processes, and geometries must be quantified and incorporated into the reliability assessment accurately.

By incorporating the reliability analysis results into a decision-making framework, asset managers would be provided with a powerful, accurate and easy-to-interpret tool to decide on the maintenance planning of their assets in both the short and the long-term.

The current design standards being used for the design of marine structures should be revised to include a system-based reliability approach based on the specific requirements of aquaculture and offshore renewable energy industries. The revised standards would be adapted from the conventional offshore oil and gas industry standards in terms of construction materials, structural features, failure modes, health monitoring requirements and reliability targets of the MPOPs.

Finally, it is recommended to conduct a workshop for the selection of the best concept of potential MPOPs identified in this project for further R&D projects considering site-specific conditions. Prospective projects by the CRC will involve several stakeholders across various disciplines and perspectives, each with unique sets of criteria for feasibilities of future projects.

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Project Reports/Publications

ARYAI, V., ABBASSI, R., ABDUSSAMIE, N., SALEHI, F., GARANIYA, V., ASADNIA, M., BAKSH, A.-A., PENESIS, I., KARAMPOUR, H., DRAPER, S., MAGEE, A., KENG, A. K., SHEARER, C., SIVANDRAN, S., YEW, L. K., COOK, D., UNDERWOOD, M., MARTINI, A., HEASMAN, K., ABRAHAMS, J. & WANG, C.-M. 2021. Reliability of multi-purpose offshore-facilities: Present status and future direction in Australia. Process Safety and Environmental Protection, 148, 437-461.

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1.20.005 Review of Fish Pen Designs and Mooring Systems

Research Program

RP1 Offshore Engineering & Technology

Introduction

This study reviewed the literature for offshore/ high energy fish pen designs. The study identified operating envelopes, failure modes and knowledge gaps, and present recommendations for future studies. The study also reviewed the performance of existing inshore fish pens, assess their suitability for offshore/high energy application, and identify opportunities for improvement in their current environment. The study considered failure modes, maintenance requirements, environmental compatibility, and end-of-life strategies.

Key Points

- A definition of offshore fish farming is given.
- Challenges for offshore fish farming are identified.
- Fish pen designs are reviewed, categorized and their advantages and disadvantages discussed.
- Types of mooring system and anchor foundation for fish pens are reviewed.
- Fish pen designs and future of offshore fish farming are discussed.
- Knowledge gaps and future research topics are identified.

Figure 1. Selected offshore fish pens for modifications and fusion to produce suitable offshore fish pen designs for BE CRC.

The Challenge

The challenge is to identify offshore fish pen designs for modifications and fusion to suit the BE CRC partners' energetic sites. So far, only a few offshore fish pens have been constructed (such as Ocean Farm 1, Shenlan 1 and Havfarm 1) and they are still in the testing stage.

This nascent stage of offshore fish farms poses challenges in establishing the robustness and durability of the fish pen designs over their lifespan, during which they would be exposed to many instances of severe weather conditions. Another challenge is the lack of guides and design standards for offshore aquaculture systems and mooring systems in Australia and New Zealand. This means that BE CRC designers have to develop guidelines in tandem with the research and development of offshore fish pens.

The Opportunity

As offshore fish farming is still in its infancy, there are great opportunities to develop novel offshore fish pens with their mooring systems. Such offshore fish farms with spacious and pristine water allow unprecedented fish production levels to meet the ever-increasing demand for high quality fish products. A game changing collocation/integration of fish farms and offshore renewable energy production and storage plants will provide synergetic benefits to both aquaculture and offshore energy industries. Some of these benefits include better utilization of sea space, reduced service and maintenance cost by combined labour and transport, integrated operations and process engineering synergies, integrated disaster management, joint monitoring and control, combined product lifecycle management and shared platforms and mooring systems.

Research

DEFINITION OF OFFSHORE FOR FISH FARMING

For a common understanding on the use of the word "offshore" among members of BE CRC, we define offshore for fish farming as characterized by (1) an unsheltered site which is at least 3km seaward of the shoreline but within the EEZ, (2) a water depth greater than 50m, (3) current speeds between 0.1m/s to 1.5m/s and (4) significant wave heights exceeding 3m.

OFFSHORE FISH FARM DESIGN CHALLENGES

There are seven major environmental challenges (water depth, current speed, wave action, seabed condition, adverse weather and storms, biofouling, pathogens and predators) that affect two functional criteria (conducive environment for fish welfare and infrastructure & economic sustainability for operations including accessibility) for offshore fish farms.

TYPES OF FISH PEN DESIGNS

By adopting the categorization of pen designs by the nature of the structures for supporting the holding net and the pen containment methods, fish pens may be divided into the open-net pen system and the closed containment tank system.

The open-net pen system may be further categorized into six types (floating flexible pens, floating rigid pens, semi-submersible flexible pens, semi-submersible rigid pens, submerged pens, bottom-resting pens) and the closed containment tank into two types (rigid closed containment systems and flexible bag containment systems.

Examples of each type of fish pen design and key observations are given in the Report.

MOORING SYSTEMS FOR FISH PENS

A mooring system includes several components such as mooring lines, floaters, buoys, shackles, chains, ropes, wires, windlass, fairlead, anchors, sinkers and anchor chain. Mooring lines must withstand and transmit forces. Floaters, net and mooring components of a fish pen system should be designed together and mechanically linked. Therefore, pens and mooring design shall be "site specific" to survive major storms.

Two main types of mooring system are used for fish pens: multi-point mooring (i.e., spread moorings) and single-point mooring (i.e. catenary anchor leg mooring).

PEN DESIGNS AND THE FUTURE OF OFFSHORE FISH FARMING

Floating flexible pens have not been deployed in highly exposed sites that are expected to cause a large deformation of the floater, damage of stanchion and connectors, and contraction of net space under severe wave actions.

Floating rigid pens may be deployed at some exposed offshore sites where the occurrence of extreme storms is rare. Semi-submersible rigid pens have become the most popular type due to their submergibility and robust structure against harsh environmental conditions.

Semi-submersible flexible pens and submerged pens may be deployed at more exposed sites. In general, the volumes of these types of pens are relatively small. So far, it is not known if there are any semi-submersible flexible pen and submerged pen being deployed in offshore sites.

Floating closed containment tanks face sloshing problems and hence they have not been used offshore.

The feasibility of offshore fish farming may be achieved through adoption of new development of multifunctional, modularity for ease of construction and autonomous infrastructure that has been validated in oil and offshore industry. By co-locating offshore renewable energy systems and floating platforms (that can accommodate feed silos, equipment, harvesting cranes and nets, waste treatment plant, desalination plant) with offshore fish farms, it is possible to leverage the benefits of colocation, vertical integration and shared services and to reduce operating time and cost. Also, the use of offshore renewable energy helps to decarbonize the fish farming industry.

SHORTLISTED OFFSHORE FISH PEN DESIGNS

Shortlisted offshore fish pen designs for modification and fusion are the Ocean Farm 1, COSPAR, Havfarm 1, Zhenyu Aquaculture Platform and the GIEC's Penghu Open Sea Aquaculture Platform. An example of such a modified Havfarm 1 is the SeaFisher, which is described in the Report.

KNOWLEDGE GAPS AND FUTURE RESEARCH TOPICS

- Making aquaculture systems storm proof (more robust fish pens and mooring systems, mobile or submerged, use of floating breakwater systems)
- Enabling feasibility of offshore fish farming (colocation with renewable energy production facility, modification of nearshore aquaculture systems for energetic sites)
- Developing analysis tools for offshore fish pens and mooring systems (analysis of nets with biofouling, aero-hydrodynamic analysis of integrated fish pen and wind turbines)
- Developing closed containment systems for fish farming in exposed sites (minimize sloshing).

Outcomes

The scoping study has revealed the challenges in offshore fish farming, different types of fish pen designs and mooring systems for nearshore and offshore sites, the lack of Australian guides and design standards for offshore fish pen designs, the kinds of analysis performed and software packages used in pen designs, and knowledge gaps. Several existing offshore fish pen designs have been shortlisted for modification and fusion with the view to produce suitable offshore fishpen designs tailored for application in the identified offshore sites in Australia and New Zealand. COSPAR and SeaFisher are two offshore fish pen designs that have been proposed by members of the scoping study team for further research.

Next Steps

Research and development on novel offshore fish pens will be conducted in a proposed general project; by modifying and fusing shortlisted existing and proposed offshore fish pen designs for energetic sites, as identified by BE CRC fish farm operators.

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Project Reports/Publications

Wang, C.M. et al. (2020). *Review of Fish Pen Designs and Mooring System, P.1.20.005 – Final Project Report.* Launceston, Tasmania, Australia: Blue Economy Cooperative Research Centre.

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2.20.001 Seaweed Aquaculture Scoping Study

Research Program

RP2 Seafood & Marine Products

Introduction

The Australian seaweed industry is in its infancy, but a recent Seaweed Industry Blueprint has identified a strategy that could result in an AU$1.5 billion GVP industry supporting 9000 jobs by 2040. Offshore aquaculture is increasing globally and can be a significant part of this strategy. This scoping study aimed to determine the opportunities and priorities for developing offshore seaweed aquaculture within the Blue Economy CRC. There is currently a high level of interest from Australian funding sources, State Government, Universities and research organisations to support research and development. This suggests opportunity for unique BE CRC as well as collaborative projects.

Specifically we: i) engaged with stakeholders to determine priority seaweed species of commercial interest; ii) identified knowledge gaps for the cultivation of these priority seaweed in offshore environments and; iii) assessed the effects of seaweeds on hydrodynamics and the implications of these effects for offshore aquaculture. We ran two workshops and completed two literature reviews to achieve these aims.

Stakeholders identified three main seaweed groups of commercial interest: Asparagopsis, kelps (several species), and Durvillaea (bull kelp). These groups reflect two broad strategies of seaweed aquaculture: i) smaller seaweeds of high value per-unit biomass (e.g. Asparagopsis) and ii) larger species of lower value per-unit-biomass (e.g. kelps, bull kelp). For all these groups there is currently insufficient production to meet market demand.

Key Points

- This project has identified three seaweed groups of commercial interest for offshore seaweed aquaculture within the Blue Economy CRC – Asparagopsis, kelps, and Durvillaea (bull kelp).
- For all these seaweed groups there is currently insufficient production to meet market demand.
- Key knowledge gaps exist for these groups, and we recommend a research program of two stages to develop offshore seaweed aquaculture.
- Phase 1 (2021-2025):
    - Develop knowledge and capability in basic biology, hatchery and grow-out methods for offshore cultivation (designed for offshore cultivation but developed using inshore sites), and
    - Understand how these seaweeds attenuate hydrodynamic forces around offshore structures.
- Phase 2 (2026-2030):
    - Transfer knowledge to offshore arrays with a view to optimising grow-out methods, spatial array designs, infrastructure requirements and hydrodynamic attenuation

The Challenge

The Australian seaweed industry is in its infancy, but a recent Seaweed Industry Blueprint has identified a large opportunity for a thriving seaweed industry in Australia. Offshore aquaculture can be a significant part of this strategy but there are large knowledge gaps for seaweed aquaculture in Australia – especially offshore aquaculture. Moreover, the technological challenges in cultivating seaweed offshore in high-energy wave-exposed environments including the strength, deployment, and functioning of infrastructure as well as the viability of the seaweed themselves are not insignificant.

Critically, those challenges must be overcome in a cost-effective manner to support the commercial viability of offshore operations. This scoping study aimed to determine the opportunities and priorities for developing offshore seaweed aquaculture within the Blue Economy CRC.

