ecoENERGY Innovation Initiative

Research and Development Component

Public Report

Project: RENE-082

Contents

1 Project Snapshot

Project Title	West Coast Wave Initiative (WCWI)
Project Identification Number	RENE – 082
Proponent	University of Victoria
Number of Participating Partners	14
Total Project Cost ($000s)	$3,771.40
Total Contribution from Proponent and partners ($000s)	$1,299.30
Total ecoEii Contribution ($000s)	$1,930.30
Total Government Contribution ($000s)	$2,472.11
Project Highlights	○ Gross Resource: Industry leading 12-yr hindcast and 48-hr forecast of wave conditions off Vancouver Island at 50m nearshore spatial resolution ○ Net Resource: Detailed coupled hydrodynamic and power-take-off simulation models of five (5) leading national and international wave energy conversion (WEC) technologies. ○ Useable Resource: Simulated and quantified understanding of the impact and value of wave energy for remote communities (Hot Springs Cove, BC) and utility scale power generation (British Columbia).
Date submitted to NRCan	20/02/23

2 Executive Summary

The West Coast Wave Initiative (WCWI), within the Institute of Integrated Energy Systems, at the University of Victoria is Canada's premium wave energy research and development program. Under the ecoEii, WCWI collaborated with leading national and international Wave Energy Converter (WEC) technology developers, Canadian service providers, and academic partners to accelerate the development of the Canadian marine energy sector; to both improve competitiveness in the international market, and attract international players to Canada.

The development of the Canadian wave energy industry has historically been hampered by a dearth of sufficiently resolved information about the gross wave energy resource, the net power production from (WECs) in Canadian waters and the impact of usable wave energy in to electricity grids. The financial impacts and personnel requirements to adequately quantify the gross, net and usable wave energy resource are beyond the financial and technical resources of a single developer. The WCWI was conceived and mandated to provide the wave energy industry with the knowledge, tools and databases to overcome these barriers.

The WCWI effort was characterized by three parallel research streams; gross wave energy resource assessment, net energy WEC technology modelling and useable energy integration studies. The WCWI wave energy resource assessment provided a significant step-change in the understanding and knowledge of Western Canada's wave energy resource; based on high-fidelity numerical SWAN models and development of the world's largest reconfigurable network of wave energy specific measurement buoys. The resulting 12 year hindcast and continuous 48 hour forecast of wave conditions, allowed WCWI to provide industrial collaborators Resolute Marine Energy (RME), Seawood Designs (SD) and Carnegie Wave Energy with definitive technical resource assessments. The knowledge and data generated assisted in the development of TS 62600-101 for the International Electrotechnical Commission (IEC), and benefiting local communities by live- streaming of current wave conditions.

Working in direct collaboration with RME, SD, Ocean Energy Ltd, AOE Accumulated Ocean Energy and Dynamic Systems Analysis, the WCWI technology modelling research stream developed a unique and internationally recognised suite of modelling tools for wave energy technologies. The unique coupling of hydrodynamic and Power Take Off (PTO) software packages, using unique device control algorithms, provided each collaborating technology with improved device performance metrics and better understanding of their device dynamics. The modelling was validated using experimental wave tank testing. The best practices informed the IEC TS 62600-100 and were published in high impact peer review academic journals.

Finally, the opportunity and impact of integrating WEC-generated power into remote community and utility scale grids was quantified. Utilizing the resource and technology modelling databases, the integration research stream was able to provide the necessary and sufficient data to quantify the opportunity and hurdles for wave energy integration, at a variety of scales. These results benefited to BC Hydro, WEC developers, and off-grid communities' integration efforts.

3 Introduction

The West Coast Wave Initiative project was divided into two subprojects; Subproject A covers the original project conducted during 2011-16, and Subproject B covering the ecoEii Add-on Project which was conducted during 2015-16.

Subproject A: West Coast Wave Initiative

Subproject A consisted of four (4) phases; Project Initialization and Administration, Wave Energy Resource Assessment, WEC Performances Assessment and WEC Integration Studies.

