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Perspectives on a way forward for ocean renewable energy in Australia☆

Mark A. Hemer [a, *], Richard Manasseh [b], Kathleen L. McInnes [c], Irene Penesis [d], Tracey Pitman [a]

[a] CSIRO Oceans and Atmosphere, Hobart TAS 7001, Australia
[b] Swinburne University of Technology, Hawthorn, VIC, Australia
[c] CSIRO Oceans and Atmosphere, Aspendale VIC, Australia
[d] University of Tasmania, Launceston TAS, 7250, Australia

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ABSTRACT

Australia has considerable wave and tidal ocean energy resources. Development of the emerging ocean renewable energy (ORE) industry in Australia offers opportunities to build Australia's blue economy, while actively contributing to committed carbon mitigation measures. Many interdisciplinary challenges are currently hampering development of the industry in Australia, and globally, including technology, cost reduction, policy and regulations, potential for environmental effects, awareness and investment, amongst others. In October 2016, ORE technology and project developers, researchers, academics, policy makers and other stakeholders in Australia's emerging ORE industry came together to identify these challenges and develop possible pathways to grow ocean energy in Australia. Four themes were identified: Technology Development; Education and Awareness; Policy and Regulation; and Finance and Investment. This paper documents the outcomes of the meeting identifying challenges and a way forward against each theme. A key element identified across all themes was the need for stronger coordination across the sector, and the need for a representing body to lead necessary initiatives to support growth and management of the ORE industry in Australia, as one element of a burgeoning blue economy.

1. Introduction

1.1. The opportunity

1.1.1. Background

Ocean renewable energy (ORE) has the potential to provide an important contribution to Australia's future renewable energy mix. It has been estimated wave energy alone could contribute up to 10% of Australian renewable energy needs by 2030 (Behrens et al. [1]).

Australia has considerable ocean energy resources. The development of technologies to exploit this resource offers significant opportunities to grow Australia's ‘blue economy’ (growing Australia's economy by supporting future sustainable marine and offshore industries) whilst ultimately seeking to reduce carbon emissions to ensure a sustainable future. To realise these opportunities, ORE requires ongoing support through continued development of the technologies to capture the resource; strong government leadership and policy support; and a considered, coordinated organisation of the Australian ORE sector, that is, those who are actively engaged and invested in its success.

The Australian ORE community came together for the inaugural Australian ORE symposium in October 2016. On the final day of the 3 day meeting, facilitated sessions focussed discussion on future directions for the sector in a ’way forward‘ workshop, with objectives to identify: 1) the challenges hampering the ORE industry in Australia, and 2) the potential strategies and research priorities to address these challenges. This paper summarises the outcomes of the meeting: it describes the current status of the sector, the challenges and a possible pathway to grow ocean energy in Australia; building on the progress and investment made to date, and outlining the strategies to realise ORE opportunities in Australia in the coming decades.

The paper is structured as follows. First we provide an overview

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* Corresponding author. CSIRO Oceans and Atmosphere, Hobart TAS 7001, Australia.
E-mail address: Mark.Hemer@csiro.au (M.A. Hemer).

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of the opportunity for ORE in Australia. In Section 2, a brief description of the workshop is given, and the methods used to develop the shared understanding which we present in this manuscript. Section 3 presents the outcomes of the meeting, including the challenges and suggested way forward for ORE for the coming decades across four themes: Technology Development; Policy and Regulation; Education and Awareness; and Finance and Investment. We present a summary of these viewpoints in Section 4.

1.1.2. ORE in the blue economy

Australia is a marine nation that has made significant efforts – both nationally and internationally – to promote development of a blue economy. Marine industries, spanning traditional maritime industries (e.g., fisheries, coastal tourism, oil, gas and mineral production, boatbuilding and shipping and ports activities) and new and developing industries (aquaculture, bio-products, blue carbon and ORE technologies) are projected to grow through to at least 2025 at approximately three times the projected growth rate of Australia's GDP (National Marine Science Committee [2]). The 2013 position paper ‘Marine Nation 2025: Marine Science to support Australia's blue economy’ (National Marine Science Committee [2]) recommends a decadal plan be established to focus investment on the key development and sustainability challenges facing Australia's marine estate. Australia's National Marine Science Plan 2015–2050 (Treloar et al. [3]) outlines priority science challenges to meet this need, with a strong focus on Australia's comparative advantage for development of its blue economy.

Australia's wave energy resource is arguably the largest of any nation on earth (Hemer et al. [4]), predominantly focussed around the southern half of the continent (Fig. 1). Our national tidal resource remains unquantified, but large tidal ranges particularly across northern Australia indicate a sizeable resource (Fig. 1). Global tidal dissipation studies (Egbert and Ray [5]) shows a significant proportion of global tidal energy dissipation occurs on the NW Australian shelf, reflecting the size of resource in the region. Assessing the technical tidal resource for Australia is an objective of the underway Australian Tidal Energy (AusTEN) project (Penesis et al. [6]). Together, our ORE resources far exceed our current electricity demand (which is somewhat unique in a global context; Fig. 2). Australia also has access to other large fossil-fuel (coal) and renewable energy (wind and solar) resources (Geoscience Australia and BREE [7]), but ORE offer advantages that are complementary in a portfolio of clean energy technologies. While ORE also varies in time and space, wave power is largely uncorrelated with wind power; has only a third of the variability seen by wind power; and can be forecast three times further ahead than wind (Behrens et al. [1]). Tidal energy is predictable over very long time-frames, and completely uncorrelated with wind. Neither of these technologies are limited diurnally like solar photovoltaic (PV). As a result. ORE has the potential to smooth out supply within an integrated, distributed power network.

1.1.3. Australia's energy/emissions commitments

The major driver for transition to renewable energy in Australia is the commitment to the 2015 Paris agreement, which aims to limit global warming to well-below 2 °C (UNFCCC [8]). With electricity generation accounting for 33% of Australia's national greenhouse gas inventory in 2013–14 (Australian Department of Environment [9]), decarbonisation of Australia's electricity systems would contribute significant reductions to Australia's emissions. Presently, Australia has a large scale renewable energy target of 33 TW h by 2020 (Australian Department of Energy and the Environment [10]) to contribute in part to the necessary emission reductions. This equates to about 23.5% of Australia's electricity generation in 2020 being from renewable sources. To meet this target will require about 18000 TWh of annual renewable energy generation in addition to what currently exists. This requires around 6000 MW of capacity to be installed – approvals for wind and solar generation plants already exceed this threshold (Clean Energy Council [11]). Current Australian Government priorities are to implement a ‘National Energy Guarantee’, to address electricity affordability, reliability and emissions challenges. The guarantee proposes an emissions guarantee, to contribute to Australia's international

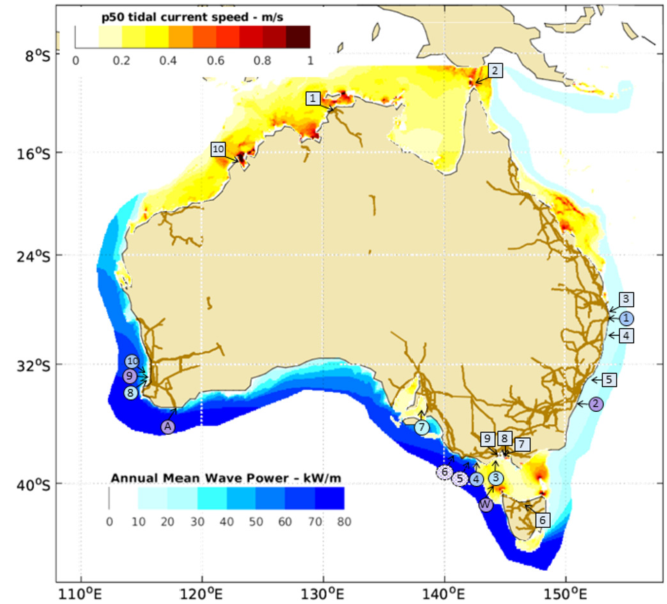

Fig. 1. Map displaying distribution of Australia's wave energy (Hemer et al. [4]; blue colours) and tidal energy (Behrens et al. [1]; red colours) resource. The tidal resource is derived from a coarse resolution model, and underestimates available resource, but demonstrated distribution of the most energetic regions. Wave and tidal resource areas are almost mutually exclusive. Circles (squares) represent locations of wave (tidal) energy developments. Colours correspond to TRL (see Fig. 3). Numbers correspond to projects listed by Manasseh et al. [25]. Two projects not included in Ref. [25] are (A) – Carnegie Clean Energy Ltd's CETO6 Albany Wave Project, and (W) – Wave Swell Energy Ltd's bed mounted OWC project planned for King Island. Both projects have progressed since the AORES. Distribution of Australia's transmission lines are displayed.