The Opportunity

The Australian Seaweed Industry Blueprint (Kelly 2020) identifies the potential for an industry of AU$100 million GVP and 1200 direct jobs by 2025, and provides a strategy towards achieving an AU$1.5 billion GVP industry supporting 9000 jobs by 2040. There is currently insufficient production of seaweed in Australia to meet demand for the diverse markets that exist for seaweed products (e.g. human food, animal feed, fertiliser, nutraceuticals, pharmaceuticals, novel polymers). Seaweed aquaculture is well-established worldwide and there is a AU$10 billion industry globally with ~ 97% of this coming from aquaculture, highlighting the large opportunity in Australia. Seaweed also provide significant environmental benefits (nutrient mitigation, carbon sequestration, habitat provision).

Research

PROJECT AIMS

This project aimed to identify and prioritise opportunities for seaweed aquaculture projects within the Blue Economy CRC. We sought to achieve that by i) engaging with stakeholders via two workshops to determine the needs, opportunities, and potential for seaweed aquaculture, including the identification of priority species of interest); ii) reviewing current cultivation knowledge and how that might align with offshore potential for priority seaweed species and, iii) considering the effects of seaweeds on hydrodynamics and the implications for offshore aquaculture.

These workshops and reviews generated several key questions and/or projects of immediate importance across 4 broad themes. Key linkages with BE CRC Research Programs are noted, whilst more general projects and those of specific relevance cultivation knowledge are presented elsewhere.

Theme 1: Hydrodynamic fundamentals

1. Fundamental hydrodynamics of the priority seaweed species, and of potential farm arrays proposed for offshore cultivation (RP1).

   Species-specific applications, such as *Macrocystis* for current attenuation, and *Durvillaea* for waves.
2. Seaweed biomechanics (ability of the seaweeds to withstand the hydrodynamic forces) (RP1, RP2)

   e.g. 'fatigue impacts' and repetitive stresses
3. Species-level risk-opportunity matrix (RP2)
4. This theme will generate critical data and parameters for work under the following themes.

Theme 2: Improved scenario-testing and capacity to conduct trials

1. Modelling/simulations:
   a. Flow redirection/channelling (RP1)
      E.g. for energy production (RP3)
   b. Testing different aquaculture growing configurations (RP1) and seaweed densities (RP2)
   c. Testing different site and environmental conditions (e.g. depths, storms, etc) (RP1)
   d. Biogeochemical (RP4)
2. Tank/flume experiments
   a. Testing in wave/flow tanks and model test basins, especially any with variable and asynchronous wind and current conditions (RP1)
3. Small-scale field measurements (RP1, RP2, RP4)
   a. To calibrate and validate modelling and tank experiments
   b. Take advantage of existing seaweed farms and offshore infrastructure (i.e. what is currently available that we can learn from?)

Theme 3: Trade-offs and values

1. Understanding the economics:
   a. Valuation of specific hydrodynamic applications of seaweed

      E.g. What is the value of increasing 'operational windows' for other offshore aquaculture (RP2)?
   b. Improved benefit-cost analyses and technoeconomic analysis by incorporation of hydrodynamic knowledge (RP5)
2. Examine infrastructure benefits of attenuation by seaweed (RP1)
3. Are hydrodynamics/ renewables the key co-benefits? (RP1, RP3, RP5)

Theme 4: Infrastructure

1. Cultivation infrastructure will be driven largely by the species' biology (RP1, RP2)
   a. What will/won't the particular seaweed grow on?
   b. Especially relevant for Durvillaea (bull kelp), where cultivation is poorly understood and specialised methods may be required
2. Associated biodiversity of seaweed arrays
   a. Positives (e.g. provision of habitat) (RP4)
   b. Negatives (e.g. biofouling) (RP1)
3. Engineering solutions – align with existing engineering options for wave breaks/ renewables (RP1)
4. Cost effective substrates
5. Recyclability and repurposing (RP1, RP5)

Outcomes

SEAWEED OF COMMERCIAL INTEREST

Stakeholders identified three main seaweed groups of commercial interest: Asparagopsis, kelps (several species), and Durvillaea (bull kelp). Key knowledge gaps for these groups, and thus potential projects that would allow for offshore seaweed production, include:

- Development of hatchery and grow-out methods for Asparagopsis;
- Optimisation of grow-out and harvest methods (including infrastructure requirements) for offshore cultivation of kelps; and
- Basic biological information on reproduction and growth, development of hatchery methods and grow-out requirements (including infrastructure) for offshore cultivation of Durvillaea.

EFFECTS OF SEAWEED ON HYDRODYNAMICS

The cultivation of large seaweed such as kelps and bull kelp will likely affect hydrodynamics around offshore structures, but will depend on the density and morphology of the species being grown and the hydrodynamic conditions they are grown in. Key knowledge gaps for the effects of seaweed on hydrodynamics and potential projects were identified in four broad areas:

- A greater understanding of the effects of priority seaweed on hydrodynamics;
- Scenario-testing using modelling, tank/flume tests and small-scale field measurements and experiments;
- A greater understanding of the trade-offs and value-add (including economics) of attenuation of hydrodynamic forces; and
- Infrastructure needs and possible alignment with existing engineering options for wave breaks/renewables.

Next Steps

This scoping study highlights a strong opportunity for offshore seaweed aquaculture within the Blue Economy CRC to contribute to the development of the Australian seaweed industry. We propose a research program of two phases, where Phase 1 (2021-2025) focuses on developing knowledge and capability in the cultivation of priority seaweed species and effects on hydrodynamics, and Phase 2 (2026-2030) focuses on transferring knowledge gained from Phase 1 to offshore arrays.

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Project Reports/Publications

Wright, J. et al. (2020). Seaweed Aquaculture Scoping Study, 2.20.001 – Final Project Report. Blue Economy Cooperative Research Centre.

BLUE ECONOMY COOPERATIVE RESEARCH CENTRE

Australian Government
Department of Industry, Science, Energy and Resources

AusIndustry
Cooperative Research Centres Program

2.20.002 Key Challenges for Offshore / High Energy Salmon Aquaculture Production

Research Program

RP2 Seafood & Marine Products

Introduction

Atlantic salmon is the second most economically valuable aquaculture species and has the ninth highest production globally (FAO 2020). Norway dominates the sector when production, innovation and research investment are considered together. Of the other main producing countries, Canada and Scotland also have considerable research capability. Chile has production to match Norway, and China is emerging as a contributor around offshore/high energy technology development.

In Australia, the Tasmanian Atlantic salmon aquaculture industry dominates seafood production and accounts for over half of aquaculture and a quarter of all seafood production (Mobsby 2018). Tassal, Huon Aquaculture and Petuna are all vertically integrated and grow salmon from egg to market. Chinook salmon aquaculture is dominated by New Zealand where New Zealand King Salmon (NZKS) is the largest producer. It is marketed as King Salmon, and whilst the global industry is currently relatively small New Zealand is making considerable investments to grow the industry.

These four companies are partners in the BE CRC and have members of this Scoping Project's Research Team. The BE CRC has considerable capability for applied salmon research and four research organisations are represented on the Research Team (RT). This Scoping Project aims to meet a critical need to understand current knowledge and optimise our strategy for meeting unmet end-user needs.

Key Points

The unique nature of Tasmanian Atlantic salmon and New Zealand King salmon is recognised. Research should use local stocks whilst testing and translating knowledge generated elsewhere to make best use of BE CRC resources.

There are knowledge gaps that BE CRC research should address immediately through:

a. Incorporation of a Production Assessment Tool to capture key production biology data. This will support benchmarking and be used to make comparisons and predictions that support decision making for more effective R&D and changes to production SOPs.
b. Projects aimed to improve growth and production efficiency at current offshore / high energy sites with the aim to improve current production SOPS. Research should support decision making in production management and consider smolt quality, feed formulation, feeding management, impact of abiotic factors and product quality at harvest.
c. Developing an advanced approach to monitoring health and welfare that adopts available and emerging technology to be remote, autonomous and real-time and is tuned to local issues.

Research Program 2 takes the lead to develop linkages and incorporate facilities by:

a. Building research teams to address the immediate needs of the salmon industry and opportunities presented by the transition to offshore / high energy sites.
b. Ensuring BE CRC salmon research projects collaborate with ongoing or future large research projects in Australia and New Zealand to access families from selective breeding programs.
c. Identifying opportunities to access facilities that have the potential to generate new knowledge and conduct research that improves production at current offshore / high energy sites and informs the use of future sites.

The BE CRC includes salmon as part of the strategy for long-term development of integrated aquaculture systems for deployment at offshore / high energy sites. Temperate integrated systems would include salmon production at the core, recycle salmon waste streams and take advantage of renewable energy and oxygen by-products to increase the efficiency.

RP2 maintains ongoing dialogue with salmon stakeholders and that is encapsulated by the BE CRC structures and processes. In particular:

a. The mechanisms to ensure effective cross-linkages between Research Programs are continued.
b. The BE CRC through RP2 leads in the formation and management of a salmon production biology network that includes salmon aquaculture industry, aquaculture service industry, research organisations and organisations involved in education and training.

The Challenge

The specific challenge is to develop unique BE CRC research projects that address salmon industry production biology needs in a fast-moving space where priorities change, only some research is pre-competitive, solutions offer competitive advantage and there are major international initiatives that may or may not provide solutions for our local industry.

Long-term challenges include resolving different stakeholders' priorities to achieve integration of multiple aquaculture species and of aquaculture with renewable energy systems.

The Opportunity

The immediate opportunity is for the BE CRC to conduct focused research that provides timely solutions to production biology issues identified from current operations. Setting up a Production Assessment Tool is an opportunity to benchmark progress and inform decision making around research priorities. Combining the significant expertise and resources across BE CRC partners presents a considerable opportunity to make progress.

On a longer timeframe the advanced position of salmon aquaculture can inform the development of offshore aquaculture for other species as well as the integration of multiple species.

Research

The Horizon Model was used to develop the research questions, with different timeframes and levels of challenge.

Five major themes were thoroughly explored through discussion in the expert Project Team and through workshops and 59 research questions were identified. These were distilled into five major projects:

Monitor and Mitigate: Develop technologies and procedures for real-time and remote monitoring of fish health and welfare in offshore / high energy sites and incorporating assessment of external environmental risks.
Producing smolt for offshore: develop a future smolt strategy to integrate onshore, inshore and offshore sites to ensure cost effective harvest production of optimal quality fish year-round.
Experimental platform: Adopt or develop models to support a Production Assessment Tool, a Species Selection Tool and integration and translation of data across different experimental facilities.
Breeding fish for offshore: assess GxE of pedigreed fish in offshore / high energy sites to re-evaluate the overall breeding goal.
Maintain and enhance growth performance: incorporate feeds and feeding technology; smolt quality; early maturation; critical abiotic factors (temperature, DO, current velocity); critical biotic factors (feed-days, growth depensation, submergence); feed formulation and nutrient requirements.

Outcomes

Clear view about the range and extent of research and development that could be achieved by the BE CRC by identifying 59 research questions, 9 PhD topics and 5 major project themes. Recognition of critical areas to address immediately in order to set the foundations for effective R&D in production biology.

Next Steps

Initiate projects identified as requiring immediate attention to address knowledge gaps as listed above in 1.7.4.