The Wave Energy Resource Assessment phase focussed on deploying three (3) wave measurement buoys off the coast of Vancouver Island and developing SWAN, REF/DIF and SWASH nearshore computational wave models to build a precise picture of the wave resource off Vancouver Island. The WEC Performance Assessment phase utilized the wave data to drive high-fidelity computer simulations of four (4) partnering organizations full-scale WEC devices, and methods to control the WEC. The WEC Integration Studies Phase utilized the WEC performance data to study the integration of wave energy at three scales: remote off-grid community (kW), Vancouver Island (MW) and Western Canada (GW).

The key stakeholders in the Subproject A included four (4) wave energy device developers (Resolute Marine Energy, Seawood Designs, Ocean Energy Ltd., and Carnegie Wave Energy), a WEC tuning technology developer (Triple X Energy), a oceanographic measurement device manufacturer (Axys Technologies), simulation and modelling tools developers (Dynamic Systems Analysis and Cascadia Coast Research) and other academic and research institutions (Pacific Institute for Climate Solutions)

Subproject B: West Coast Wave Initiative Add-on

Subproject B consisted of three (3) phases; Project Management and Communications, Improved WEC ProteusDS Simulations, and Refined Techno-Economic Analyses.

The Improved WEC ProteusDS Simulation phase focussed on adding a new Canadian WEC developer (AOE Accumulated Ocean Energy) to the WCWI collaborative, developing novel plug-ins for ProteusDS to account for their unique PTO design, and improving the run-time speeds of ProteusDS. The Refined Techno-Economic Analyses focussed on provide the most up-to-date economic analysis of offshore cables expenses and the integration of wave with other renewable energy supplies for remote off-grid communities.

The key stakeholders in Subproject B included an additional Canadian WEC developer (AOE Accumulated Ocean Energy), an international undersea cabling specialist (MacArtney Underwater Systems) and a remote community engagement specialist (Barkley Group).

This report will provide additional detail on the background for the West Coast Wave Initiative, the project objectives, the deliverables made to project partners and the value to Canada, and finally provide an objective view of the challenges and next steps for this research and development effort.

4 Background

While the magnitude of the Canada's raw wave energy resource is widely acknowledged, there was little detailed information to realize the promise of wave energy in Canada. To support the development of Canada's wave energy potential, the West Coast Wave Initiative proposed to develop a precise description of:

- The Canadian wave energy resource – a region of strategic importance for the development of a future marine energy industry,
- The expected performance of full scale commercial wave energy converters (WECs) when deployed in that region, and
- The best techno-economic strategy for the integration of the WEC supplied power at off-grid and grid connected community scales.

The Project utilized the significant expertise centered in the Proponent's Integrated Energy Systems Institute (IESVic) hosted in the Faculty of Engineering. The Proponent, and IESVic in particular, is an established international leader in energy systems research. Science Watch ranked IESVic the fifth most influential institution internationally in terms of the impact of its research in the area of energy and fuels between 1998 and 2008. Faculty members in IESVic have been very active in the past eight years in the area of renewable energy research with a focus on energy storage technology development, renewable energy integration and wind turbine technology.

This Project built upon the former West Coast Wave Collaboration Program (WCWCP). The WCWCP maintained a WatchMate wave monitoring buoy at Ucluelet and developed a Simulating WAves Nearshore (SWAN) model of lower Vancouver Island. The WCWI greatly expanded the geographic scope of the SWAN modelling to cover the South and Central coasts of British Columbia, increased the model spatial resolution and deployed an additional two (2) wave measurement buoys. These research efforts were needed to address the resource uncertainty gap in the Canadian wave energy industry. The marine energy specific deployment locations and development pathway for the SWAN model are innovative and industry leading. The WEC modelling effort evolved from Dr. Buckham cabling modelling efforts and previous interactions between Dynamic Systems Analysis and UVic. The WEC modelling within WCWI is beyond the economic and personnel capabilities of many wave energy developers – hence, WCWI will help bring the necessary fidelity of WEC modelling to mitigate uncertainty in full-scale WEC power production.

Finally, the IESVic researchers engaged in the WCWI have already developed various community, regional and provincial scale electrical grid models and have used these models to consider how intermittent renewable energy (primarily wind) can be utilized at these scales. The WCWI will help address the knowledge gap in terms of the value of utilizing the local wave energy resource to produce electrical power.