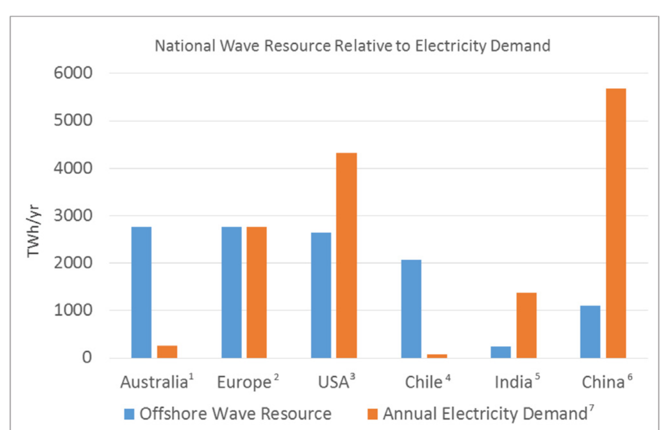

Fig. 2. Wave Energy Resource relative to Total Electricity Demand by Country. Offshore Wave Energy Resource data is presented, derived from (1) Hemer et al. [4]; (2) Clement et al. [57]; (3) EPRI [58]; (4) DCNS [59]; (5) Kumar and Anoop [60]; (6) Zhang et al. [61]. Electricity demand or production for each country is taken from the Global Energy Statistical Yearbook 2016 Enerdata [62].

commitments, and a reliability guarantee. The reliability guarantee proposes sufficient availability of dispatchable energy (coal, gas, battery or hydro) to ensure reliability within a mix of variable generation renewables (Australian Government Department of Energy and Environment [12]). No recognition of the greater reliability of the ORE resources relative to wind or solar is evident. In order to bring Australia's renewable energy policy in-line with emission reductions required to meet our international commitments, members of Australia's Climate Change Authority recently proposed increasing the renewable energy target to 65% by 2030 (Hamilton and Karoly [13]). This would require a rapid, large scale transition to alternative emission-free energy systems.

1.1.4. Electricity demand projections

Australia's electricity consumption has remained largely flat over the past several years (AEMO, 2016). Furthermore, despite a projected 30% growth in Australia's population and the Australian economy over the next 20 years, energy efficiency gains and increased uptake of domestic PV lead to a flat demand forecast over this period (AEMO [14]). This limits demand for new electricity generation for the Australian grid. However, 72% of Australia's coal-generation fleet (which provide ~50% of Australia's electricity needs) are past their original design life (Climate Council of Australia [15]). Regardless of climate factors, Australia must plan to replace its coal-fired power stations and look to install new electricity generation to replace ageing generators (Climate Council of Australia [15]). This provides an opportunity for the transition to low-emission energy generation.

Transport accounts for approximately 27% of Australia's energy consumption (Australian Department of Industry and Science [16]) and 16% of Australia's greenhouse gas emissions (Climate Change Authority [17]). Electrification of Australia's transport systems – particularly light vehicles which account for 10% of emissions alone – will increase generation demand. Meeting this increased demand with clean energy technologies can also play a significant role in reducing Australia's emissions.

1.1.5. Existing skills and infrastructure

Australia's offshore-engineering skills and support infrastructure means that ORE developments can benefit from an established marine-industrial base. Australia has an offshore oil and gas industry which has recently declined following a major boom period. Transferring developed oil and gas technical skills and resources toward Australia's developing ORE supply chain will no doubt accelerate the delivery of renewable energy from our oceans. ORE provides opportunity for economic development of Australian coastal regional communities through increased port and harbour activities and ORE supply chain related industries.

1.1.6. Spin-off benefits

With 85% of Australians living within 50 km of the coast (Australian Bureau of Statistics [18]), ORE offers a reliable and consistent supply of energy near to demand, with most technologies deployed out of sight offshore (under the surface or sufficiently far offshore and low profile to not be seen by the casual observer) thereby not taking up limited land space. Rapid development of the wind energy sector has outpaced strategic land use planning and motivated opposition amongst some sectors of the community (Harvey et al. [19]). Offshore operations thus become a more viable option.

Ocean renewable energy offers a means of electricity generation for remote islands and other remote coastal communities which can prove to be cost-effective relative to current dependence on diesel generation. Recent studies for power generation for Pacific Islands (Bosserelle et al. [20]) projects the costs of generating energy using waves are on par with other renewable energies such as solar and wind, given the consistency of resource. Wind and solar energy however have shown rapid cost reductions which must be matched by ORE if it is to develop further.

Coastal protection infrastructure will be increasingly relied upon in the coming decades to deal with increasing exposure to coastal hazards associated with sea-level rise and other climate driven coastal changes (Manasseh et al. [21]). Integration of electricity generation within these structures (breakwaters, sea-walls and offshore reefs) provides examples of the potential co-benefits of ORE, ultimately reducing the effective levelised cost of electricity from ocean sources.

Another growth industry in the blue economy providing opportunity for ORE is aquaculture, which increasingly seeks to move operations offshore (Huon Tasmania [22]). This introduces alternative demands on power with ORE providing a potential solution to meet this need. Australia's tidal resources are predominantly located across northern Australia. The northern Australia development plan (Australian Government [23]) will increase demand for electricity across Australia's north, providing opportunity for tidal energy development. The potential of exporting Australian ORE has also been noted (James [24]; Manasseh et al. [25]).

Energy, carbon and water are inextricably linked, and intersections arise in multiple areas of supply and demand. In addition to committed reduction in greenhouse gas emissions, Australia faces strong future regulation of water consumption in the face of increased demand (with increasing population) and reduced availability associated with climate change and land-use changes. Desalination is identified as one method by which this water gap can be addressed, but is dependent on high energy availability (PMSEIC [26]). ORE, with power at the source provides a natural mechanism to support this objective. Furthermore, ORE does not have the same water demands as other electricity generation (coal, concentrated solar thermal and PV, and biofuel cultivation and processing all have water demands which exceed that of wind or ORE technologies (Spang et al. [27])).

Application through these multiple niche opportunities provides a path for technological development of ORE devices. This provision of energy, beyond the utility scale application, will enable the suitability of ORE to be demonstrated as a legitimate contributor to Australia's future energy mix. The presence of all ORE options in Australian waters offers further opportunities for the nation to be a test-bed for technology development. This may offer an economic advantage beyond meeting local power demands.

1.1.7. International standing

Whilst Europe has provided substantially greater resources to support the emerging ORE industry, notable developments have taken place in Australia (see reviews by Behrens et al. [1] and Manasseh et al. [25]). Carnegie Clean Energy Ltd (formerly Carnegie Wave Energy Ltd) projects have demonstrated application of the CETO technology for extended deployments (Carnegie Clean Energy [28]), and are comparable in maturity with other international wave technologies. Carnegie Clean Energy Ltd's current wave energy project is based in Albany, financially supported by the Western Australian State Government. This project aims to develop and demonstrate deployment of the 1 MW CETO6 WEC, and establish a Wave Energy Research Centre (with partners University of Western Australia) as a regional development incentive (WA Govt [29]). Atlantis Resources Ltd, the developer leading the world's most mature tidal energy project 'MeyGen' in Scotland was founded in Australia before heading to Singapore in 2006 to access increased support (Atlantis Resources [30]). The ORE industry remains sufficiently immature that domestic support for the industry would reduce the risk of innovators shifting offshore, thereby losing opportunities for Australia to export technological IP and skills overseas. Since the 2016 meeting, Bombora Wave Power have established and concentrated operations in Pembrokeshire, Wales.