BLUE ECONOMY COOPERATIVE RESEARCH CENTRE

Australian Government
Department of Industry, Science, Energy and Resources

AusIndustry
Cooperative Research Centres Program

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Project Reports/Publications

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3.20.001 Hydrogen Storage and Distribution

Research Program

RP3 Offshore Renewable Energy Systems

Key Points

- The report examined 21 technologies for storing and/or distributing hydrogen, including pure gaseous hydrogen (GH2) and liquid hydrogen (LH2), chemical hydrogen carriers and materials-based absorption - desorption systems.
- Broadly speaking, GH2 and materials-based storage are technically viable at the smaller scales required for microgrids, while LH2 and chemical hydrogen carriers are technically viable at export scale.
- The only technologies with both Technological and commercial readiness levels (TRL and CRI) high enough to allow them to be widely implemented quickly are pressurised gas (GH2) and liquid (LH2), with GH2 more commercially mature. Each of the other technologies has a limitation on its readiness, caused by low CRI and/or TRL somewhere in the process chain. In most cases the weak link occurs in the decomposition of a chemical carrier and recovery of hydrogen.
- Hydrogen storage in metal hydrides is the next most ready technology, with high TRL and moderate CRI across the process chain.
- The costs of storing and transporting hydrogen are very sensitive to the energy investment required to operate the storage - recovery process. For this reason, chemical storage of hydrogen for energy is unlikely to be profitable in comparison to GH2, although the hydrogen-containing chemicals may have alternate markets that are more profitable.
- The technologies in which pure hydrogen is stored as GH2, LH2 or in solid form as a metal hydride are the most energy efficient and therefore likely to be the most cost effective.
- Pure hydrogen storage as GH2, LH2 or a metal hydride is best suited to the scale of the BE CRC's demonstration project.
- A team of four from three organisations contributed to this project.

The Challenge

Hydrogen is a highly flexible alternative energy carrier to fossil fuels and electricity. The penetration of hydrogen energy technology into the global energy system is accelerating. The fundamental attractiveness of hydrogen is that it can be produced from water using renewables and oxidised to liberate energy in a sustainable cycle that does not involve carbon directly.

The intermittency of most renewable energy resources makes inclusion of energy storage mandatory. Hydrogen storage is a major challenge because of its low density under ambient conditions: one kilogram of hydrogen gas occupies 11.94 cubic metres at 20 Celsius and 1 atmosphere pressure. Compression is required to store hydrogen gas in a reasonable volume, or alternatives such as liquefaction or solid-state storage must be employed.

The optimal mode of hydrogen storage/distribution depends on scale and end use. Some applications, such as islanded microgrids, require storage only, since the hydrogen is used internally, while export demands local storage and long-distance distribution. The challenge is to associate hydrogen storage and distribution modalities and technologies with the needs of the industry under consideration.

The Opportunity

In the context of the Blue Economy CRC, hydrogen will play a key role in integrating the supply side with the demand side, which needs not just electricity, but also oxygen and fresh water for aquaculture, and clean fuel for transport and survey vehicles.

Opportunity exists to build demand for hydrogen in the maritime sector, and the magnitude of this opportunity for Australia remains unclear. Growth is being seen internationally, with a targeted transition of shipping fleets to sustainable solutions (including hydrogen powered vessels) underway. Whilst much attention is paid to the global shipping fleet, service vessels, as used in the aquaculture industry, represent a significant fraction of global marine vessels and a major opportunity for a transition to sustainable propulsion. This presents an opportunity for the CRC but will require additional partners filling identified gaps. Further demand opportunities for hydrogen in the blue economy should be identified. Growth in demand for hydrogen will lead to increased need for cost-effective storage and distribution technologies.

In the wider picture, distribution of hydrogen within and between industries, and its export to international destinations, are increasingly recognised as important opportunities for Australia.

Research

OBJECTIVE

The objective of the study was to identify and characterise hydrogen storage and distribution technologies so that their applicability to the Blue Economy CRC and enterprises supported by it could be understood. The study considered the technological suitability of particular hydrogen carriers and storage technologies for the range of energy scales from small islanded microgrid to major export industry, as well as technological readiness, reliability, survivability, economics and opportunities for new Australian industries.

METHODOLOGY

To conduct this study, we used energy and efficiency values extracted from the literature to calculate the energy requirements and costs of 16 hydrogen storage and transport modalities.

We analysed a total of 21 modalities, but were unable to complete the analysis on 5, due to insufficient data. There are three major assumptions made in this analysis:

- Each process has the same output to enable direct comparison;
- Energy input was generally best-case scenario (most efficient process); and
- Economic calculations are for comparison and should not be taken as absolute as they do not include costs such as labour, equipment, etc.

These assumptions enabled the calculation of energy costs for 16 hydrogen energy storage modalities: gaseous hydrogen, liquid hydrogen, ammonia, methane, methanol, dimethyl ether, formic acid, urea, carbons, metal-organic frameworks, two interstitial metal hydrides, two complex hydrides, methyl cyclohexane toluene cycle, and perhydro-dibenzyl toluene dibenzyl toluene cycle.

Outcomes

The costs of storing and transporting hydrogen are very sensitive to the energy investment required to operate the storage recovery process.

From this work, we were able to show that for small-scale applications, storing pure hydrogen as compressed gas, liquid hydrogen, or hydrogen taken up by a material (e.g. adsorbed carbons or MOFs, or absorbed as an interstitial metal hydride) is the most energy efficient, providing the highest energy return on investment and the lowest break-even H2 sell prices in our example scenarios.

Because of the very high energy investment required, chemical storage of hydrogen for energy is unlikely to be profitable in comparison to GH2 at below-export scales, although the hydrogen-containing chemicals may have alternate markets that are more profitable.

Next Steps

A number of opportunities arise out of this scoping study. To enable the use of hydrogen in supportive markets, short term opportunities might include:

- A detailed study should be carried out on storage scenarios for delivery of high-pressure hydrogen at 350-700 bar for vehicles and vessels, comparing (i) GH2 plus mechanical compression, (ii) LH2 plus mechanical compression, (iii) metal hydride plus mechanical compression and (iv) metal hydride with direct delivery at the demand pressure.
- A scoping study should be carried out on distribution scenarios at sub-export scales, comparing the newest near-commercial technologies: (i) compressed and containerised Type IV GH2 tanks, (ii) LH2, including the newest lattice-tank technology and (iii) metal-hydride in the form of a magnesium slurry.
- Compressed GH2 storage systems able to contain a higher mass percentage of hydrogen than the current Type IV tanks should be investigated for stationary storage and distribution, especially those able to be carried on current freight transport vehicles.
- Reversible hydrogen storage materials (principally metal hydrides, as these have higher TRLs) should be investigated for stationary long-term storage in the offshore context, noting that some metal hydrides are able to deliver hydrogen at 20 bar without compression.

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3.20.002 Offshore/High Energy Sustainable Hybrid Power Systems

Research Program

RP3 Offshore Renewable Energy Systems

Key Points

- More market-oriented research and closer collaboration between the Blue Economy CRC and relevant industries, organisations and government are required to support the progress of offshore renewable energy in Australia.
- The flagship demonstration project to build a hydrogen microgrid offshore is a vehicle for drawing together the wide-ranging capabilities within the BE CRC relating to offshore engineering, renewable energy, markets, analysis, risk and modelling.
- In view of the early stage of development of offshore renewable energy systems, careful consideration of risk is needed to support the successful completion of the demonstration project.
- In seeking to reduce complexity, cost and risk, adoption of commercialised technologies is advised, where possible.
- Realistic modelling is essential for risk mitigation at every stage of such a project from concept to implementation.
- A team of 29 researchers from ten BE CRC partner organisations contributed to this project.

The Challenge

Energy is fundamental to the growing blue economy, for powering industries located offshore, for shipping, for supply to onshore energy grids, and for export. At present most of the blue economy relies on fossil fuels. The need to limit emissions within and improve the sustainability of the blue economy is increasingly being recognised. This recognition is seeding activity internationally to identify optimal solutions to meet the resource needs of offshore industries and harness the available energy resources sustainably, with technological readiness, reliability, survivability and economics all posing significant challenges.

According to the Department of Industry, Science, Energy and Resources, there are currently no offshore renewable energy projects in Australia, and there is no legislation in place to support their development, although the Offshore Clean Energy Bill was due to be introduced in 2020, and The Star of the South project to build the world's biggest wind farm in Bass Strait has received an exploration licence. Offshore energy is at the very beginning of its development in Australia.

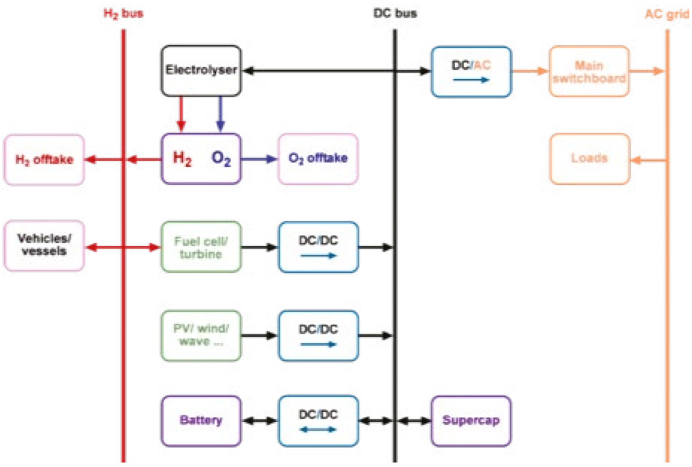

Figure 1. Hydrogen microgrid.
Figure courtesy of Evan Gray.

The Opportunity

Abundant renewable energy resources are available in the offshore environment: solar, wind, wave, currents, tidal flows, thermal gradients and salinity gradients. Electricity generation by offshore wind is the most advanced technology in terms of availability and cost of energy supplied.

According to the International Energy Agency (IEA), the potential for offshore wind is 36,000 TWh of electricity per year for installations in water less than 60 metres deep and within 60 km from shore, which is more than 150% of the present global annual electricity demand.

IEA analysis predicts that in Australia, based on near-term costs, 1000 GW of generating capacity is available at less than about AUD0.13 per kWh, compared to Australia's average electricity consumption of about 24 GW. The potential for export is huge, particularly when conversion to hydrogen is included. Because other energy capture and conversion technologies for the offshore environment lag behind wind, opportunity exists for the development and manufacture of novel devices to harness other resources, such as wave energy, that are abundant around the Australian coast.

Research

The underlying theme of the project was the linking of devices for energy capture, storage and end use by means of electricity and hydrogen into a hydrogen microgrid. This is an electricity microgrid with a second energy carrier - hydrogen - embedded. An electrical architecture and control system are employed to integrate the sources of electricity with storage and other generation devices, providing reliable electricity to the load and hydrogen (and as appropriate oxygen and fresh water) for associated end uses. The concept is scalable from a small off-grid system to support telecommunications, for instance, to an entire hydrogen export enterprise.

OBJECTIVES

The objectives of the scoping project were:

1. To clarify the numerous challenges associated with
   - employing renewable energy conversion technologies offshore;
   - building hydrogen microgrids that are robust in this environment;
   - modelling the components of a hydrogen microgrid and the entire energy system.
2. To identify clearly the strategic strengths of the CRC capability aligned with Research Program 3, capture lessons learned from prior national and international projects, provide guidance as to how to tackle the challenges and thereby identify strategic priorities over the first several years of the CRC.

METHODOLOGY

The study focused on four main tasks:

1. Review offshore renewable energy conversion technologies, providing perspective on current status, concentrating on technologies at Technology Readiness Level 6 and higher.
2. Review microgrid architectures suitable for offshore deployment, encompassing control system, storage (other than hydrogen storage, which is covered by Scoping Project P.3.20.002: Hydrogen Storage and Distribution), and other end-product requirements.
3. Review software models for the components of offshore renewable energy systems, including in addition to the standard devices for energy capture, electrolysers, oxygen and hydrogen storage, fuel cells, microturbines and desalination plant.
4. Identify priority opportunities that play to the strengths of the Blue Economy CRC, and capture lessons learned from similar international programs.

Outcomes

The review of technologies for offshore renewable energy pointed to the need for more research to better understand where the market opportunities for offshore renewable energy developers lie in Australia; identify end user requirements and which technologies best meet these requirements; identify the technical, commercial and legislative gaps hindering these opportunities from developing; and towards closer collaboration with ORE-related industries, organisations and government to investigate market opportunities and support development.