5 Objectives

The Project built an accurate and precise description of:

- The raw Canadian wave resource
- The potential of wave energy converters to harness that resource
- The means to incorporate that converters power in electrical grids

The Project focused on the West Coast of Vancouver Island (WCVI), a strategic region for wave energy. The Project aimed to develop a low cost numerical test bed for WECs in the WCVI region and use simulated performance data to consider the means for wave energy integration at multiple scales: kilowatt (kW) scale at the case study off grid, remote First Nations community of Hot Springs Cove on the shores of Hesquiaht Sound BC; megawatt (MW) scale on the Vancouver Island grid; and gigawatt (GW) scale on the BC provincial grid.

Under Subproject B, the WCWI added some additional more specific objectives. These included: expanding the numerical test bed for a novel pneumatic Canadian WEC technology; adding additional techno-economic layers to the integration studies at kW and MW scale; and implementing new algorithms to improve the computational speed of numerical tools.

The following sections describe the project Phases in detail, address any changes since initially proposed, and the relative impact of meeting each individual objective on the overall project, and the wave energy industry as a whole.

5.1 Wave Energy Resource Assessment

The Project used a combination of three (3) field deployed wave measurement buoys and three (3) differing numerical wave propagation models to build a precise picture of the wave energy resource off Vancouver Island.

The wave measurement buoys were used to gain precise wave energy resource data at locations within the measurement area and to validate the numerical wave propagation model. The WCWI worked closely with partner, AXYS Technologies, to deploy, maintain and recover WCWI's three (3) wave measurement buoys. These included two WatchMate buoys and TriAXYS buoy.

The wave propagation model involved building a 40,000 km^2 SWAN model for the WCVI and a smaller, higher fidelity REF/DIF model for Hesquiaht Sound. Initially, it was proposed that the SWAN model would be coupled with a nearshore SWASH model, to allow further detail for shallow water depths, yet this was deemed non-critical path by partnering WEC developers.

The additional time budgeted for SWASH modelling were invested in increasing the spatial resolution of the SWAN model in regions of specific interest. The SWAN model utilized data from the European Centre for Medium Range Weather Forecast (ECMWF), the United States Fleet Numerical Meteorology and Oceanography Centre (FNMOC) and Oregon State University (OSU). The 12yr hindcast (2004 – 2015) and rolling 48 hr forecast of wave conditions for the entire WCVI region was completed.

The combination of the suite of wave measurement buoys and the numerical wave propagation model allowed the most complete and precise assessment of the wave climate for WCVI to be completed. The characteristics of the wave climate, its potential energy, its fluctuations and annual pattern was quantified and passed to the WEC Performance Assessment phase.

The energy industry has been impacted via:

- The partner developers have been provided with high resolution data from the buoys that can be used for further WEC development and control.
- An overview of the wave climate has been released through scholarly works and at internationally recognised conferences.
- A summary of wave data is available to the public though the WCWI website and it constantly used by developers, marine vessel captains, fishers and surfers on Vancouver Island
- Input into the Natural Resources Canada's Clean Energy Resources and Projects Atlas.
- WCWI is internationally recognised for its wave resource measurement, modelling and assessment programs.
- WCWI have ensured research findings are helping inform International Electrotechnical Commission (IEC) Technical Specifications 62600-101 and 62600-102.

5.2 WEC Performance Assessment

The Project used gross wave resource data to drive high-fidelity, coupled hydrodynamic and power-take-off (PTO) computer simulations of four (4) partnering wave energy converters at full scale.

The four (4) different WECs were: WCWI's international self reacting two body point absorber (SRPA), Resolute Marine Energy's oscillating flap, Seawood Designs' Surfpower float, and Ocean Energy Ltd's floating oscillating water column (OWC). The simulation software, ProteusDS, was provided by Dynamics Systems Analysis and was used to model each device at full scale to predict their power production for the seastates that were determined from the wave resource assessment. Different control schemes were implemented on each device to improve power production.

For the WCWI's SRPA, a 1:20 and 1:55 physical model were built, tested at Memorial University of Newfoundland and the resulting data was used to validate the numerical results. The two body point absorber was modeled with a theoretically optimal PTO system, its mooring system was investigated for robustness under extreme conditions, and a 1:20 system was built incorporating the Triple X Energy wave energy tuning system.