1.1.8. ORE as part of the australian national marine research priorities

The National Marine Science Plan proposes a National Blue Economy Innovation Fund (Treloar et al. [3]) (as one of six priority investment initiatives in the plan). An intention of this fund is to capitalise on new opportunities to sustainably develop Australia's blue economy by promoting and commercialising innovation in ORE, amongst other industries. Here we intend to outline priorities for direction of the fund to incentivise transition of existing skills to support the ORE sector, reduce risks and ultimately costs of technology and accelerate the industry to the point that it becomes competitive both nationally and internationally.

1.2. ORE technologies in Australia

Ocean renewable energy comprises a number of different technologies, but in Australia – at least in the next couple of decades - the predominant focus is on wave and tidal technologies. Ocean Thermal Energy Conversion technologies are also in development internationally, but Australia offers limited resource opportunities (Behrens et al. [1]). Australia currently has no deployed offshore wind, although Offshore Energy's 'Star of the South Energy Project' is in the initial stages of development to investigate and assess an area off the south coast of Gippsland, SE Australia, to determine its suitability to eventually construct a 2 GW offshore wind farm. Other technologies are also in development internationally that are similarly classified as ORE (e.g., ocean current, to harness the energy of the major ocean boundary currents such as the East Australian Current, and salinity gradient technologies), but are less mature than wave and tidal. Offshore wind energy is also recognised as an ORE technology, more mature than wave and tidal technology we focus on here. Prior Australian assessments have identified limited opportunity for offshore wind (Messali and Diesendorf [31]), however development of floating turbines will overcome this limitation. Regardless, wave and tidal energy are the focus of the current study. Several Australian developers of wave and tidal energy technologies exist, which were classified and described in detail by Manasseh et al. [25] and are summarised in Figs. 1 and 3.

Wave Energy Converter (WEC) technologies derive energy from the motion of the waves. There are a great variety of WEC designs in development, which harness the oscillating motion of the waves in different ways. These each have different conditions to which they are ideally suited, and can be deployed in a range of situations from on the shoreline, in near-shore water depths, and offshore in water depths exceeding 100 m. The range of devices can be classified into point absorbers, attenuators and terminators, based on the effect the devices have on the wave field, but other characterisations exist (Manasseh et al. [25]; Falcao [32]; Lopez et al. [33]; Fig. 3).

Tidal Stream turbine technologies harness the flow of currents to produce electricity. There are several companies developing turbines, with a smaller variety of types. Horizontal axis turbines are

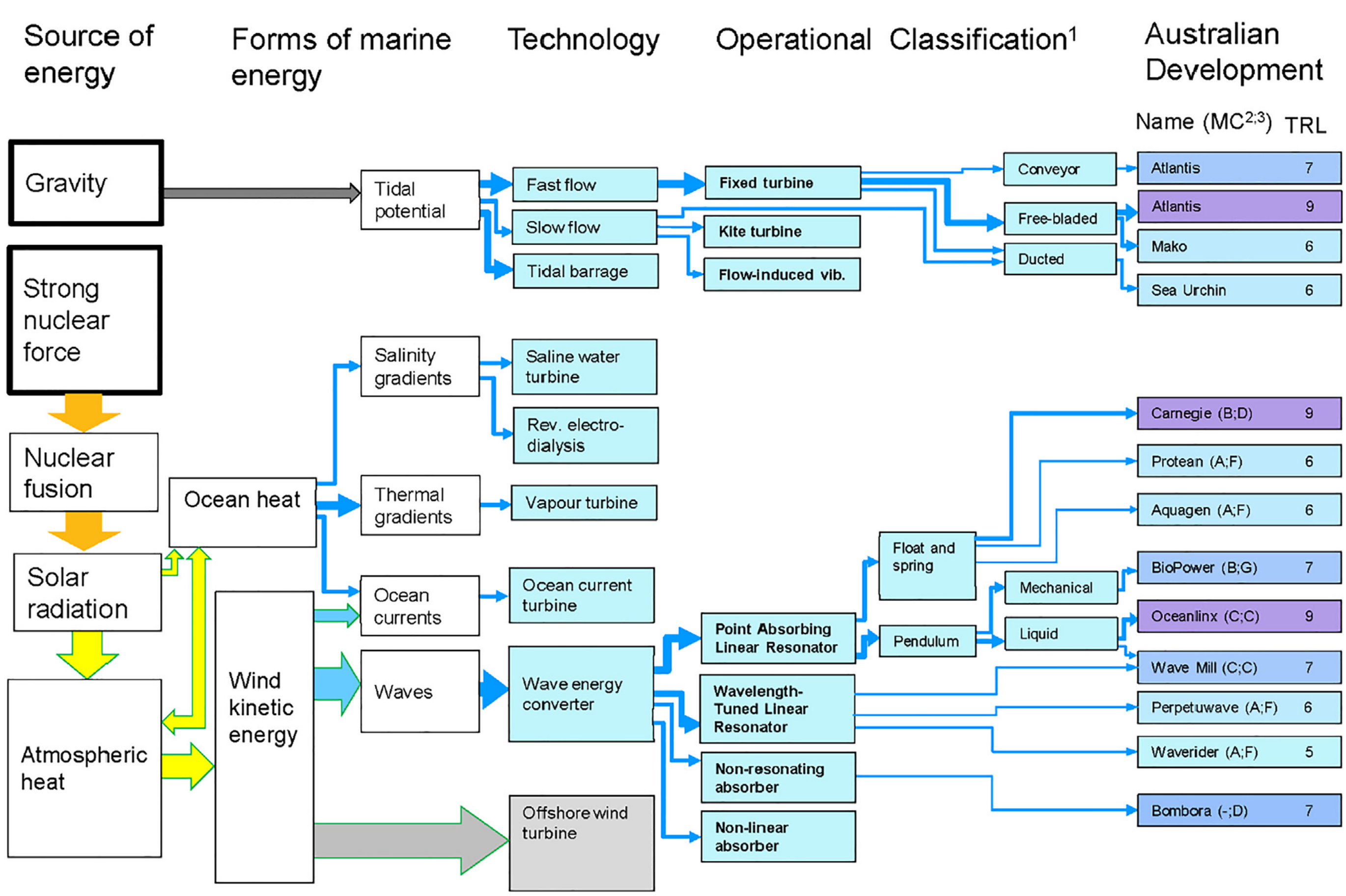

Fig. 3. Australian marine renewable energy developments, displaying Technological Readiness Levels (TRL's). 1 – Operational characterisation follows Manasseh et al. [25], 2 - The morphological classification classification codes follow Falcao [32]: A, oscillating body, floating; B: oscillating body, submerged; C, oscillating water column; and 3 – classification following Lopez et al. [33]): D, submerged pressure differential; E, overtopping; F, floating structure; G, oscillating wave surge converter.

similar in concept to wind turbines, but operating under the sea. A slight variant of the horizontal axis turbine are ducted 'open-centre' turbines. Vertical axis turbines, tidal kite turbines and oscillating hydrofoils are alternative technologies able to harness energy by moving through the tidal stream. Tidal turbines can be mounted directly to the seabed, or buoyant and moored to the seabed, floating on the surface or mid-water column.

Tidal range energy systems rely on the difference in sea level between high and low tides to create power. It uses the same principle as conventional hydropower and requires a barrier to impound a large body of water. Historically, this has included tidal barrage systems only, but small scale artificial lagoon systems are now being developed internationally. A tidal barrage system has been proposed for north-western Australia [see Manasseh et al. [25], Fig. 1].