Risks associated with designing and building offshore renewable energy systems based on microgrids were identified and recommendations for mitigating these risks were made.

The need for realistic modelling at every stage of a project was identified.

Significant relevant capability across nearly the entire CRC was identified. The flagship demonstration project to build an offshore hydrogen microgrid is a vehicle for drawing together this capability to develop and demonstrate solutions to the challenges associated with offshore renewable energy technology.

Next Steps

The outcomes of this scoping study are to be synthesised, along with the results of all initial scoping studies, to support the establishment of a phase 1 research plan for the Blue Economy CRC. There are several areas of ongoing research recommended in the study and captured in the final report.

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Project Reports/Publications

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3.20.003 Energy demand analysis of Offshore Aquaculture Systems

Research Program

RP3 Offshore Renewable Energy Systems

Introduction

The Offshore Renewable Energy Systems program has the objective to develop and demonstrate offshore renewable energy systems optimised to meet the demands of offshore industry. Aquaculture is an example of an offshore industry which requires electricity to support several offshore operations, which at present are met via off-grid diesel generators. As the aquaculture companies look to more exposed and offshore lease sites, meeting these demands via diesel generators becomes less economic. This offers an opportunity for emerging renewable energy technologies, in that the target LCOE to match the status quo will be higher than if the demand was being met with grid-connected electricity. Prior to this study however, the electricity and other energy intensive resource demands of the offshore operations of the aquaculture sector were poorly known. This project set-out to address that knowledge gap.

Key Points

This study provided a number of insights into the opportunity for a potential sustainable energy transition for the offshore operations of the aquaculture sector. These include:

- The demand for energy intensive resources of the offshore operations of the aquaculture industry were assessed.
- The study focused on energy demands of sea-cage aquaculture systems, with particular emphasis on the salmon sector of Tasmania and New Zealand.
- Resources required include electricity (typically provided by diesel generator) for feed barge operations, lighting, venturation, and other miscellaneous electrical loads for monitoring and domestic use; freshwater for bathing, which could be delivered via electrified desalination of seawater; and fuel for other vessel movements (supply and recovery).
- Daily stationary electrical demand for an offshore salmon facility, with an annual production of 10,000 HOG t pa, is estimated at approximately 6000 kWh/day, with an additional 9000 kWh/day load for vessel transport. This is an order of magnitude larger than demand estimates derived from literature for salmon sector in Norway.

The Challenge

Electricity required for offshore aquaculture operations are most typically met using diesel generators. Expansion of the aquaculture sector offshore is anticipated to introduce further complexities and costs associated with diesel use, including transport expense, site access, fuel storage, and spillage risks in addition to the environmental costs of diesel generated electricity. The volume of diesel used could be greatly reduced with incorporation of renewable energy generation at the offshore site.

Concurrently, emerging offshore renewable energy technologies seek pathway markets via which their technology can be demonstrated to meet demand, enabling further cost reductions and an increased value chain. This study seeks to resolve the energy (and other energy intensive resource) demands of the aquaculture sector, in an offshore setting, and determine the size of the opportunity for emerging offshore renewable energy technologies.

The Opportunity

The relatively high cost of diesel generated electricity in an off-grid, off-shore setting presents a potential market opportunity for emerging offshore renewable energy technologies. This cost sets a more accessible threshold at which emerging technologies can be competitive, potentially enabling further development and cost reductions for these technologies, spurring access to potential further markets.

Aquaculture is one such market currently dependent on diesel powered operations, that might benefit from increased energy efficiency and transition to more sustainable power operations, to further reduce the footprint of their business.

However, it should be recognised that aquaculture will be a limited market for deployment of emerging technologies, and will likely have limited impact as a market to aid commercial maturity of these technologies. The program must have a broad view of potential markets for technologies.

Research

The offshore operations of sea-pen aquaculture systems, and their associated energy and resource demands, were reviewed. The bulk of the stationary electricity demand occurring offshore is associated with the distribution of feed to the pens, via the feed-barge. Sub-sea lighting, venturation and net-cleaning add further load. Site monitoring and domestic use on the feed barge also use electricity. The freshwater bathing requirements of salmon as treatment for AGD could add further electricity demand in scenarios where the freshwater is supplied via desalination of seawater. In addition to the stationary electricity demand, vessel movements have an energy demand at least as large as the stationary demand. Our best estimates of the daily stationary electricity demand for an offshore salmon facility with an annual production of 10,000 HOG t pa is estimated at approximately 6000 kWh/day, with an additional 9000 kWh/day load for vessel transport. This is an order of magnitude larger than demand estimates derived from literature for salmon sector in Norway.

A preliminary techno-economic optimisation was carried out using the software tool HOMER energy, to evaluate potential renewable energy systems optimised to meet the identified energy demand profile. A number of scenarios were explored, with consideration of diesel, PV, wind and wave technologies, with and with-out subsea cable connection to the grid. Under considered assumptions, the optimisation points to an off-grid hybrid diesel energy system providing electricity at lowest cost to the system.

A number of assumptions should be clarified before results are relied upon, but this preliminary assessment provides some guidance for the CRC to consider in its support of emerging technologies.

Outcomes

This study has provided key underpinning data to resolve the magnitude of the demand for energy offshore, to support aquaculture operations. Furthermore, it has provided initial guidance on optimal technology options to meet the demands of aquaculture offshore. Daily stationary electricity demand for an offshore salmon facility with an annual production of 10,000 HOG t pa is estimated at approximately 6000 kWh/day, with an additional 9000 kWh/day load for vessel transport. This translates to an installed capacity of approximately 1 MW offshore renewable energy generation. With 10,000 HOG t pa representing approximately 1/10th of the total 2030 salmon production target for Tasmania, the market should be recognised as small.

Next Steps

The recommendations from this project are listed below.

- Continued monitoring of energy use at an offshore marine farm site, beyond the two-week time-period obtained in the scoping study, to resolve variations in energy demand for operations by season / fish maturity.
- A thorough audit of energy use by vessels used in marine operations be carried out in order to improve on understanding of the energy requirements for vessel movements.
- The energy system optimisation should be revisited with more accurate estimates of costs (existing and proposed), site location, resource information, once available. This presents a valuable tool for navigating an optimal ORES for offshore application.

- The CRC has opportunity to have impact in reducing energy costs, more sustainably, for aquaculture partners via efficiencies and transition to sustainable more mature RE options. The CRC must find an appropriate balance between support for operational blue industries with visible impact during the life of the CRC, and horizon 3 program objectives whose impact will not be seen in the CRC's life.
- Diesel-hybrid systems identified here as being most cost-effective systems should be factored into program plans as pathway towards full renewable systems.
- To identify market opportunities for offshore conversation technologies (solar, wind, wave, tidal), there is opportunity for the CRC to quantify offshore renewable energy resources available to existing offshore industry locations (being that of prospective pathway market opportunities). The recommendation includes mapping from modelled products (existing and new), and purpose in-situ monitoring of resource(s).
- Maintain momentum in determining resource (electricity, freshwater, transport fuel, oxygen and other) demands of the aquaculture sector, and resolving relative cost:benefits (economic, environmental and social) of supply of these resources via renewables vs status quo. Expand the scope of energy demand assessments beyond aquaculture to determine demands of other offshore systems/sectors. This presents international collaboration opportunities to other ocean energy market development activities.
- Australia's 2030 targeted offshore aquaculture market is a potentially sufficient pathway market to support development of emerging ORES technologies to meet diesel competitive LCOE targets, opening further commercialisation opportunities. Additional pathway markets are required to support development to be competitive in broader markets. There remains a need to determine the energy demands of other potential off-grid markets for ORES, and size of potential markets. Further market identification is warranted to map out path of growth for ORES via these market opportunities.
- Account for GHG emissions associated with Australia's blue economy industries, and establish whether emissions associated with Australia's blue economy are proportionally equivalent to their contribution to GDP.
- The CRC consider lifecycle assessments of emerging technologies in its assessments and suitability in an expanding blue economy.

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4.20.001 Monitoring and Assessing Offshore/High Energy Production Structures

Research Program

RP4 Environment & Ecosystems

Introduction

This study aimed to undertake a comprehensive review of literature and current knowledge to:

- Understand the scientific basis of site selection criteria, indicators of ecosystem health and reference points/baselines against which environmental performance can be evaluated; and
- Identify state of the art techniques for resource and habitat characterisation and the mapping of impacts of potential aquaculture and energy production, and selection of control sites to support an ongoing monitoring design.

Key Points

Coastal seas are used by a wide variety of stakeholders and have cultural and historic significance. Development of activities in these areas needs to be carefully planned with respect to existing users and to ensure environmental, social and economic sustainability. Marine spatial planning has the potential to manage conflicts and develop sustainable approaches but both a recognised common framework and key data/understanding are currently missing.

A major challenge for offshore sites is high natural variability with sites subject to wide scale and long-term drivers of change such as global heating. It is thus difficult to establish a clear baseline state against which to assess changes in monitoring data.

The adoption of approaches which use a limited suite of simple, cost effective metrics that if triggered will initiate further investigations to establish the true extent and cause of the problems, instead of triggering a potentially inappropriate direct management response, is seen as having potential.

The Challenge

For many countries the marine estate (as represented by the Exclusive Economic Zone) is vastly greater than the land area and so provides opportunities for sustainable economic growth. However, the marine environment is a much more physically challenging environment and levels of knowledge are much lower than for terrestrial systems. Providing knowledge to underpin the development of sustainable activities in the marine environment is the big challenge for the Blue Economy.

It was noted during the project (and in a series of strategic planning meetings following completion of the project) that the currently available information platforms (such as the renewable energy atlas) do not always match industry needs regarding resolution so considerable duplication of effort occurs proponent to proponent as they do their own downscaling. It was also noted that overseas there has been a tendency to ask for very extensive baseline surveys given the greenfields nature of offshore production, which may be beyond what is actually required for decision making and can be prohibitive for new entrants.

The Opportunity

This project sought to identify the most pressing knowledge gaps and research priorities associated with site selection, and environmental assessment and monitoring, in order to guide the BE CRC in addressing the development of economic activities in offshore water.

Research

The opinions of 23 Australian and international industry, research and government representatives from 14 organisations were sought to identify key knowledge gaps associated with aquaculture and renewable energy site selection procedures, and environmental assessment and monitoring practices.

Policy and legal frameworks

Stakeholders recognised the immediate requirement for a consistent and definitive regulatory framework which extends beyond State territorial boundaries. This should include the development of comprehensive assessment and monitoring guidelines to reduce regulatory uncertainty.

Site Selection

There remains a lack of data for comprehensively assessing offshore site suitability, particularly in respect of benthic environments.

The long-term goal should be to link all physical, environmental, cultural and heritage, resource potential, operational logistics and risks into a comprehensive decision support tool. Site selection should also consider other users and how offshore projects may impact them. These risks may be mitigated through developed marine spatial planning tools through and accessibility to geospatial databases.

Environmental Effects

Research is required to address the cumulative impacts linked to large scale offshore development and co-located activities including but not limited to renewable energy and aquaculture operations. Stakeholders identified the need for research data in order to improve modelling that can accurately predict offshore impacts and risks including occurrences of algal and jellyfish blooms, spread of pathogens, noise pollution and dispersion of nutrients. Stakeholders also identified the need for further work on preventive measures to avoid marine megafauna entanglements.

Assessment and Monitoring

Interviewees recognised as a priority, the need to standardise assessment and monitoring practices and develop government endorsed guidelines. There is a need to identify appropriate sentinel indicators for offshore environments and to provide guidance on correct use of statistical models.