The Resolute Marine Energy oscillating flap was modeled with a fully hydraulic PTO system, which was controlled for different objectives, and a simpler nonlinear spring and columbic damper system. It was also physically and numerically modelled at 1:40 scale in the UVic wave flume. Seawood Designs' SurfPower float WEC was modeled at full scale and controlled via a proprietary energy management system, with variable sea-state dependent system pressures. Ocean Energy Ltd's OWC was numerically simulated at smaller scale model to validate against provided company data and due to the delayed delivery of the full scale dimensions. A full scale model of a comparable backward bent duct buoy (BBDB) WEC, proposed by the US National Renewable Energy Laboratory, was developed and simulated.

The energy industry has been impacted via:

- The partner developers have been received fully developed numerical models of their technologies, and been provided with reports detailing their performance.
- For specific technologies, optimization studies and the implementation of control methods have improved power production significantly.
- Control methodologies have been published through scholarly works and at internationally recognised conferences.
- Physical models of WEC's have been build, test and numerical models validated.
- WCWI has developed an internationally recognised centre for the numerical modelling and control of WEC technologies.
- WCWI have ensured research findings are helping inform International Electrotechnical Commission (IEC) Technical Specifications 62600-100 and 62600-102.

5.3 WEC Integration Studies

The WEC performance data was fed into detailed studies of wave energy integration at three (3) scales: remote off-grid communities (kW), Vancouver Island (MW), and Western Canada (GW).

At the kW remote community scale, research focussed on the First Nations community of Hot Springs Cove near the Hesquiaht Sound and utilized a unique database of power demand between 2010-2011. Implications for an electricity only and a Combined Heat and Power (CHP) system were studied.

At the MW scale, the integration of ten (10) 50 MW wave energy farms offshore of Vancouver Island were simulated were simulated using PLEXOS; an commercial energy systems modelling software. The study illustrated that energy dependency of Vancouver Island on the bulk BC utility was greatly reduced through wave energy integration and the seasonal nature of wave energy was shown have positive correlation with local demand. For larger GW scale integration research, WCWI provided the 2060 Project, a Pacific Institute of Climate Solutions (PICS) research programme, with the necessary wave data to include in long-term pathways to decarbonizing the Western Canadian power system.

The energy industry has been impacted via:

- Remote First Nations communities were investigated and the opportunity for wave energy to provide electrical power clarified.
- Results from the Vancouver Island 500 MW wave integration report were provided to BC Hydro and used in their upcoming Resource Options Report (ROR); a precursor to their long-term Integrated Resource Plan (IRP).
- The Pacific Institute of Climate Solutions is building WCWI outputs into their long-term efforts to drive decarbonized our energy system.
- WCWI has become internationally recognised for the comprehensive wave-to-wire approach; an approach which covers all major aspects of marine energy technology development.

5.4 Add-on: Improved WEC ProteusDS Simulations

The ProteusDS WEC numerical simulation toolbox was modified during 2014-2015 to allow for modelling of a unique pneumatic Canadian WEC technology and improve the computational efficiency of the software.

AOE Accumulated Ocean Energy WEC has a unique pneumatic cascaded WEC design that required the DSA ProteusDS software to be updated. A full scale AOE WEC numerical model was developed and tested with a baseline PTO control strategy; this included a fully coupled hydrodynamic, pneumatic and thermodynamic model. Additionally, the numerical architecture of ProteusDS calculations were updated to improve computational speed and numerical accuracy.

The energy industry has been impacted via:

- Canadian AOE Accumulated Ocean Energy has been provided with a detailed numerical model of their WEC and the ability to generate the necessary knowledge to design the device.
- Canadian Dynamic Systems Analysis now has an improved numerical simulation tool to assist in energy and military companies with resource extraction and water-borne procedures.
- WCWI has generic pneumatic numerical PTO models to complement the existing PTO models and is able quickly assist future WEC developers with commercialization activity.

5.5 Add-on: Refined Techno-Economic Analyses

The WEC Integration Studies phase was expanded to included detailed economic analysis of 'at-WEC' costs, provided by international cable constructors, and improved representation of wave energy potential in existing remote and Vancouver Island renewable energy electrical grid models.