2. Methods

The third day of the Australian Ocean Renewable Energy Symposium comprised a full day facilitated workshop with three aims, including to identify: a) the 'desired future state' for an Australian ORE Industry, b) what was required to motivate progress towards that desired future, and c) possible bases of collaboration to facilitate ongoing progress. The workshop attracted 96 attendees in total, including representatives from industry (wave and tidal technology and project developers; 18 attendees); publically funded research agencies (predominantly marine scientists; 19 attendees); the University sector (predominantly marine engineering; 17 academics, 11 graduate students); and Government (policy developers and regulators from State and Commonwealth; 9 attendees). Other attendees came from a range of industries including grid network operators, the finance sector, engineering consultants, and renewable energy advocates. Four international invitees (from the UK, US and NZ) recognised as experts in identified fields of interest to the Australian community were also present. The workshop followed two days of plenary conference sessions, which included valuable oversight of the international industry via keynote presentations, and an overview of the current research and industry activities underway in Australia.

Two weeks prior to the workshop, an on-line survey was circulated to all registered participants. The survey asked participants to share their expectations of the workshop, and to identify what they considered to be the most pressing needs' to enable the industry to progress over the coming three years. They were asked to categorise these needs into themes: Technical; Policy and Regulation; Education and awareness; Investment; or other. They were also asked why they identified these as priority needs, and what benefit would come from addressing these needs. Responses to the pre-workshop survey guided the workshop planning and were summarised and presented in the first session of the workshop.

The first session of the workshop also included a number of keynote presentations to motivate discussion, with speakers from the broader renewable energy sector, the Australian ORE industry sector, Australian Government renewable energy financiers, and the International ORE research community. The following session involved table-group and plenary discussion, where participants further elucidated the challenges and opportunities for the Australian ORE sector.

In the third session, more in-depth small-group discussions were carried out. Participants worked in theme-groups and were free to choose the theme of most interest to them, and were also free to move between groups. Each theme-group was asked to identify and list the challenges and opportunities associated with their theme and possible strategies to meet these. Once this list was compiled, each theme-group was asked to place each strategic action on a grid: with one axis to prioritise their list on the basis of potential impact, and on the other axis a timeline required to address or address the challenge or deliver need. A final session, also in self-selected table groups, discussed collaboration mechanisms, with a final plenary reaching consensus on next steps and ongoing collaboration. The key recommendation from this plenary was an agreement to hold a biennial Australian ORE Symposium.

Outcomes from all workshop sessions were compiled, and summarised and were the foundation for the first draft of this manuscript. That draft manuscript was circulated to all meeting participants for further input. This manuscript incorporates consideration of all feedback on the first draft received from the workshop participants.

3. Supporting a successful ORE industry in Australia

This section details the outcomes of the workshop discussions across the four themes identified above (Table 1). Addressing these four themes is critical for success of the ORE industry in Australia.

3.1. Technology development

3.1.1. Challenges

ORE is an emerging technology, and Australia is home to

Table 1
Top ranked priorities for each theme on short and longer term (5-yr) time-frames.

Theme	Short-term priority	Longer-term priority (5-yr time-scale)
Technical	Assess the benefit of an Australian ORE test facility to accelerate development of the local industry.	Convergence of ORE technologies; Established assessment model; Share common infrastructure; Standardise parts/ suppliers. Body of knowledge built on effects (economic, social, environmental) of ORE deployments on other sectors of Australia's emerging Blue economy.
Policy and Regulation	Develop a streamlined permitting pathway for ORE projects, covering environmental, OHS, multi-use management and other requirements; Tiered permitting for R&D; Trials; small-medium scale developments; medium-long term developments	ORE development target within the revised post 2020 Australian Government Renewable Energy Target. Recognition of values beyond cost for alternate renewable energy systems (e.g., resource consistency).
Education and Awareness	Establish a cross-sectoral ORE body which has the role of representing Australian ORE domestically and internationally, communicating to policy makers, and among industry, researchers and community	Strong connectivity of Australian ORE sector internationally; with Australian Government; and partnerships with complementary industry and established supply chain. A knowledgeable community.
Investment	Development of an investment tool to assess ORE project readiness, and providing information to developers of potential finance options, latest research and approvals procedures	Development of an Australian Government energy strategy which addresses all renewables (see P&R above). This demonstrates importance of policy certainty for growing investment in emerging renewable energy technologies.

approximately ten ORE technology development companies, ranging from less mature groups seeking to demonstrate concept devices, through to globally recognised companies with high levels of operational experience. The designs of ORE technologies, particularly wave energy converters, have not yet converged on a smaller number of optimal device designs, which is expected to occur as the sector matures. Manasseh et al. [25] note, however, that the apparent diversity in outward appearance need not translate to fundamental differences in efficiency or practicality, and the wave energy converters will likely maintain a level of diversity greater than seen for wind, for example, owing to advantages of some technologies for secondary applications (e.g., coastal protection). The financial support available to any individual technology is limited when such a diverse range of technologies are to be considered by potential investors. The challenge remains to converge device design towards preferred, most cost-effective, and most site-appropriate wave and tidal technologies. Developers feel pressure to focus on utility-scale energy solutions, but opportunities to apply the technology to niche markets (such as the remote-area or coastal-protection applications mentioned in Section 1) may provide a viable path for developing and demonstrating performance. In some cases, a "niche" market from the perspective of the Australian economy could nevertheless feed into a large global market.

The ocean is a harsh environment in which to deploy infrastructure. Therefore structures must not only be designed to maximise energy performance in average energy conditions, but also withstand the high structural loads associated with extreme sea conditions. An ongoing challenge is the design of technologies to meet both these needs and keep capital costs down.

The technical challenges facing ORE extend beyond wave energy converter or tidal turbine device development. Research is required at all stages of the value chain, with a potential advantage of ORE in a low emission energy mix being the ability to stabilise the network. Furthermore, technological development in the industry must be mindful of the environmental effects of deployments (discussed in Section 3.2 below). To meet these end-to-end challenges, strong ongoing collaboration is warranted across academia, industry and government, to identify key knowledge gaps and develop a robust industry development plan.

3.1.2. A way forward

ORE technology is at the difficult point of maturity where significant investments are needed to deploy demonstration devices to obtain the most learnings. Multi-year datasets measuring performance and effects of deployment, typically over 5 year, or 25 device year deployments, are required. These deployments will provide information not only on power outputs (which has been the focus of much technological development), but also on stress fatigue measurements, environmental impacts, and provide knowledge on deployment and installation, operations and maintenance practice and associated costs. This experience will provide the information required to more accurately understand the relative costs of the whole system, and will help identify which aspects of the system should be the focus for research and development (R&D) activities to reduce levelised cost of electricity (LCOE) of ORE systems. Development of ORE technologies in Australia is being led by the private sector. Demonstration deployments will be industry-led, with support from the research community to address identified challenges. Strong industry-research collaborations, supported through co-investment and Government incentives can accelerate technological development of systems and company growth. Research and development to support policy frameworks and environmental assessments are less likely to be accessed via this path, and will require alternative funding support.

Funding in Australia has supported development of a range of wave energy technologies, and internationally technology diversity is high. The large variety of WEC technologies is seen as an obstacle to be overcome to achieve maturity of the wave energy industry, with convergence of technologies identified as an objective to be achieved in the coming decade. This will require collaboration and openness amongst the technology developers who are understandably protective of their IP. Technology development (and R&D policy and funding) should be carried out within a framework that enables device performance to be assessed while ensuring an equitable opportunity is provided to alternate technologies. Ultimately this will support convergence towards a reduced number of optimal device types that are best suited to particular geographical or economic circumstances. Incentivising collaboration between ORE device developers and encouraging amalgamation of technologies can support this desired outcome, with funding contingent on sharing results and lessons learnt. Clear international guidelines for assessing technologies, based on transparent decision making processes, must be developed to justify decisions.