Outcomes

Site Selection

Site selection criteria commonly used in Multi Criteria Decision Making methods need to be developed specifically for offshore sites. Furthermore, consideration should be given to multi-use platforms (Aquaculture and Renewable Energy). New emerging technologies can alter the requirements of offshore structures and therefore the site selection criteria. Cross disciplinary research is recommended to update site selection parameters and model inputs. The participation, acceptance and support of all stakeholders – including other industry sectors and community members - is necessary to ensure sustainable offshore expansion. Processes to engage all parties during the marine spatial planning process need to be addressed.

Assessment and Monitoring

The requirements of environmental monitoring will differ depending on the type of aquaculture and energy system deployed. Both renewable energy and aquaculture offshore platforms have the potential to impact on local marine organisms including large predators and those in benthic habitats, and so monitoring programs must focus on detecting and quantifying the nature of these interactions. Aquaculture platforms have the additional environmental concerns of sedimentation, nutrients changing planktonic dynamics, spread of diseases, and for finfish aquaculture, depending on the species and region, the interbreeding of escapees with native populations. Environmental monitoring can reduce the risk of adverse effects, operational costs and maintain public confidence in the associated industries.

Advances in monitoring approaches will see development of autonomous and remote monitoring platforms (e.g. ROVS, AUVs, SUVs, vertical profilers) to improve monitoring efficiency and reduce health and safety risks. Standardisation of monitoring systems is desirable to ensure comparability between related projects/ industries, with the added benefit improved data sharing and accessibility to historical datasets.

Barriers to the adoption of ecosystem-level monitoring approaches and indicators (including eDNA) need to be identified and eliminated, so that new approaches can be used where they have a cost, health, safety or environmental advantages, or are better suited to monitoring targets.

Monitoring requirements should be linked to clear management responses and trigger values. The focus should be on a limited suite of robust indicators not on blanket measurements of 'everything we can'. There is an urgent need to provide regulators with a critical evaluation of the appropriate suite of metrics and advise on the development of (location specific) trigger values.

To ensure workforce health and safety, the focus for offshore sites should be automated and remote sensor technology ideally supported by AI systems.

Next Steps

The BE CRC Research Program 4: Ecosystems and Environment should initially focus research effort on:

- Identifying key metrics of environmental performance in offshore waters and designing cost-efficient monitoring strategies for offshore platforms that are suitable to assess environmental impact and satisfy regulatory requirements;
- Developing a MCDM site selection framework. This should be capable of providing information on single sector and of multi-use platforms;
- Developing approaches and data layers to underpin a Marine Spatial Planning tool;
- Data collection for feeding into bio-geochemical models to assess environmental interactions and impact on ecosystem services; and
- Continually examine the extent to which emerging approaches and new technical equipment for monitoring strategies can contribute to environmental monitoring and specifically reduce workplace Health and Safety risks to operators.

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Project Reports/Publications

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4.20.002 Operational modelling for offshore aquaculture and energy

Research Program

RP4 Environment & Ecosystems

Introduction

The goals of this scoping study are listed below.

- Understand the global trends that will influence the move towards Offshore Aquaculture (OA) and Offshore Renewable Energy Systems.
- Determine the present uses of operational modelling systems by industry.
- Determine the likely future operational modelling needs of the OA and ORES sectors as they move into more exposed and energetic offshore environments.
- Review the state of the science of Operational Modelling to support OA and ORES.
- Identify the research and development needed for operational models to support the information requirements of industry.

Key Points

An online survey was conducted and collected responses from 33 participants across six sectors associated with the Aquaculture and Renewable Energy sector.

Through the survey results and subsequent detailed discussion with industry it was found that the industry already uses a number of operational modelling products, however, they are not currently tailored to the needs of industry as the sector moves offshore.

From industry feedback there was a clear need for some specific model products on new time scales and involving new variables, in particular:

- Multi-week forecasts with processes and time/spaces scales relevant to offshore facility managers, with the ability to capture both the mean and extreme site conditions.
- Move away from a single deterministic forecast and towards probabilistic forecasts.
- A number of additional variables would be useful, specifically:
  - Water Clarity
  - Harmful Algal Blooms, Jellyfish and pathogens.
  - Phase resolved wave fields.
- A central location that data (observed and modelled) can be discovered, used and contributed to.

Operational modelling to support site selection was also identified as a high priority and has strong links in other BE CRC research programs.

The Challenge

To determine the future operational modelling needs of industry and identify the research and development required to achieve these needs.

The Opportunity

The aquaculture and renewable energy sector currently uses operational modelling products in their daily decision making. However, as the industry moves offshore, it is recognised that there will be a reduction in the number of human hours that a site can be occupied and therefore a shift towards higher levels of automation of tasks on site. Having the ability to predict the environmental conditions on a site multiple weeks into the future and out to seasonal scales, will allow for better operational decision making.

Research

The research that underpinned the findings of this study focussed on a combination of survey techniques. The first method used was a broad online survey was conducted, that took approximately 20 minutes to complete. This was then followed up with detailed discussions with eight industry representatives selected from the OA, ORES, Offshore Engineering and Consulting Industries.

Outcomes

During the detailed discussions with industry, there was a general recognition across the OA, ORES and associated support sectors, that as industry moves offshore, the time windows available for the safe human occupation of the site to undertake functions such as maintenance and feeding operations will be less than at sheltered inshore sites. This will lead to a growing reliance on autonomous systems and ROV's that use underwater video systems to relay real-time information back to various control centres. Therefore, the following operational modelling products will need to be developed to support these shifts in operations:

- Multi-week probabilistic forecasts at scales relevant to farm/device operations, this will increase the lead times available for planning to be onsite.
- Water Clarity predictions to understand when AUV/ROV and diver led operations can take place.
- Data needs to be easily accessible with methods to interface with Decision Support systems.

For the OA, ORES and engineering/consulting sectors that assist in the planning and site selection stage, there was a strong need for modelling products rapidly deployable tools to aid in site selection.

Specific to OA, the online survey and in-depth discussion with industry representatives highlighted the need for operational prediction systems that can estimate the likelihood of Harmful Algal Blooms (HABS) and the presence of Jellyfish. Both HABS and Jellyfish impact on production at a site, and if these phenomena were predictable, operational management actions could be taken to mitigate their impact.

The ORES industry has few sites in operation, but it is expected that short-term forecast (i.e. on forecast time scales of the next 30-180 seconds) of the phase resolved wave field would be useful for the optimisation of the power take-off system.

Next Steps

A number of recommendations for general projects were made on the back of the report's findings that would be off benefit to both the OA and ORES sectors. Some general suggestions include:

- Multiweek Probabilistic Forecasts tailored to OA and ORES needs.
- Rapidly Deployable Model Systems to make regional/global forecasts relevant to a facility site.
- BE CRC Data infrastructure that operational modelling systems can interrogate and deliver into.

There are a number of ideas reported that cut across many of the BE CRC Research Programs. These would be of high value as they typically aim to develop decision Support System that built on the output of operation models.

A number of barriers to the use of operational models were identified, and recommendations from this section will assist in facilitating a smooth uptake of modelling output in operational decision making.

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Project Reports/Publications

Jones et al., (2020). Operational modelling for offshore aquaculture and energy, 4.20.002. Hobart: Blue Economy Cooperative Research Centre.

4.20.003 Tools to assess cross-sector interactions

Research Program

RP4 Environment & Ecosystems

Introduction

The report reviewed the tools being used to assess trade-offs among industries when planning for blue industries. A survey of ocean industry stakeholders was undertaken to identify the tools they currently use and key challenges they face in assessing cross-sector interactions.

Key Points

Multiple ocean sectors compete for space and resources, creating potential conflicts but also opportunities to plan for synergistic outcomes that benefit multiple sectors.

The review highlighted the different modelling tools (that vary in complexity) that are needed at different stages of the planning process, including to support site selection for new infrastructure and the management of cross-sector interactions.

The survey of industry stakeholders identified four primary needs for successful future offshore developments. We make recommendations for addressing these needs with existing tools, and highlight where new tool innovation is required to address:

- stakeholder concerns regarding obtaining social licence;
- limitations in baseline and monitoring data;
- cross-sector interactions and feedbacks between sectors and the environment; and
- use of integrated-assessments to address site selection and operational impacts of multiple sectors.

The Challenge

Marine coastal areas are quickly becoming space-limited as blue economy industries expand. The cumulative effects of their expansion and overlap can negatively impact marine environments. Furthermore, interactions across industry sectors cause trade-offs in economic, spatial and operational outcomes.

The assessment of cross sector interactions can be time consuming due to the fundamental lack of readily accessible data to support stakeholder engagement and planning, a lack of clear guidance on the data that needs to be synthesized, and lack of appropriate tools to assess cross-sector interactions.

The Opportunity

A number of modelling tools have been developed that assess the significant issue of cross sector impacts, though they vary in their complexity, data needs and application.

By reviewing and identifying the tools and frameworks previously utilised to support blue development planning, this project helps identify environmental, economic and social wins and help streamline impact assessments for legislative approvals processes.

By also surveying industry experts, we were able to identify addition tools that were not identified in the literature review, helping bridge the gap between information in industry and academia.

Research

Literature review

We reviewed and classified modelling tools into four categories: conceptual/semi-quantitative models, spatial static tools, spatial prioritization tools, and process/dynamic modelling tools. We found that multi-sector studies generally approach the assessment of cross-sector interactions using a range of tools that fall within spatial modelling and prioritization frameworks. The most well-developed modelling tools for assessing multiple Blue Economy sectors are spatial prioritisation tools such as Marxan and multi-criteria decision support tools, and spatial static tools such as cumulative effect mapping using GIS.

In contrast, dynamic ecosystem and oceanographic models are well developed for single sectors, particularly commercial fisheries, but have been less commonly applied in multi-sector studies.

The review also found studies that had site selection as a priority primarily utilised spatial prioritisation approaches, whereas studies examining operational impacts tended to use conceptual and semi-quantitative methods to assess trade-offs. In both instances, tools that simulate change in ecosystems over time are under-utilised, and our results indicate that there is room to develop and utilise more complex approaches to assess cross-sector interactions.

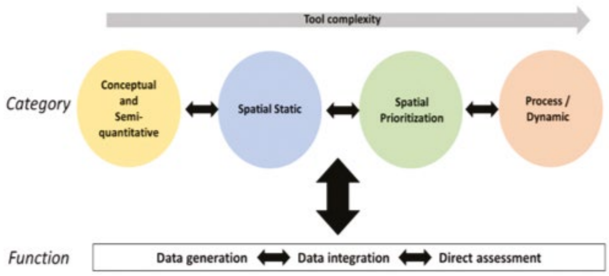

Figure 1. Conceptual integrated modelling toolbox to support complex decision making for the Blue Economy. A variety of different modelling tools with varying complexity and function are needed throughout the planning and implementation process.

Industry survey and challenges

The survey of industry stakeholders identified four primary needs. First, there was a need to address stakeholder concerns, primarily to obtain social licence, and address negative social perceptions of industries. Second, there was a need for more baseline and monitoring data for environmental impacts assessments, including understanding of the social and cultural values of coastal and marine environments. Third, there was a need to address cross-sector interactions and account for feedbacks among multi-sector operations and the environment. Finally, the survey identified a desire for more integrated assessments (e.g., ecological and economic) and real-time data integrated web tools for assessing cross-sector interactions and site selection.