Through collaboration with MacArtney Underwater Technology, WCWI has been able to determine the cost optimum WEC farm deployment arrangement; based on cabling costs and deployment activities. This allows WCWI to extent its economic analyses of wave energy development to an ‘at-WEC’ level. Implementing these economic layers in the Remote Community Optimization Model (RCOM), WCWI has been able to better quantify the implication of integration wave power into existing remote community electrical systems. Finally, through significant high-powered computing, WCWI has able to develop novel methods to easily quantify the variability of farms of WEC’s through detailed knowledge of a single WEC device.

The energy industry has been impacted via:

- The marine energy industry has been impacted by WCWI improved understanding of cabling and underwater infrastructure expenses.
- Remote communities have benefited from an improved understanding the positive interactions between wave power and their existing electricity system, when compared against other more variable renewables.
- WCWI research findings are helping inform International Electrotechnical Commission (IEC) Technical Specifications.

6 Results of Project

6.1 Project Achievements

Overall the West Coast Wave Initiative project was successful. The overarching goals of assessing the gross wave energy resources in BC, the potential to harness this resource through Wave Energy Converters (WECs), and implications of wave energy integration into electrical grids were achieved.

While many smaller (but no less important) contributions and results were achieved through the project, the following list details the higher level achievements under the three themes of WCWI.

6.1.1 High resolution knowledge of the wave climate off the WCVI

The combination of the development of the highest resolution coastal wave propagation model available for Vancouver Island and the deployment of three fully-directional wave measurement buoys off the British Columbia coast (the only directional buoys in BC) marked a step-change in the collective understanding of wave conditions and associated energy resources in BC. The associated level of detail and fidelity captured in the resulting 12 yr hindcast and continuous 48 hr forecast, in temporal and spatial wave characteristics, allowed a high level of confidence in the results, and mitigated significant risk and uncertainty when used as inputs to the WEC numerical modelling.

The validated resource dataset includes the full frequency and directional wave spectrums, thus allowing detailed post-processing to assist the development of IEC TC-114 marine energy standards development, in higher accuracy WEC numerical modelling, and for use in BC Hydro’s ROR. Additionally, the wave data from the suite of WCWI buoys are posted on-line and frequently used by ocean vessel captains, recreation boaters and surfers.

This work has lead to an NSERC Collaborative Research and Development (CRD) grant application with BC Hydro, IBM Canada, and the BC Ministry of Energy and Mines.

6.1.2 Numerical tools to accurately predict power production of WECs

Through direct collaboration with industrial WEC developers and Dynamic Systems Analysis, the WCWI team has developed a suite of WEC modelling tools that is internationally recognized for its comprehensiveness and resolution. The dynamic coupling of hydrodynamic, thermodynamic and detailed PTO models have allowed WCWI to provide the collaborating WEC developers with increased understanding of device motions and associated power production. Through the development of novel PTO control strategies and architecture optimizations, each WEC developer has the necessary numerical tools to predict their devices performance for any global location. These results have been used by WEC developer partners for business development and funding applications. For example, WCWI output was used by AOE for a Sustainable Development Technology Canada (SDTC) application.

Within BC, the combination of the detailed wave resource assessment data and the developed numerical modelling tools have allowed WCWI to output precise estimation of power production from different WECs, if deployed off the WCVI. This work has lead to an approved NSERC CRD with the BC Ministry of Energy and Mines, and AOE Accumulated Ocean Energy.

6.1.3 Integration studies to assess the impact of wave energy onto remote and utility scale electricity grids

Over the past 4 years, the WCWI team has been able to quantify the impacts, opportunities and hurdles for the integration of marine renewable energy at both the remote community and utility scale. WCWI's unique knowledge of the wave energy resource and the performance of the specific WEC designs in the measured resource, provided the necessary foundational knowledge to perform uniquely high resolution wave energy integration studies.

Through collaboration with Barkley Group and the Hesquiaht First Nations, WCWI personnel have assessed the opportunity and diesel consumption reductions associated with integrating wave energy into Hot Springs Cove. Further work, under the Add-on program, allowed this work to be expanded to include currently planned (but not operational) mini-hydroelectric and wind projects at the community. This work was expanded to include a Combined Heat and Power (CHP) model of the community and associated value proposition.

Through collaboration with the 2060 Project, the integration of 500 MW of wave power on Vancouver Island was shown to greatly improve the energy independence of the island; reducing demand on the bulk BC Hydro grid by 11% annually and reducing peak demands by up to 15%.