Prior to full scale deployments, technology developers must demonstrate maturity by following best practice development pathways, as established internationally (e.g., Ingram et al. [34]; Day et al. [35]). This requires device developers to proceed through the Technology Readiness Levels (TRLs) (e.g., Mankins [36]). TRL 1–3 correspond to research stages up to and including proof of concept, TRL 4–5 correspond to component, sub-system and system validation in laboratories and/or simulated operational environments and TRL 6–9 correspond to prototype demonstration in operational environment through to system proving via successful deployment.

In addition to optimising power output, and ensuring lowering of cost, technology development should focus effort on meeting the shortcomings of current renewable energy technologies by seeking to deliver a reliable and secure low-emission energy system. For example, can ocean energy systems provide inertia which helps stabilise the frequency of the grid, or dispatchable power for the network? How does ORE best integrate with other low-emission energy technologies and storage solutions?

Being less variable, ocean wave and tidal resources can provide a more consistent form of renewable energy than wind and solar. A diverse and distributed energy supply will limit variability across a network, and thus inclusion of ORE amongst wind and solar will reduce fluctuations in supply, for the reasons mentioned in section 1. Energy storage technology is recognised as a solution to variable energy supply. Ocean technologies, being less variable, will require less storage capacity. The challenge for ocean renewables is for ocean energy plus required storage capacity to be cost competitive with wind/solar plus required storage capacity. Rapid reductions in cost of storage, as seen in recent years (Schmidt et al. [37]), may limit this advantage for ORE. Investigation of cost-effective storage solutions which best complement ocean energy resources should be carried out, with consideration of battery technologies, the suitability of pumped hydro (terrestrial and marine), hydrogen and compressed air technologies (traditional and marine). Integration of storage systems within ORE devices could provide consistent inertial power supply sought by grid operators. Energy storage has its limitations, for example under scenarios such as successive cold, windless winter nights, which is of concern to electricity-market operators (AEMO [38]). The consistency of ORE has capacity to limit these risks.

Many open ocean test facilities for ORE devices have now been established internationally (e.g. European Marine Energy Centre - see http://www.emec.org.uk), and these provide opportunities for Australian device developers to test their systems under fully instrumented and monitored conditions. However, there are several arguments for having a national test facility to accelerate development of ORE in Australia, which include; supporting the development of local ORE supply chain related industries, enhancing education and awareness, and facilitating development of policy frameworks for the industry. As example of the potential benefits of a test facility, site assessment (characterisation and environmental approvals) and cable connection to shore can account for a considerable portion of the total cost of a project. A test facility would effectively share this cost between projects, and enable investment to focus on development and performance of the ORE device(s), assess devices on benefits associated with grid stabilisation, and reduce potential risks associated with cable connection problems for individual projects. A cost-benefit analysis of the value of such a facility, which could provide infrastructure for an overarching centre of excellence for ORE, should be undertaken to assess whether these benefits are adequately addressed by the available international facilities. Such a facility would provide the foundation, installation and power delivery solutions for a range of technologies and significantly reduce the capital required to test different technologies.

Major funders (e.g., The Australian Renewable Energy Agency, ARENA) carry out due diligence on the structural, geotechnical and installation challenges associated with proposed projects. This creates a significant body of knowledge from which the industry as a whole can gain knowledge. Capturing information from ‘failed’ projects, with cause of failure understood, is also important to ensure that knowledge is maximised. The knowledge base must be nurtured among a strong collaborative network crossing industry, government and academia. This network should regularly review knowledge gaps and identify these as priorities for targeted research activities. There is high value in these priorities being defined from a sectoral perspective as opposed to from the individual company level.

3.2. Policy and regulations

3.2.1. Challenges

As an early stage technology, the policy framework for ORE is sparse. Renewable energy as a whole has been subject to high policy uncertainty in Australia for several years, and this has also been felt by the less mature technologies such as ORE. Bipartisan Government support for renewable energy generally, co-ordination amongst the States, and recognition of ORE as a valid renewable energy technology, is critical for ORE to continue to mature in Australia. ARENA is an Australian Commonwealth agency whose role is to fill the notable gap in investment to accelerate emerging renewable energy along the innovation chain from early stage research to large scale pre-commercial deployment. The ARENA investment focus for ORE is centred on capturing and sharing data from existing projects to add to the pool of global knowledge; continuing to engage with the Australian marine energy companies; and monitoring global developments (ARENA [39]). Contrary to some other countries, no targeted policy or market incentive support (e.g., Capacity targets, or Feed in Tariffs) exists to support ORE in Australia. ORE requires Government incentives to ensure Australian companies continue to develop IP in Australia. It also requires support to monitor and actively engage in international activities. Several Australian companies have already shifted their operations offshore, which contributes to Australia's ‘brain-drain’, loss of exportable IP, and decreased capability to build the required skills for future industry.

Another argument for increased International engagement by Australia within the ORE sector is associated with development of standards for ORE technologies. Australia's lack of engagement in the IEC working group leaves the local industry potentially exposed to having to comply with standards not suited or excessively stringent for Australian conditions. Furthermore, adherence to these standards may stifle innovative R&D.

Marine spatial planning is an important component of the legislative framework for ORE developments, and requires consideration of complementary (particularly for niche applications) or competing uses of the marine domain (Flocard et al. [40]). There is a well-established policy framework related to maritime use and offshore exploitation. However these typically focus on single issues or sectors (e.g., zoning of fishing). A framework for management of multiple sectors in the marine environment is not well established. For example, environmental impact assessments are a critical aspect of approvals which must be overcome for a development to proceed. Current impact assessment methods consider a linear ‘additive’ approach to assessing risk of industry on the marine environment. This has been found to be insufficient for addressing the cumulative impacts of multiple sectors (Business Council of British Columbia [41]). How environmental impact assessments address multiple stressors is an important consideration for future marine planning, and possible growth of ORE in Australia. The development of appropriate planning frameworks will ultimately help industry by smoothing the development process, giving greater certainty and timelines for approvals, providing social license to operate, and avoiding costs associated with potential approval-related project delays.

Marine planning for ORE in Australia is complicated by the lack of consistency between different jurisdictions in which ORE developments may occur (e.g. State and Commonwealth waters). The EU has similar difficulties, and resolving marine spatial planning policies across jurisdictions, under EU or International agreements (Jacques et al. [42]). Australia has strong capability in marine spatial planning policy, but to date ORE has not factored strongly within the conversation. Australian engagement in the international discussion for integrated ocean planning and management with due consideration of ORE is required (Warner [43]).

Whilst progress has been made through the IEA OES Annex IV (Copping et al. [44]), understanding of the environmental effects of ocean energy deployments, including potential impacts on marine organisms through noise, mechanical interference impacting the surrounding wave environment and consequent sediment movement, or habitat destruction, continue to be based on limited knowledge, particularly at a community or ecosystem level. Adaptive management approaches are largely followed. This enables small scale developments to proceed, which can be monitored for associated effects. As example of the necessary research required to build knowledge in this area, Carnegie Clean Energy enabled independent access to their Perth Wave Energy project, to assess the effects of the deployment of their array of three CETO-5 WECs on the surrounding wave field (Contardo et al. [45]). Whilst developments must undertake environmental impact assessments prior to deployment (e.g., Biopower Systems [46]), the immaturity of the sector requires that a knowledge base on the potential environmental impacts of device deployment continue to be collected, preferably independent of the project proponent(s). This is critical as ocean energy developments expand towards array scale deployments where potential impacts may occur over long time-frames, and regulation frameworks are developed.

ORE developments are targeted at locations ranging from on or very near shore, out to deep water exceeding 100 m depth. Depending on the site, developers may need to gain consent from the land owner at point of cable crossing (e.g., local government), and from Government for the marine operations (e.g., State Government for region between high water at the coast and 3 nautical mile limit, and Commonwealth Government for area beyond the 3 nm limit). Local and State Government process differs by jurisdiction, with some regions having more mature process than others. As ocean energy becomes more familiar, this process will improve, but establishing consistent policy between jurisdictions will support ORE project development. Strong engagement with indigenous Australia should underpin ongoing development of ORE in Australian waters.