Outcomes

A number of different modelling tools (with varying complexity) are needed at different stages of the planning process to support site selection and the management of cross-sector interactions. Assessing the environmental, and operational suitability of sites for blue infrastructure in conjunction with operational impacts, trade-offs and decommissioning considerations requires:

- a toolbox of approaches that covers a range of spatial, temporal and trophic scales (e.g., biogeochemical to ecosystem; instantaneous monitoring to system lifecycle; and plankton to large marine mammals).
- tools that capture interactions and feedbacks among sectors, and between sectors and the environment, without being unnecessarily complicated (i.e. they must be tractable to use and allow for effective communication of content and findings).
- continued synthesis of approaches and tools across disciplines (e.g., aquaculture, fisheries, marine renewables, oil and gas).
- finally, information generated by planning tools must be easily accessible, as stakeholders identified the need for integrated and accessible online tools for assessing multi-sector impacts.

Next Steps

Tools vary in their complexity, data needs, and function, therefore no single tool or process can comprehensively satisfy all stakeholder objectives. We make a number of recommendations to the BE CRC to address cross-sector interactions and stakeholder concerns. These recommendations should be explored in conjunction with the development of a toolbox to support complex decision making that involves complex trade-offs for the Blue Economy.

1. The BE CRC should use a participatory approach to stakeholder and community engagement when developing tools. A participatory approach is aided by modelling frameworks that are transparent and encourage stakeholder participation, such as multi-criteria decision analysis.

2. The BE CRC should identify critical information data gaps in regions that may have potential for Blue Economy development, and invest in technology supporting the collection of baseline and monitoring data.
3. The BE CRC should further develop dynamic modelling tools that can assess operational impacts and interactions among sectors. These tools can capture dynamic and non-additive feedbacks among sectors, as well as support direct scenario comparisons. Dynamic tools are well developed for single sectors, but their application to multiple Blue Economy sectors is nascent and needs further development (e.g., modelling of energy infrastructure-fishery interactions). This must be done with care to ensure that tools remain useful rather than being overwhelmed by complexity, especially in dimensions where there is little available data for validation.
4. The BE CRC should investigate implementing an overarching management framework such as Management Strategy Evaluation to analyse complex interactions between sectors. This approach would incorporate dynamic feedbacks, account for uncertainty (potentially through multiple-model ensembles) and can make explicit and transparent the trade-offs in triple bottom line performance.

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5.20.001 Economic Assessment of Blue Economy

Research Program

RP5 Sustainable Offshore Developments

Introduction

Across the world, blue economy growth is expected to be led by the offshore wind sector. The port sector is expected to have the second largest growth rate. Fish processing is expected to have the third highest growth rate in both GVA and employment. The value of Australian blue economy has been declining recently largely due to lower commodity prices (Fig 3). Estimated values could change significantly depending on the estimation method, and several evaluation and analysis methods have been found from the literature review such as satellite account, input-output analysis, cluster analysis, data envelopment analysis, and social cost-benefit analysis, stated preference.

Australia has the third largest marine jurisdiction with the exclusive economic zone of 10.2 million sq. km, much larger than its land area of 7.69 million sq. km. For the 2015-2016 period, the Australian blue economy had GVA of $71.4 billion comprising of $39.8 billion of direct value adding and $31.6 billion of indirect value adding and employed 197 thousand full time equivalent workers. The economy is currently dominated by the offshore oil and gas industry contributing about 50%, and the tourism and shipping service sectors contributing about 40% to the blue economy output. By 2025, its GVA is expected to reach $100 billion driven by the renewable energy, offshore oil and gas, and aquaculture sectors (AIMS, 2018).

Figure 1 (Shown on right). Blue economy research output by countries and authors internationally.

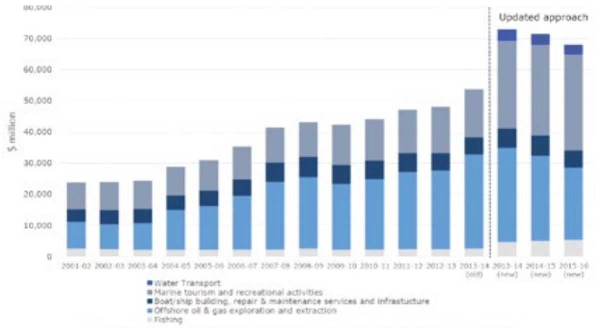


Figure 1: Measurable output from selected blue activities (AIMS, 2018)

China, U.S., U.K. and Australia are the four countries with largest volume of research on blue economy (Fig 2). The number of studies has been growing steadily since 1959 and accelerating in recent years with nearly 60% of studies published in the last three years (2018-2020), and 90% in the last 10 years (2010-2020) (Fig 3).

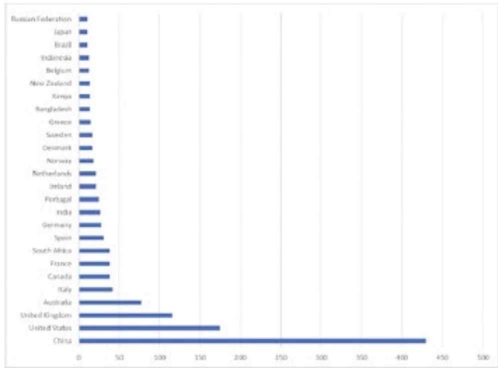


Fig 2: Blue economy research output by countries (authors)

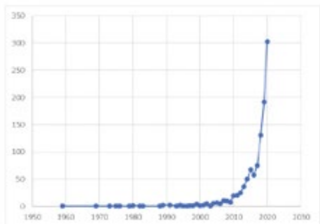
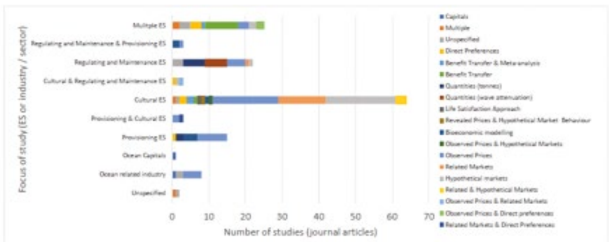


Fig 3: Blue economy research by year (authors)

Much of research using the non-market value approach to date has focussed on 'Cultural services' with a largest quantum of research on tourism and recreation (Fig 4). The second most represented grouping in the literature was 'Multiple ecosystem services'. Studies on 'Regulating and Maintenance Ecosystem services' was the third most represented category with a focus on the capacity of particular habitat types to offer coastal protection.



Multiple ES = The quantification/valuation of multiple ecosystem services

Cultural ES = Non-material, and normally non-consumptive, outputs of ecosystems. E.g. recreational, tourism and visitation (e.g. wildlife tourism), species conservation, aesthetic values

Provisioning ES = This is defined as all food resources/sources, material, and energetic outputs from ecosystems. E.g. included commercial fisheries (not recreational), aquaculture, Marine Protected Areas.

Ocean related industry = This covers studies focusing on marine linked industries. These include ocean-related industries and industries directly linked to ocean resources.

Regulating and Maintenance = This covers the impact of the flow of waste, solids, liquids, and gases on human and ecological well-being. Studies included in this grouping focus on coastal erosion impact and management, storm surge protection, habitat restoration and carbon storage.

Regulating and Maintenance & Provisioning ES = e.g. Fishery sustainability /fishery management

Cultural & Regulating and Maintenance ES = e.g. coastal erosion Maintenance for beach tourism use

Fig 4: Focus of Quantitative Papers identified through the systematic review

Key Points

This scoping study aimed to conduct a systematic review on blue economy evaluation and analysis, and in doing so, answered the following research questions:

1. What are the integration frameworks for blue economy?
2. How is the economic impact of blue economy evaluated?
3. How can the total economic value of sustainable marine and coastal development be evaluated?
4. What are the implications and recommendations for sustainable offshore developments?

A team of 8 researchers from 2 organisations contributed to this project.

The Challenge

Blue economy output evaluation and analysis are critical to decision making and policy formulation. Yet, various definition and studies methods used in existing studies worldwide resulted in inconsistent and incompatible data.

The Opportunity

Australia has the third largest marine jurisdiction with the exclusive economic zone of 10.2 million sq. km, much larger than its land area of 7.69 million sq. km. In terms of volume, more than 99% of Australia's international trade is carried by sea.

Australia has the fourth largest output of blue economy research in the world despite its small population and economy. Australian blue economy is expected to have much larger share of GDP in the future, contribute to global sustainable development goal and meet increasing food demand.

Research

SYSTEMATIC REVIEW ON BLUE ECONOMY EVALUATION AND ANALYSIS

- A wide range of research methods and their application from local, micro to international, macro level have been identified.
- Both market and non-market value approaches were considered.

INTEGRATION FRAMEWORKS OF BLUE ECONOMY

- Integration frameworks are used to present the organisation of blue economy. They show blue sectors, their links and interactions.
- An integration framework can be presented in various forms, i.e. as a conceptual framework, colour-coded table, graphical complex network, or input-output table.

BLUE ECONOMY EVALUATION AND ANALYSIS METHODS

The review covers study methods to:

- Evaluate the economic value of blue economy, especially gross value added (GVA) and total economic value (TEV).

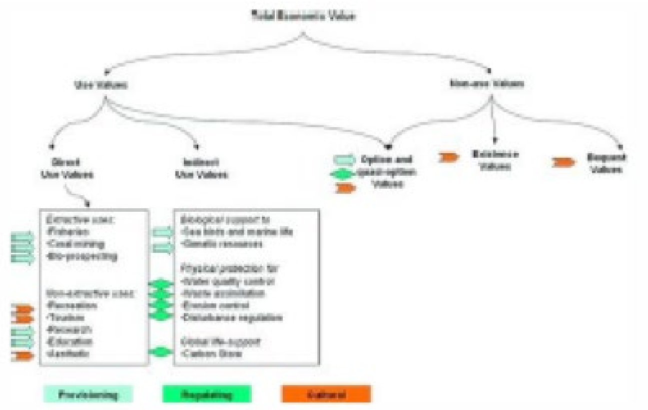


Figure 2. TEV framework (Stoeckl et al., 2011)

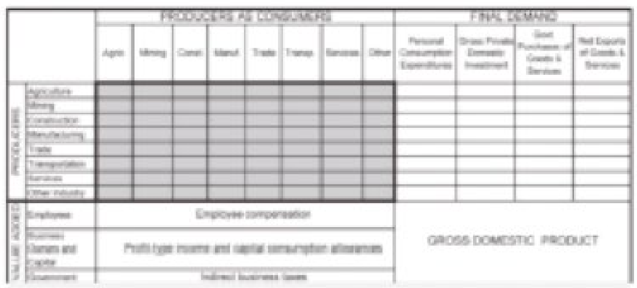


Figure 3. Input-output table (Miller and Blair, 2009)

- Analyse the impact and efficiency of blue economy.

Outcomes

Blue economy research has started in about 1959, and the number has been increasing rapidly in recently years with 90% of studies in the last 10 years (2010-2020) and 60% in the last two years (2018-2020).

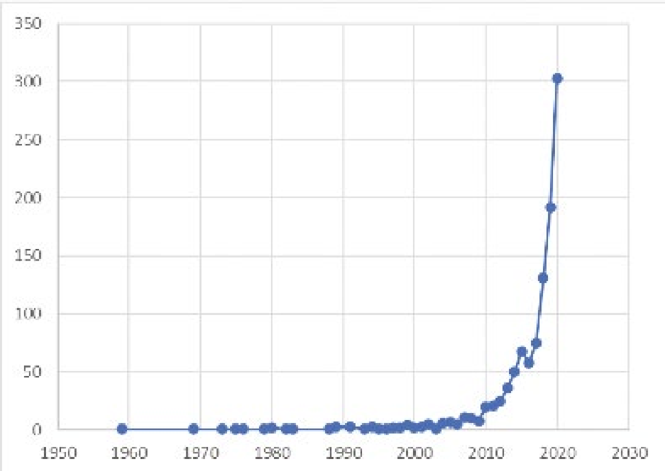


Figure 4. Blue economy research output by year.