This work continues within the 2060 Project and several tasks within the NSERC Collaborative Research and Development (CRD) grant application with BC Hydro, IBM Canada, and the BC Ministry of Energy and Mines.

6.2 Benefits and Technology/Knowledge Development Objectives

The following section provides a description of the benefits to the WCWI collaborators, service providers and academic partners that have accrued as a result of the Project. It details how the project overall has contributed to individual technologies and associated knowledge advancement. It describes the impact of this advancement of technology/knowledge and is divided by collaborator, service providers, academics and the broader marine energy industry in Canada.

6.2.1 Benefits to WCWI Collaborators

Under the WCWI program, the collaborating WEC developers were able to realise a significant step-change in the knowledge and understanding of their technologies, and the wave energy resource off the coast of Vancouver Island.

Resolute Marine Energy, Seawood Designs and Carnegie Wave Energy each received a detailed wave resource assessment report, for specific locations chosen by the company. The resource assessment reports were based on technical standard 62600-101 from the International Electrotechnical Commission (IEC). The reports were the first wave energy resource assessments conducted in British Columbia using the new IEC standards.

Resolute Marine Energy, Ocean Energy Limited and Seawood Designs also received a validated numerical model of their devices, a full performance matrix of device power production in BC waters, and a series of technical reports detailing the methods, assumptions and performance of the numerical models. Due to a delay in providing technical details on their device, Ocean Energy Limited was provided with a numerical model proxy of their device; based on the National Renewable Energy Laboratories Backwards Bent Ducted Buoy OWC. For the WEC technology developers, the numerical modelling provided by WCWI was beyond the internal modelling capabilities of each company and allowed for higher precision understanding of their device performance.

Two (2) physical models of Triple X proprietary WEC tuning system, SWELS, were constructed and tested in the wave tank at Memorial University of Newfoundland. In addition, detailed numerical modelling provided the necessary theoretical and numerical evidence to show significant WEC device performance, when their core SWELS IP was installed. This work continues through the implementation of Graph Theory to better understand the opportunities and implications of SWELS.

AOE Accumulated Ocean Energy joined WCWI through the EcoEii Add-on project. During 2015-2016, the baseline ProteusDS code was modified to allow for modelling of AOE's proprietary cascaded pneumatic PTO. Through this combined effort, WCWI was able to provide AOE with the first complete estimation of their device performance – a key driver of the company's application to SDTC and subsequent growth. Higher fidelity numerical modelling of the AOE system continues under a NSERC CRD with AOE and the BC Ministry of Energy and Mines.

6.2.2 Benefits to WCWI Service Providers

AXYS Technologies, Dynamic Systems Analysis, Cascadia Coastal Research and MacArtney Underwater Technology all provided specialized services to WCWI under the ecoEii program. For each company, the WCWI provided them an opportunity to expand their technical expertise and data products; as well as an opportunity to work directly with international leaders in the wave energy community and develop relationships for future research and consulting.

For example; Cascadia Coastal Research and AOE Accumulated Ocean Energy have expanded their commercial relationship beyond WCWI and gained international recognition through the development of tools and knowledge about AOE's novel WEC design.

6.2.3 Benefits to WCWI Academic Partners

Under the EcoEii project, the WCWI academic partners and students were able to conduct global leading research in marine energy resource assessments, technology modelling and power integration. The impact of the research was demonstrated through approximately 15 peer-reviewed journal papers, 23 conference papers, membership on international standards development committees and numerous requests for panel discussions.

The Highly Qualified Personnel (HQP) graduating from the program have universally been employed, or started small consulting companies, within the marine sector; thus indicating the high level of industrial confidence in WCWI graduates.

6.2.4 Benefits to Canada

This Project has provided valuable support to the emerging Canadian wave energy industry. With its significant wave energy potential and well developed marine industry, Canada has benefitted greatly from a detailed overview of the wave energy resource off the BC coastline, its potential to generate carbon-neutral power, and its impact on the grid. Specifically, this Project has provided a shared understanding of the usable extent and potential of the wave energy resource off the WCVI, across a variety of ocean stakeholders. The Project has provided a sorely needed four (4) year database of physical wave measurements and a twelve (12) year numerical model simulation describing the WCVI wave energy resource.