3.2.2. A way forward

Critical to development of any renewable energy technology is a policy framework which continues growth of the renewable energy target beyond the current levels set for 2020–2030. A coordinated ORE sector network would provide a framework from which to express a common ORE industry voice on the role of ORE. Therefore the establishment of a coordinated ORE network is considered an important step to ensure ORE can actively engage and gain consideration during policy reviews (e.g., the Finkel review into the Future Security of the National Electricity Market (Finkel [47]), and the anticipated 2017 climate and clean energy policy reviews).

The ORE network could also provide a single point of communication to consult with State and Commonwealth planning bodies, to guide development of a streamlined permitting (legislation and consent) pathway for ORE developments. These should be scaled relative to the stage of development, from R&D, through demonstration and trials to small-medium scale developments to ultimately medium-long term array scale developments. A network representative can provide a focus for ministerial liaison, and departmental contacts. The network must increase international engagement so that greatest learning can be gained from environmental assessment and consenting processes that have been developed and implemented elsewhere, and adapted to Australian conditions.

The potential value of a test facility has been highlighted. Such a facility would streamline the permitting process to allow for device testing and improvements to be made without the restriction and overhead of repeatedly obtaining approvals. The test site could facilitate demonstration of device performance, support technology development, enable rigorous assessment of the environmental effects of device deployment, and with demonstrated performance, ultimately reduce insurance costs and improve industry access to finance.

3.3. Education and awareness

3.3.1. Challenges

The ORE industry in Australia is small and has developed over the past decade from a number of small companies making good progress. Being a relatively immature technology in Australia, there is still a low awareness and understanding of ORE technologies amongst the community and decision makers. Low societal understanding can impact on the social license to operate to allow the industry to move forward. Low understanding amongst decision makers may lead to a lack of recognition of the benefits of ORE and limit the development of clear regulatory frameworks, thereby disadvantaging ORE relative to other clean energy technologies. Visible failures of ORE technology on Australia's shorelines, left stranded and not removed from public view, have also contributed to some negative views on the industry.

Australia has some significant ORE developments, but these more mature developments have largely proceeded through engagement by individual companies acting independently of an industry ‘group’. Prior efforts to coordinate the ORE sector in Australia have attempted to unite the industry, but have been unable to sustain themselves. This has limited how the ORE sector is perceived in Australia, and internationally. Relative to other countries, Australia does have some notable activities. However vision of these activities from the international community has been limited owing to a lack of engagement of Australia within international working groups who act to support development of ORE more broadly.

3.3.2. A way forward

The benefits of a coordinated sector are now recognised. Clear oversight of the roles of participants from industry, investment, government and academic sectors is required. The Australian Ocean Renewable Energy Symposium was recognised as a useful mechanism towards a more coordinated sector, but there remains an ongoing need for an Australian ORE network that communicates both upwards and laterally.

An Australian ORE network would establish a framework from which the sector could contribute unified information on ORE to the public debate and influence policies; take ownership of developing a clear industry message and development plan; support start-up developers to identify funding opportunities and the requirements to maximise success; establish a database for all associated information across industry/research/Government; and facilitate information and secure data sharing to support growth of the industry. Such information sharing must be sympathetic to both industry and academic requirements, ensuring protection of IP where applicable, but working towards a goal of building support for the sector.

The network would unify the sector in Australia, and in addition to opening domestic level knowledge sharing, would provide a conduit for Australian activities to be communicated inwards and outwards internationally. Australian engagement in international activities such as the IEA ocean energy systems working group, the IEC technical committee developing international standards for the industry, international ocean observing networks to support the sector, the postgraduate INORE network and engaging in postgraduate exchange programmes would ensure that Australia is maximising its investment in ORE, and obtaining maximum benefit from the larger international community to support growth of the local industry.

The network must engage with related industries (e.g., the oil and gas sector who have required expertise and infrastructure to support ORE, and may also seek to diversify and de-risk from fossil fuel-based industries, but also other industries who will make up the supply chain in a mature sector). The network should span industry, government and academia and seek to be inclusive of multiple disciplines (currently academic interest in ORE in Australia is limited to the engineering disciplines, but much could be achieved with greater engagement from the ecological and social sciences). Outreach to Ministers and engagement with Government policy makers will ensure awareness and funding and regulatory frameworks are developed in consultation with industry. Development of a community engagement plan can be established to overcome issues to obtain a social license to operate.

Such networks have been established in other countries/regions with attractive ORE resources (e.g., Ocean Energy Europe, Marine Energy Wales, Oregon Wave Energy Trust), and similar networks have been established in Australia for other renewable technologies facing issues similar to ORE (e.g., Bioenergy Australia, Australian Geothermal Energy Association). Such networks have been instrumental in promoting and attracting investment to support growth of the industry (e.g., European investment in ocean energy, US Govt investment in a test centre in Oregon, ocean energy development targets).

Accelerating Australia's shift to renewable energies depends, among other things, on the accessibility, diffusion and mobilisation of new skills and training – both for young people, and current workers outside the sector with transferrable skills (NMSC [2];

Hatfield-Dodds et al. [48]). An efficient training system must be integrated with considered policies to deliver targeted education to ensure enough qualified workers can fill current and future critical positions in a growing ORE sector. The associated change in demand for skills, will present a challenge for providers of training and education in ORE supply chain related industries. Australian higher education and vocational education and training (VET) centres have identified that implementing coordinated curriculums and programs that focus on future needs of the maritime industry supply chain is required – including, for example, engineering and construction, research and development, manufacturing, operations and maintenance, maritime logistics, and business services (Penesis et al. [49]). Education providers in other parts of the world are already delivering targeted training to support the growing ORE industry, for example in Canada (Natural Resources Canada [50]), Europe and America (Joint [51]), and have recognised that a new generation of engineers are needed to meet the challenge posed by ORE (Borthwick [52]). It is likely that collaboration between university, VET and industry will lead to breakthroughs necessary for commercialising Australia's ORE resources. Achieving this will involve a coordinated approach to addressing future skill requirements for the ORE supply chain, of which there are many, although most fall under STEM skills and supply chain management. Quantifying these flow on benefits will provide a stronger argument for attracting Government support for the sector.

An institutional focus, for example through a Centre of Excellence or Test Centre, also provides opportunity to educate and build awareness of ORE through all levels of society, forming a nexus for communication and sharing of knowledge. Such a facility may also provide opportunity for public demonstrations and communication and education programs (primary, secondary and tertiary).

3.4. Investment

3.4.1. Challenges

The level of investment is a prominent challenge facing the ORE industry in Australia. The Australian Renewable Energy Agency (ARENA) is currently a leading source of funds to support development of an ocean energy industry in Australia. To date, ARENA has contributed more than $47 million (ARENA [53]) to at least eleven ORE projects. Two of these (Oceanlinx Port MacDonnell deployment and the OPT Portland project) were closed prior to completion owing to technical and financial challenges. With other funds, more than $130 million has been invested in ocean energy in Australia. Other Government support for ORE has come through the Australian Research Council Linkage program, and potential opportunities exist through the National Science and Innovation agenda.

Obtaining private investment to cross the gap between R&D and deployment is an ongoing challenge owing to high finance risks associated with early stage technologies. A number of external factors have also hindered access to this investment, including uncertainty surrounding renewable energy policy, a perception of increased risk owing to prior industry failures (e.g., OceanLinx), and the competiveness of alternative technologies (e.g., solar, wind, storage), which have demonstrated rapid cost reductions. These factors require the industry to more strongly demonstrate the value of ORE, in order to attract funds to support fundamental research, coordination and knowledge sharing, as well as demonstration and deployment of Australian technologies, which can contribute to Australian energy needs and can be exported to the world. This should be achieved by focussing R&D on reducing the LCOE of ORE (achieved through innovation, experience, and scale of operations), and advocating advantages of ORE (predictability and consistency of resource thereby reducing dependency on storage) in a future energy mix with high penetration of wind and solar.