The share of blue economy varies substantially across countries from 3-4% of GDP in some developed countries to 10-15% in some developing countries.

For the 2015-2016 period, the Australian blue economy had GVA of $71.4 billion, contributing 4.3% of GDP and employing 197 thousand full time equivalent workers.

Total economic value (TEV) framework can used to capture market and non-market value of blue economy (Figure 2). Input-output table can be used for economic mapping and impact analysis (Figure 3).

Other methods, such as data envelopment analysis (DEA), Malmquist efficiency index, growth accounting, social cost-benefit analysis (SCBA), cluster and network analysis are also useful in benchmarking and analysing the efficiency, impacts and interactions between blue economies and sectors.

Next Steps

Evaluating and analysis of the economic value, efficiency, links and interaction between Australian blue sectors.

Developing the application of economic reporting including non-market valuation, for Australia's blue economy.

Engaging with BECRC research teams in relevant RP5 and cross-program activities.

A systematic review of blue economy evaluation and analysis (forthcoming).

Project Team

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Project Reports/Publications

Nguyen, HO et al. (2020). *5.20.001 Economic Assessment of Blue Economy - Final Project Report.* Blue Economy Cooperative Research Centre.

BLUE ECONOMY COOPERATIVE RESEARCH CENTRE

Australian Government Department of Industry, Science, Energy and Resources | AusIndustry Cooperative Research Centres Program

5.20.002 Integrating Blue Economy Governance Integrity Research

Research Program

RP5 Sustainable Offshore Developments

Introduction

This Scoping Project falls under the BECRC's Research Program #5: Sustainable Offshore Developments (RP5) and addresses key aims of the BECRC including the examination of and advocacy for the regulatory frameworks to promote confidence for aquaculture and renewable energy industry to invest, and that developments in the offshore context are carried out under the highest environmental standards for sustainability and ecosystem integrity.

Key Points

- Research Program 5's key activities recognise that Blue Economy industries must not only seek profitability but address broader responsibilities to communities and the environment or put at risk their social licence to operate.
- The governance of the Blue Economy involves all levels of government and industry and is affected by a range of normative, regulatory, economic and policy frameworks that are poorly integrated.
- This project scoped three mutually supportive values-based general governance projects within Research Program 5, giving the highest priority to values identification of issues and conceptual analysis.
    1. "Ethics, values and social licence in the Blue Economy"
    2. "Blue Economy Integrity System analysis"
    3. "Blue Economy Certification System Project"
- The project also examined:
    - The interactions and synergies between these projects.
    - The potential synergies with these projects and others in RP5.
    - Potential synergies with projects in other research programs.
- A team of five academics from two universities and three industry collaborators contributed to this project.

The Challenge

Industry and academic participants are aware of the many benefits the Blue Economy can deliver, but face barriers to achieving sustainable development as a result of the complexity of the ethics and governance issues facing them. This in part reflects the lack of clarity over the values justifying the Blue Economy.

The Opportunity

The results of this Scoping Project will inform future CRC projects with the overarching aims through which the Blue Economy may retain its social licence and live up to the values that justify its existence. In doing so, this project and subsequent projects will assist industries operating in the Blue Economy to consider, prioritise and implement the values justifying their operations to the communities in which they operate.

Research

METHODOLOGY

The scoping project adapted a methodology developed by the Institute for Ethics, Governance and Law (IEGL), and its predecessors, for dealing with complex governance systems. The National Integrity System Assessment (NISA) offers a method for examining the combination of interconnecting norms, institutions and mechanisms to promote the positive goal of good governance rather than the negative goal of limiting corruption. This methodology sought to understand the actual integrity system dynamics, starting with the institutions the studied country had, and looking at the systematic interactions between them.

This methodology has been adopted in the Scoping Project and will directly inform all the scoped projects. The shared approach will provide a method for understanding their inter-relations and situating them in a common conceptual space.

The Scoping Project method involved:

- Literature Review, covering academic and 'grey' literature:
- Ethics, values, integrity & governance in the Blue Economy.

  Interviews

  - 15-20 interviews with stakeholders from a range of perspectives and sectors.
  - Questions on social licence, personal values, codified principles or goals, and (economic, social and environmental) sustainability.

  Workshops

  - 2 x virtual (Zoom/Teams) meetings (7th & 8th December 2020)

Outcomes

DEFINING THE BLUE ECONOMY AND THE SOCIAL LICENCE TO OPERATE

Defining 'Blue Economy'

Using prior research analysis through the literature review, combined with a thematic analysis of the interview results, we developed a working definition of the Blue Economy using three themes:

- Theme 1: Economic activity on or with the marine environment,
- Theme 2: that sustains or restores that environment, and,
- Theme 3: that pays heed to social and cultural priorities.

This definition includes normative elements in Themes 2 and 3. The project also noted another definition, used by some stakeholders, that referred simply to marine economy activities (exclusively Theme 1).

Defining 'Social Licence to Operate' (SLO)

Stakeholders invoked four elements in the SLO.

1. A high standard of practice
2. Community acceptance
3. Stakeholder engagement
4. Social contract

Elements 2 and 4 led to our working definition of the SLO as:

"The acceptance of an activity by stakeholders, where such acceptance is to some degree necessary for its continued undisrupted operation."

Elements 1 and 3 offered guidance on how the SLO could be achieved and improved, including through aiming for higher levels of acceptance (e.g., 'support'), informed consent, and requirements that stakeholder participation be inclusive and fair.

BLUE ECONOMY VALUES

Three types of Blue Economy values were identified in the literature and interviews.

1. Governing values (ethical priorities): SDGs, sustainability, biodiversity, blue/de growth, human rights
2. Framework values (decision making practices): Stewardship, equity, balance and mutually benefit
3. Governance values (governance of activities and processes): Transparency and accountability, independence, honesty, inclusive, informed, honest, long-term, verified.

BLUE ECONOMY INTEGRITY SYSTEM ELEMENTS

The project produced a preliminary list of integrity system elements drawn from the literature review and interviewee responses. The norms, regulations, institutions, and other governance arrangements (including formal bodies, NGOs, enforcement regimes and certification schemes) were identified at multiple levels including global, regional, national, subnational, professional, and corporate. Results of this initial review point to highly complex interactions, with scope for analysis of how such elements align with the Blue Economy's overarching values and purpose.

CERTIFICATION

The project produced a preliminary examination of existing approaches to certification including:

- What is being certified (process vs performance)?
- How is it certified (e.g., public vs private v mixed)?
- How the process is governed (regulatory vs multi-stakeholder)?

Preliminary findings identify challenges to certification in general and BE certification schemes in particular.

CHALLENGES

Integrity based challenges were identified to inform future collaborative research opportunities.

The preliminary list of identified challenges include: the challenges of monitoring at sea; misplaced competitiveness; regulatory vacuums and institutional weaknesses as well as jurisdictional complexities; uneven and ambiguous application of the 'social licence to operate'; and challenges of certification.

Next Steps

In this project, we scoped three related projects with priority given to the ethics, values and social licence project. The approved General Project Ethics, values and social licence in the Blue Economy will extend upon the results of this scoping project and develop a strengthened basis on which to articulate the ethical issues and values debates around the BE.

The three scoped projects aim to integrate with each other, and further projects, to deliver an overall picture of the integrity system—including normative, legislative, policy and economic elements.

By strategically employing the results of these three scoped projects, including their governance, ethical, policy and certification outcomes, the sustainability of the BE—and its ongoing social licence to operate—will be supported, ensuring that the good results from other areas of the CRC are not imperilled by unforeseen breakdowns in the project's or the industry's legitimacy.

To be published after confirmation of final report.

- Literature Review on ethics and integrity in the Blue Economy.
- Preliminary listing of values at stake in the Blue Economy.
- Preliminary listing of norms, laws, institutions and governance mechanisms in the Blue Economy integrity system.
- Report on the recommended scope of the general projects, their links with each other, and with other RP5 and cross-program projects.
- An updated chart mapping the scoped projects with RP5, and planned interactions.

Project Team

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Project Reports/Publications

Sampford, C., Breakey, H., Lewis, M. (2020). *5.20.002 Integrating Blue Economy Governance Integrity Research - Final Project Report.* Blue Economy Cooperative Research Centre.

5.20.003 Logistics Challenges to Offshore/High Energy Co-location of Aquaculture & Energy Industries

Research Program

RP5 Sustainable Offshore Developments

Introduction

The scoping project identifies and maps the BE supply chains and explores the logistics challenges to the offshore/high energy co-located aquaculture and energy supply chain. It provides emerging solutions to the challenges and charters further directions for the development of co-located activities in offshore/high energy environment.

Key Points

- This project is a scoping project undertaken within BECRC Research Program Theme Five(RP5): Sustainable offshore developments.
- The outcomes of this project are related to the following BE CRC milestones RP5.2:
  - Report on the mapping of marine and offshore energy and aquaculture supply chains (RP5.2.1)
  - Identify and report on challenges and potential for an integrated co-location approach (RP5.2.2)
- A team of 15 researchers and from 8 organisations contributed to this project.

The Challenge

The BE CRC program is interested in exploring the potential viability for establishing an offshore co-located multi-use platform involving aquaculture and renewable energy businesses. The inherent challenge is that from an industry and conceptual perspective this is still in an emergent phase. Such an offshore platform can be explored via multiple lenses such as regulatory, environmental impact, and technological. This scoping study examines the issue through a logistics and supply chain lens as it is a means of examining the development and viability of the offshore platform through a systems approach.

The challenge of the logistics and supply chain lens is the paucity of available academic and industry research, and industry practitioners only recently considering offshore opportunities with some being in the prototyping phase. An additional challenge is that any outcomes of the scoping project are likely to be at the conceptual level rather than specifying actual industry activities.

The Opportunity

The major opportunity of the scoping project is in examining the development of an offshore co-located multi-use platform offshore from the perspective of logistics and supply chain, which is a key management activity in other industries that enables an integrative approach from producers to consumers, is widely recognised as a source of competitive advantage, and enables a staged approach that remains agile and relevant to the offshore business as it progresses from a single linear supply chain to an integrated value chain focused industry. The other opportunity is in academic researchers being able to closely interact with industry participants to test ideas that are mainly at the conceptual level. The interaction with industry keeps the focus on the research remaining relevant and useful in providing various scenarios.

Research

OBJECTIVES

- Develop a general framework for mapping supply chains within the BE, including a process mapping approach and data collection tools.
- Identify the current challenges and opportunities in offshore/high energy aquaculture and energy supply chains.
- Identify current and emerging infrastructure/operations/people/technological solutions of adopting integrated and coordinated approaches by multiple firms in offshore/high energy aquaculture and energy supply chains.
- Chart directions to prepare industry sectors for potential logistics challenges to the offshore/high energy co-location of offshore aquaculture and energy business development.

METHODOLOGY

- A qualitative research approach was employed in the scoping project by four steps, i.e. conducting a comprehensive literature review; development of the SCOR model-based supply chains and identification of logistical challenges; validation of the SCOR model and further exploration of logistical challenges through meetings with industry professionals; and refinement of the supply chains through industry partners and subject experts and, synthesising findings on logistical challenges.