In addition, this Project has formed a hub for innovation in wave energy in Canada. The data and tools provided by this Project have enabled wave energy technology developers to focus on accelerating Canadian based innovation in wave energy conversion. By offloading the resource assessment burden, the Project has also made the WCVI region much more attractive for the international population of WEC developers who are currently focussed on non-Canadian markets.

6.3 Challenges and Barriers

6.3.1 Wave monitoring buoy maintenance

The WCWI wave monitoring buoys required more operational support and maintenance than initially forecasted. This resulted in slight financial over-expenditures and increased personnel support. Working in direct collaboration with AXYS Technologies, the wave monitoring buoys and ancillary technology packages were re-assessed and altered to improve buoy deployment robustness. This results in a 2-yr suggested maintenance cycle, rather than the previous 6 month cycle.

6.3.2 Numerical model validation data

The WCWI technology modelling relied on collaborating WEC partners to provide the necessary tank or field testing data to validate numerical models. For some technology partners, this data was released to WCWI too late for complete validation of model performance within the project timeframe. In order to ensure deliverables were met, WCWI personnel developed numerical models for these technologies around the best publically available data.

6.3.3 Modelling software misrepresentation

In year 2 of WCWI, personnel noticed odd and unexpected numerical power production estimates from WEC simulations. Through a thorough analysis, it was determined that the representation of the wave field within the commercial software was incorrect and unrepresentative. WCWI personnel wrote an additional piece of pre-processing code as a work around and provided this to the software developer for inclusion in future releases. By year 4 of WCWI, this numerical issue had been fixed in the commercial software. Through the identification and correction of this error, the software now provides and accurate representation of the seastate – directly improving their product. Additionally, this alteration will benefit all future marine energy technology developers utilizing the software package.

6.3.4 Electrical system databases: remote and utility scale

In order to investigate the impacts of integrating wave energy into an existing electrical grid or system, detailed information about the system architecture (generators, demand, transmissions, etc) was required. For both the remote community and utility scale aspects, it took longer than expected to collect all the necessary databases to accurately represent the interactions between the existing electrical system and the wave energy generation. After working directly with the Hesquiaht First Nations and BC Hydro, these details were ultimately collected. For future integration studies, these databases have been prepared. In addition, personnel at both Hesquiaht and BC Hydro are now prepared to act on industry requests for such datasets.

6.4 Gender Based Analysis

Phase	Male	Female	Total
Project Planning/Construction/Delivery	15	4	19
Ongoing Operations	2	1	3
Total	17	5	22

7 Conclusion and Follow-up

This Project formed a hub for innovation and development of wave energy in Canada. The data and tools developed by this Project have ensured that Canada plays a leadership position in the research and development of wave energy and associated technologies. It enabled local and international wave energy technology developers to focus on accelerating needed innovation in wave energy conversion process. By offloading the industry wide need for detailed gross wave resource assessment data and grid integration burden, the Project has also made the WCVI region much more attractive for the international population of WEC developers who are currently focussed on non-Canadian markets.

The WCWI gross wave energy resource assessment and net energy technology modelling methods have been used to inform the next generation of international standards from the IEC. By developing detailed grid integration models, the WCWI has provide the first detailed view of the significant opportunity associated with the development of Canada's international completive advantage on natural wave energy resources.

7.1 Next Steps

For partnering WEC technology developers, the results from the WCWI program have lead to Sustainable Development Technology Canada (SDTC), NSERC Collaborative Research and Development (CRD), BC Innovation Council (BCIC) Ignite, Western Economic Diversification (WED) and Industrial Research Assistance Program (IRAP) grant applications. Internationally, the results from WCWI efforts have assisted in successful applications for wave energy technology deployments in Hawaii and Europe. Within the academic sphere, the numerical tools and knowledge continue to evolve and be improved, through financial support from the mentioned grant programs, to assist future WEC developers to increase the efficiency and lower the associated costs of their devices; allowing them to compete on the international stage.

The WCWI also laid the framework for the BC Ministry of Energy and Mines to investigate the technical, economic and governmental opportunities associated with developing in a dedicated Marine Energy Centre in BC. This centre would provide the necessary infrastructure and access to financial supports to allow WEC developers to accelerate their technology development lifecycles by perform scaled field tests and graduating to first commercial deployments.