There are many contributing factors to the LCOE of ORE devices: development; infrastructure; mooring/foundation; device structural components; power take-off; subsystem integration and profit margin; installation; contingency; OpEx. For individual units at the pilot stage of development, the cost of infrastructure is a significant component. This component is substantially reduced with the scale up to arrays with 100 units (Jenne et al. [54]). Environmental monitoring OpEx costs are a significant component in the early phase of development, which can also be expected to be reduced. The costs of cabling to offshore generation have been noted as a large (up to 40%) component of costs, and so mutualising these costs through arrays, or combining with other technologies (e.g., offshore wind) provides potential cost reductions (Fig. 4). A large component of costs can be attributed to the structural components of a device that must be engineered to withstand ocean extremes (e.g., high wave load conditions).

3.4.2. A way forward

For ORE to progress, it must be recognised as making a viable contribution to the low-emission energy mix of the future. This requires the benefits and risks of ORE to be identified and quantified relative to other clean energy technologies. A key consideration in such an assessment is the environment in which ORE must operate (requiring engineering to withstand significant loads) in comparison to the relatively benign conditions in which on-shore wind and solar PV operate. Industry, Government and Academia must work together to develop a clear long-term ORE industry development plan. Development of ORE technologies requires considerable investment. The relatively small investment to support a coordinated network (as detailed in above sections) has been shown in other regions of the world to be effective in increasing investment in the ORE industry to support these capital intensive projects.

Niche applications for ORE provide potential investment opportunities which can help support development of systems. These include integration of ORE technologies into the design of other infrastructure, such as coastal management and protection infrastructure, power for offshore industry, or recreational amenities. Integrated systems also serve to ultimately reduce relative costs of

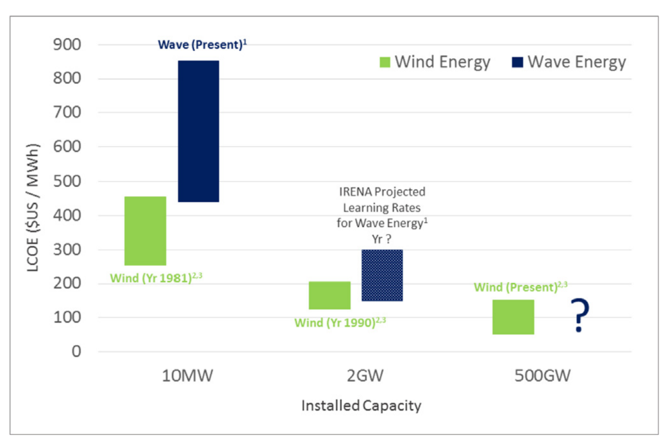

Fig. 4. Cost projections for wave energy by installed capacity, relative to on-shore wind energy cost reductions. [1.] Wave energy costs and projected learning rates are taken from International Renewable Energy Agency (IRENA) Wave Energy Technology Brief (2014), available from http://www.irena.org/DocumentDownloads/Publications/Wave-Energy_V4_web.pdf. [2.] Historical wind installed capacity was derived from the Global Wind Energy Council. [3.] Wind energy LCOE were derived from the World Energy Council World Energy Resources: Wind report, 2016, available at: https://www.worldenergy.org/wp-content/uploads/2017/03/WEResources_Wind_2016.pdf.

the energy produced.

Upfront capital is critical for development of ORE technologies. To support the transition from technology development to revenue-based support, diverse sources of funding are required. Current Commonwealth support for ORE is obtained through recognition of the potential value of the renewable energy generation. The potential value of the blue economy in Australia is slowly being recognised and the National Marine Science Plan's proposed national blue economy innovation fund (one of six priority investment initiatives in the NMSP) is intended to capitalise on opportunities to sustainably develop our blue economy by promoting and commercialising ORE amongst other new ocean technologies. The Commonwealth has provided significant investment in ORE technologies through the Advancing and Emerging Renewables programs. Funding support for emerging technologies, such as the Emerging Renewables program, must be kept distinct from support for mature technologies. There is potential for the impact of this investment to be lessened should this support be removed too early.

The industry would benefit from the development of a dynamic investment tool, which directs developers to potential financing options (e.g., R&D funding and private investor schemes), guidelines for policy and legislation requirements, and research contacts and advances, and assessment of project readiness. Identification of LCOE, taking into account additional benefits (e.g., grid support), would provide guidance of where cost reductions are best achieved.

Renewable energy policy in Australia prioritises introduction of lowest cost renewable energy, without consideration of other factors which offer value in the energy system. Development of policy which recognises the added value of predictability and consistency in the renewable energy system would support development of a robust and reliable renewable energy electricity network for Australia. Focussed research effort on the energy security benefit of ORE in the energy mix is required to justify whether a tiered investment strategy (e.g., banded feed-in-tariff as has been implemented in the UK (Renewable Obligation Certificates, ROCs) (DECC [55]) and Canada (Nova Scotia Department of Energy [56]) is warranted to support development of a diverse energy mix across the future distributed renewable energy network.

Significant cost reductions for ORE may be achieved by collaborating more closely with other sectors. Supporting secondment of personnel from offshore industries and/or the electricity/power industry would introduce experience into the emerging sector, and offer a means to redirect government investment in O&G/Maritime industries (which hold a considerable skill base) to support the emergence of ORE.

4. Key recommendations

A number of key recommendations were identified from the workshop documents that are believed to support growth of Australia's ORE industry.

4.1. A supported and expanded Australian ORE network

While some networks of AORE exist in Australia, a strengthening and broadening of the network was identified across all four themes of the ‘way forward’ workshop as a key (necessary) mechanism to accelerate ORE development in Australia. Prior attempts at establishing such a network have proven unsustainable, relying heavily on individual persons to motivate the group. Prior networks have been industry-focussed only, without crossing to academia or government research agencies. There is much capability within Australia's research and development sector to support Australia's ORE industry (Table 2) and the broader inclusion of this capability within a future network may be beneficial for ongoing sustainability. There are many forms such a network may take. The Clean Energy Council already operates to support the ORE in a minor way, but representation is limited by the income of member organisations (which is small for ORE). To increase representation of ORE, injection of financial support (recognising the less mature status of ORE) to support an officer responsible for ORE would be beneficial. Industry-government co-investment to support the officer therefore emerges as a recommendation. An alternative model is a grass roots organisation, which could build off the success of the AORES, in the form of a community society, which would rely heavily on in-kind contributions from members (e.g, rotating chair). Operating costs would be supported via membership costs, which span a broad range of members.

4.2. An Australia ORE officer

The community advocated the appointment of a central ORE officer. Such a position would have many and broad responsibilities, identified as:

- Lateral communication across the ORE network (email newsletters, social media)
- Upwards communication of status of ORE sector to Government (ARENA and Ministers) and other stakeholders
- Central point of contact for membership activity and in ORE working groups (IEA OES, IEC TC, INORE and similar), and associated communications
- Knowledge database development of Australian ORE industry learnings, and development of an investment tool to assess and guide project readiness
- Development of an Australian ORE industry roadmap, and industry development plan
- Organisation of working group meetings and future AORES
- Facilitation of PhD and industry secondments (domestically and internationally)

The industry (network) must consult closely with State and Commonwealth Government to establish streamlined consenting process for ORE developments, particularly at the demonstration (small scale) study phase.

4.3. Consideration of an Australia ORE test facility

An Australian ORE test facility should be considered, and assessed in terms of the value it could offer to accelerate growth of the industry in Australia. Such a facility could underpin an overarching collaboration between industry, government and academia to support development of ORE technologies, build skills and capability to support the emerging industry, and grow public awareness and establish a social license to operate. Such a facility must provide significant value beyond what could be achieved by Australian companies testing their technologies at international facilities.