Results

- The Supply Chain Operations Reference (SCOR) model was used as a framework to map five supply chains within the Blue Economy i.e. Tasmanian salmon, oyster and mussels supply chains; offshore renewable energy supply chains; and the future co-located high energy offshore supply chains.
- Opportunities and synergies for offshore/high energy co-located aquaculture and renewable energy businesses are multifunctional use of space and resources; the importance of developing a positive public image; synergetic energy production; and creating economies of scale via industry collaborations to enable cost savings.
- Key logistics challenges to offshore/high energy co-located aquaculture and renewable energy industries are related to procurement and supply chain disruption, transporting and handling in offshore locations; operational safety risks in exposed offshore locations; maintenance and operations scheduling; remote monitoring and process automation; and quality assurance of BE supply chains. Other general challenges include showstoppers barriers to legal approvals for commissioning of the co-located projects; financial viability; conflicting stakeholder interests and negative interferences between the co-located activities.
- Emerging solutions to challenges include global sourcing strategies that integrate suppliers and optimise procurement that decrease supply chain disruption; robust platform and cage design to cope with operational safety issues; maintenance scheduling and optimisation to solving multi-activity scheduling; and cutting edge monitoring and automation solutions to ensure safety, sustainability and continuous operations.
- This research proposes a four-stage conceptual approach that may guide future directions and solutions for the development of a future focused medium to long term journey to establishing an offshore co-located platform accommodating both aquaculture and energy businesses.

Outcomes

As a result of the research, the following new additions to knowledge are suggested:

- There is a paucity of research, globally and Australian, that take a systems approach to developing co-located multi-use offshore platforms. Adopting a logistics and supply chain lens to the research is a useful means to begin exploring a systems approach to ensure the many relevant issues are examined.
- The SCOR model was determined to be a valid and appropriate framework for comprehensively exploring many facets of the potential offshore supply chain, and being a useful framework that is sufficiently agile to continually apply as the offshore supply chains develop and grow.
- Before achieving a value chain approach that is critical to the success of many other industries, the BE will first need to establish logistical and supply chain solutions that will greatly assist in the integration of the offshore, onshore and export activities.
- This research has implications for the industry when considering the development of co-located offshore/high energy activities particularly in site selection, financial viability research, effective spatial planning, and technological innovation.
- The industry professionals in the research indicated an interest in a greater understanding of how synergies could be achieved when moving operations offshore. Finding solutions that are 'outside the square' and looking towards solutions already implemented by other industries such as offshore oil and gas, was suggested as valuable activities of the BE CRC.

Next Steps

The following are potential short-term to medium term steps for developing a pathway towards the establishment of a functional blue economy.

The four-stage conceptual approach developed in this research creates a systems approach via the lens of logistics and supply chain management that would serve as the mechanism for creating a foundation on which the offshore industry could be built. To achieve this will require greater research efforts at the conceptual level to build a more comprehensive and robust framework including wider industry engagement, investigation of the various systems and sub-systems to be adopted to establish a foundation for offshore operations, and a mapping of the potential industry players that should be included within the new BE.

Organising a series of workshops involving interested industry participants and researchers to explore initially in an unfettered environment that encourages 'thinking outside the square' related to identifying potential synergistic opportunities in an offshore industry. This could be entitled 'Blue sky thinking for the Blue Economy'. Identification of potential operators, support businesses and interests will be an initial requirement from onshore, nearshore and offshore perspectives. This will enable the beginning of potential supply chains to be mapped. The SCOR model will be pivotal in assisting full coverage of all relevant issues occurs.

The additional research and industry workshops will conceptually advance the current proposed four stage approach by inserting practical considerations that will result in a framework and broad timelines that can become a rallying point for many of the outcomes from the BE CRC five research themes to become added and in doing so, constantly refine the pathway in an agile approach.

Project Team

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Project Reports/Publications

Chen, P, Fernando, I, Gunarathne, N, Cahoon, S, Wu, Y, Adams, L, Abdussamie, N, Bhaskar, P, Lee, K, Balk, D, Thornton, S, Dutton, I, Shepherd, T, McGookin, B & Corden-McKinley, B (2020). *Logistics challenges to offshore/high energy co-location of aquaculture & energy industries, P.5.20.003 – Final Project Report.* Launceston: Blue Economy Cooperative Research Centre.

BLUE ECONOMY COOPERATIVE RESEARCH CENTRE

Australian Government Department of Industry, Science, Energy and Resources

AusIndustry Cooperative Research Centres Program

5.20.004 Developing a policy and regulatory research plan for Australia's emerging Blue Economy

Research Program

RP5 Sustainable Offshore Developments

Introduction

Establishing a strategic policy and regulatory research agenda is paramount to develop appropriate frameworks that are fit for purpose and provide confidence for the aquaculture and renewable energy sectors to operate. Such agenda should ensure that BECRC research efforts are complementary rather than duplicated. Also paramount is developing a research agenda that is driven by the needs and priorities of BECRC's industry partners. This seeks to ensure that the findings and outputs from the BECRC research is relevant and readily available to end-users.

In the context above, the objectives of this project were to:

i. Summarise and assess the current literature on policy and regulatory challenges and opportunities for the blue economy,
ii. Identify and assess aquaculture and renewable energy sectors' short-, medium- and long-term needs and priorities in relation to policy and regulatory research, and
iii. Develop a research agenda to address such needs and priorities over the life of the BECRC.

Key Points

- We reviewed the academic literature, a range of grey literature from within and outside of Australia, and used the results of an on-line survey and discussions with key stakeholders to develop a research agenda for policy and regulatory research that can be implemented by the BE CRC.
- The research needs were prioritised in 3 categories: 1 short-term (1-3 years), medium-term (3-6 years) and long-term (8-9 years). Our focus was to establish a realistic research agenda for the Blue Economy CRC and we prioritised those projects which could be conducted within the 10-year life span of the Blue Economy CRC.
- We identified nine short term needs, four medium term needs and one long term need. These fall into four broad categories:
  - Understanding Australia's policy and regulation issues
  - Complexity and uncertainty
  - Permission system
  - Marine spatial planning

Investment in addressing these needs can be achieved in a number of different Research Programs in the CRC. The BE CRC is uniquely placed to make a significant difference in contributing to and shaping the policy agenda for offshore energy, deep ocean aquaculture and multiuse platforms in Australia and New Zealand and beyond.

A team of 4 researchers from 3 organisations contributed to this project.

The Challenge

The Blue Economy is an emerging industry with rapid advances being made continuously particularly in relation to location, scale and technological approaches. Most of these advances are being made by industry and are in advance of the policy and regulation that is required to underpin the long-term sustainability and effectiveness of the approaches.

There is a need to understand the issues and barriers and to undertake research to support the development of effective policies and regulations.

The Opportunity

Establishing a strategic policy and regulatory research agenda is paramount to develop appropriate frameworks that are fit for purpose and provide confidence for the aquaculture and renewable energy sectors to operate. Such agenda should ensure that BECRC research efforts are complementary rather than duplicated. Also paramount is developing a research agenda that is driven by the needs and priorities of BECRC's industry partners.

This seeks to ensure that the findings and outputs from the BECRC research is relevant and readily available to end-users.

Research

OBJECTIVES

The objectives of this project were to:

i. Summarise and assess the current literature on policy and regulatory challenges and opportunities for the blue economy,

ii. Identify and assess aquaculture and renewable energy sectors' short-, medium- and long-term needs and priorities in relation to policy and regulatory research, and

iii. Develop a research agenda to address such needs and priorities over the life of the BECRC.

Outcomes

RESEARCH PRIORITIES IDENTIFIED

Priority 1

Studies with a focus on Australia and substantive policy and regulatory issues addressing different and integrated sectors. In this regard, aquaculture and multi-use platforms warrant special consideration.

Complexity and uncertainty

Areas requiring investigation include:

Priority 1

1. Understanding the policy and regulatory arrangements that apply to blue economy uses, activities and resources across multiple sectors and jurisdictions. This includes: (a) mapping such arrangements, and (b) analysing gaps and overlaps that may hinder the development and operation of blue economy activities. This research is currently being funded by the Blue Economy CRC under the general project scheme (project no. 5.20.007).
2. Understanding existing policy and regulatory frameworks (including responsible agencies) that apply to offshore ocean energy and aquaculture. This should include investigating the relationships to existing environmental legislation, including the EPBC Act 1999, as well as identifying areas where blue economy activities are unlikely to be permitted under existing conservation regulation. Institutional arrangements should also be investigated, including intergovernmental committees to facilitate coordination.
3. Assessing the capacity of such frameworks to assess risks and impacts associated with offshore energy and aquaculture activities. Research in this area should also focus on policy and regulatory issues that may delay or prevent the development and deployment of offshore energy and aquaculture. Special attention should be given to such issues associated with integrated multi-use platforms, which will present additional challenges to regulate. Another key research need refers to exploring options for developing fit-for-purpose policy and regulation.
4. Investigation into regulatory frameworks that translate environmental research into levels of environmental outcome that have clear definition and enable public consultation. Identification of gaps in the environmental research for these frameworks.

Priority 2

1. Investigating mechanisms for streamlining existing regulations pertaining to multiple levels of government. Such mechanisms may include marine spatial planning and the concept of one-stop shop.
2. Examining the potential role of renewable ocean energy in climate policy, i.e. State and Commonwealth efforts to reduce carbon emissions. This research area may include investigating options for developing policy to stimulate renewable ocean energy markets.
3. Exploring options for developing policy coherence and coordination across multiples levels of government as well as policy sectors at the same level of government; as well as options for developing a whole-of-government approach to policy and regulation.

Priority 3

1. Developing guidelines for policy and regulatory best practice for the blue economy. Research in this area should investigate national and international jurisdictions that may allow for co-learning. This includes experiences with addressing policy and regulatory complexity and uncertainty; streamlining the permission system, e.g., the implementation of one-stop shop approach; and marine spatial planning.

Permission system

Areas requiring investigation include:

Priority 1

1. Investigation into optimum processes for testing, trials, and final granting of leases; including environmental monitoring that allows for adjustment to conditions of lease.
2. Investigation into conditions and areas allowed for exploration permits, including development of milestones as conditions attached to titles.

Priority 2

1. Investigation into what levels of financial assurance would be required at different stages of the permission process. This should include such assurance as that required for decommissioning.

Marine spatial planning

Areas requiring investigation include:

Priority 1

1. Exploring options for using marine spatial planning and other policy instruments to address multiple and competing offshore uses, which may include the establishment of renewable energy zones, or multi-use zones.
2. Investigating how marine spatial planning, as a policy tool, may support and accommodate existing International commitments (e.g. UN Sustainable Development Goals), Australian legislation and Ministerial responsibilities; the need for improved public consultation. This includes understanding how best to use a combination of social, economic and biophysical data/information layers.
3. Investigate how to allocate resources in a fair and equitable way to ensure that royalties from offshore sites are handled in ways that deliver the optimal public good, but which do not create a barrier to the development of the offshore blue economy. In this context, it is important to investigate how marine spatial planning may support the integration of spatial areas and the identification of areas where optimum royalties can be gained. The spatial information needs to support a transparent and competitive process while allowing balancing of diverse interests.
4. Investigation into levels of environmental degradation. Identify justified and acceptable thresholds for changes in benthic and pelagic environments. Identification of spatial zones suitable using modelling approaches to define habitat. Acknowledging that this research will be done in Program 4 of the CRC, the target of the work must be levels of environmental outcome that have clear definition and enable public consultation. It is preferable that habitat and levels of degradation have spatial orientation.
5. Investigation into migratory species and spatial right of ways that can form zones in spatial planning. This research will involve international collaboration.
6. Environmental monitoring, purpose built for the Australian environment, with consideration of dashboards for low risk to stressed environments to inform the public and scientific community. The design of robust monitoring programs and mitigation measures, if needed. Consideration of the role of these monitoring programs within regulation and public consultation in a spatial management framework.

Next Steps

The next steps of this work are to begin to implement the various high priority research questions in conjunction with other Research Programs of the BE CRC.

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Project Reports/Publications

Rissik, D et al. (2021). *Developing a policy and regulatory research plan for Australia's emerging blue economy, 5.20.004 – Final Project Report.* Blue Economy Cooperative Research Centre.

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