4.4. An economic value assessment for ORE in Australia

The benefits of ORE as a component of a growing Australian blue economy should be quantified and communicated as potential argument for growth of the industry in Australia. Such analysis should investigate the economic contributions of the sector in Australia to date, understand future development plans, and identify how ORE might contribute to Australia's future low carbon economy. The analysis should also recognise the blue economy is

Table 2
Capabilities and facilities of Australian Research and Academic institutions.

Institute/Department	Capabilities	Facilities
Research Institutes		
Australian Institute of Marine Science	Coastal Wave and Tidal resource assessments; Benthic community mapping & long-term monitoring; Cumulative impact assessment	Shelf and coastal Research Vessels, oceanographic instrumentation, tropical benthic habitat assessment.
Bureau of Meteorology	Operational ocean and marine forecasting including wind, waves, tides and currents	24/7 operations, sustained ocean and marine observing systems, supercomputing
CSIRO (Oceans and Atmosphere; Energy)	Wave and tidal resource and site assessment; Cumulative impacts and social license to operate; Economic feasibility assessment (Behrens et al. [1]; Hemer et al. [4])	Research vessels; oceanographic instrumentation; Energy economic modelling infrastructure
Geoscience Australia	Environmental impacts; Seabed characterisation (Geoscience Australian and BREE [7])	Multibeam sonar; Datacube satellite imagery portal; geomorphic and ecological models
Universities		
Curtin University (Department of Mechanical Engineering)	Mechanical load prediction; power assessment; coupled CFD modelling	High Performance Computing (HPC) resources
Deakin University (School of Life and Environmental Sciences; Energy)	Marine spatial planning, policy and regulation; Seabed mapping and Marine habitat assessment; Grid systems, battery technology and material design. (Flocard et al. [40]; Ierodiaconou et al. [63]; Kennedy et al. [64])	Coastal oceanographic vessel, multibeam sonar, remote video and unmanned aerial vehicles.
Griffith University (Griffith Centre for Coastal Management)	Coastal hydro- and morpho-dynamics monitoring and modelling, wave resource assessment, coastal zone management (Morim et al. [65])	Research vessels, coastal monitoring instrumentation, laboratory wave flume
Monash University (Dept of Mechanical and Aerospace Engineering)	CFD modelling of wave-structure interactions; Marine Current Turbine Prototype testing; Multiphase fluid dynamics	40 m glass-walled wave flume
Swinburne University (Department of Mechanical and Product Design Engineering)	Resonators in wave fields; Streaming flows driven by wave resonators; Flow-induced vibrations	10 m wave channel; random wave maker
University of Adelaide (Mechanical Engineering)	Linear and non-linear modelling and control system development for wave energy converters; Wave energy farm modelling and optimisation; Scale-model experiments of wave energy converters	Wave flume for scale tests; high fidelity numerical models; Phoenix High Performance Computing cluster (ranked in the top 5 in Australia)
University of New South Wales (Water Research Laboratory)	Physical modelling of wave energy converters; Technical coastal engineering design assessment; Field data collection for resource assessment.	Wave flumes and basin; Model instrumentation; Wave and current measurement instrumentation;
University of Queensland (School of Civil Engineering)	Renewable energy site characterisation; Model design and analysis of test results; Environmental monitoring of Renewable systems	Wave flume testing facilities; coastal and offshore field instrumentation and deployment; numerical modelling of wave processes
University of Tasmania (Australian Maritime College)	Numerical and experimental modelling of ships, offshore structures, marine renewable energy devices etc.; study of multi-body, wave-structure and array interactions; site characterisation and environmental impact assessment.	Hydrodynamic research facilities http://www.amc.edu.au/facilities; Vessels; Autonomous Underwater Vehicles (AUVs) and field instrumentation; Marine energy precinct
University of Western Australia (Ocean Institute)	Seabed characterisation, foundation and anchoring design; operational and extreme hydrodynamics; wave resource and environmental impact assessment	National Geotechnical Centrifuge Facility; Dual Paddle 50 m long Coastal and Offshore wave flume (1.2 m deep, 1.5 m wide); oceanographic field instrumentation: Wave Energy Research Centre

growing internationally and ORE technology development provides opportunity for export of Australian IP.

4.5. Renewable energy policy support

In a broader context, it was recognised that for ORE to have a future in Australia, renewable energy policy must be extended to acknowledge the need for further uptake of renewable energy beyond 2020. Future policies must focus on low-emission energy security, which requires diverse, distributed generation. Renewable energy technologies need to be valued not only in terms of cost but also in terms of reliability and consistency.

5. Summary

A transition to low-emission energy technologies to decarbonise Australia's electricity system is imperative for a sustainable future. This need is recognised by Australia's commitment to the Paris Agreement to limit warming to well-below 2 °C. Current policy supports increased uptake of renewable energy systems through to 2020, but policies to support ongoing uptake beyond 2020 must emerge if we are to meet the necessary objective. ORE technologies provide a solution which could contribute towards this goal. The advantages of ORE within the mix of energy solutions arises because the resource is less variable and more predictable than alternative renewable solutions such as wind or solar. Furthermore, ORE offers great opportunity for Australia, by utilising our comparatively large marine estate, and considerable ocean energy resources, to contribute to the rapid growth of the blue economy.

Development of ORE technologies has lagged behind other terrestrial based renewable technologies. This slower path to maturity can be attributed to challenges associated with extracting energy from what can be a harsh marine environment. This gives rise to a range of interdisciplinary challenges which must be addressed if ORE is to mature and deliver to its potential in Australia, and internationally. The Australian ORE community has recognised these challenges within four themes – (1) the technical challenges being development of technologies to generate optimum energy, at lowest cost, with least environmental impact; (2) challenges associated with educating a work force who have the capacity to meet the challenges of an emerging sector, and a community to recognise the benefits a mature ORE industry can provide; (3) the policy and regulation challenges which must be addressed to effectively manage the multiple uses of Australia's marine environment, while enabling a supportive framework for an emerging industry; and (4) the investment challenges which face an industry where policy uncertainty has hampered development and uptake of both mature and immature renewable energy technologies.

In discussing these challenges, the Australian ORE community have identified a number of activities which should be pursued to motivate future growth of ORE in Australia (and internationally). One thing is clear however; the industry and associated stakeholders are not being well represented by any existing organisation, structure or institute. The AORES workshop was successful in motivating emergence of an Australian ORE 'community'. There is now a recognised need for a cross-sectoral ORE body to be established able to maintain drive for the Australian industry domestically and internationally, through effective communication of challenges and advantages of ORE with policy makers, and among industry, researchers and community. The establishment of such a body was identified as a pre-cursor for recommended activities, which would follow and are in need of a champion (and support) to lead and facilitate them.

There are many tasks required to motivate an ORE industry in Australia, but overcoming obstacles which Australian technology developers presently face have high priority. Current developments in Australia have been responsible for development of projects which span from 'wave to wire', requiring separate permitting and grid connections, for example, in addition to the developer's primary task of developing, testing and demonstrating their technology. ORE test facilities, of which there are now many internationally, provide an option to overcome and share some of these difficulties. Consideration for an Australian facility should be given, noting that there must be value to Australian developers beyond what could be achieved by them utilising international options. Streamlining early-stage permitting, and building a knowledge-base for Australian conditions (economic, environmental and social) are good arguments to support development of an Australian facility. Attracting investment – public and private – is a challenge for the sector in a competing environment of low-emission technologies. Current investment focusses on lowest cost technologies without recognising other benefits such as consistency required for an electricity grid with high penetration of variable renewable energy systems. Increased awareness, and policy to support these benefits (e.g., tiered incentives) are required to turn this investment challenge around. As an island continent, Australians recognise the value of their oceans for many purposes. In the face of the current challenge to decarbonise the country's electricity system, our oceans again offer a potential solution. Realising this solution will require a coordinated and motivated community.

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