Institution: Queen's University Belfast

Unit of Assessment: 14 Civil and Construction Engineering

Title of case study: Transforming the Marine Renewables Industry through Wave Power Research

1. Summary of the impact (indicative maximum 100 words)

Wave power research at Queen's has led directly to the development of two types of convertor by Aquamarine Power Ltd (Edinburgh) and Voith Hydro Wavegen (Inverness). Direct employment totalling 400 person years has resulted along with hundreds of people in other companies delivering the different phases of the prototype machines. Financed by over £60 million from both the public but mainly the private sectors, this represents 20% of the total investment in wave power worldwide during this period. Internationally recognised success in wave power has led to the establishment of the Queen's team in tidal stream energy and environmental monitoring of marine renewable systems.

2. Underpinning research (indicative maximum 500 words)

The primary focus of the Marine Renewable Energy research group at Queen's has been the physical and numerical modelling of wave power and tidal current machines leading to prototype development and performance monitoring. The first major recognition of the quality of the work at Queen's came in 1994 when Professors Whittaker FREng, Wells FRS, Long FREng and Raghunathan were awarded the prestigious Royal Society ESSO Energy prize for the pioneering work of their team which culminated in the design, construction and operation of Britain's first grid connected wave power plant, as described in ***reference 1***. The 75kW unit, located on the Isle of Islay, utilised the novel Wells turbine, was the first grid connected wave machine in Britain and operated as a marine test bed until it was decommissioned in 1999. This work led to the design and construction of a second and much larger unit, LIMPET, on an adjacent site.

LIMPET, described in ***reference 2***, built on the continuing research in the 1990's into the hydrodynamics of shallow water oscillating water columns, the aerodynamic design of the Wells turbine and the practical experience gained from operating the 75kW plant. With 2 million pounds of funding divided evenly between a European grant under framework 3 and private equity from the shareholders of Wavegen Ltd, the 500kW plant was commissioned in 2001. The plant continues to operate today as a marine test bed for Wells turbine generator units and is owned and operated by Voith Hydro Wavegen Ltd.

From 2001 the QUB team has concentrated its research on surging nearshore wave energy convertors. In 2004 the final report of ***grant 1***, concluded that it was technically feasible to efficiently extract ocean wave energy using seabed mounted bottom hinged flaps located in shallow nearshore waters and the work was deemed to be internationally leading.

Today the 32 strong team at Queen's continues with fundamental research in both wave and tidal stream energy supporting this embryonic industry and maintaining its status as a World leader in this field. From ***grant 2***, (Supergen Marine 2) and ***grant 3***, (UKCMER), ***references 4 to 6*** were generated and published in leading journals. One of the most significant impacts, described in ***reference 3***, was the analysis of the nearshore wave energy resource leading to the introduction of the concept of the exploitable wave resource and the realisation that it is not significantly less than that offshore. ***Reference 4*** has led to a significant body of work now funded by ***grant 3*** researching spectral domain modelling of wave energy converter arrays which should result in much more efficient numerical models for predicting the energy output of wave farms. ***Reference 5*** describes a novel way of controlling wave power converters to maximise power output and has now been adopted by Aquamarine Power for their Oyster wave power devices. ***Grants 4 and 5*** awarded under the EPSRC Grand Challenges in 2012 dealing with environmental modelling and survivability of marine renewable devices and along with the references cited, show that the group is at the 'leading edge' of research which is of direct relevance to industry.

During the current REF period the team has continued to research this type of device now known as Oyster™ which is being commercially developed by Aquamarine Power Ltd. The work is described in ***reference 6***. This has resulted from the accumulated wealth of knowledge gained over the past 38 years.

3. References to the research (indicative maximum of six references)

(1) *Whittaker, T.J.T. et al [1997]. **The Islay wave power project: an engineering perspective**, ICE Proc. Water Maritime and Energy **124**(3): 189-201

(2) Whittaker, T.J.T. et al [2005]. **Performance of the LIMPET wave power plant - prediction, measurement and potential**. 5th European Wave Energy Conference Proceedings. 17-20 September 2003. Cork: Ireland. Eds. Lewis, A.W. and Thomas, G., Hydraulics & Maritime Research Centre, Cork, pp. 97-104 (peer reviewed)

(3) Folley, M. and Whittaker, T. [2009]. **Analysis of the nearshore wave energy resource**, Renewable Energy **34**(7): 1709-1715

(4) Folley, M. and Whittaker, T. [2009]. **The effect of sub-optimal control and the spectral wave climate on the performance of wave energy converter arrays**, Applied Ocean Research **31**: 260-266

(5) *Folley, M. and Whittaker, T. [2009]. **The control of wave energy converters using active bipolar damping**, Proc. IMechE Part M: Journal of Engineering for the Maritime Environment **223**: 479-487

(6) *Whittaker, T. and Folley, M. [2012]. **Nearshore oscillating wave surge converters and the development of Oyster**, Philosophical Transactions of the Royal Society A **370**(1959): 345-364

*References that best indicates the quality of the underpinning research.

Grants

(1) EPSRC-GR/S12326/01, 2001-2004, 'An experimental and numerical study of oscillating wave surge converters', £177,220. (Whittaker T.J.T.)

(2) EPSRC-EP/E040136/1, Supergen Marine 2, 2007-2012, Supergen Marine Energy Research Consortium, QUB part as core member - £835,844. (Whittaker T.J.T.)

(3) EPSRC-EP/I027912/1, Supergen Marine 3, 2011-2016, UK Centre for Marine Energy Research, QUB part as a core member - £400,000. (Whittaker T.J.T.)

(4) EPSRC Marine Grand Challenge, 2012-2015, 'Large scale coupled modelling of environmental impacts of marine renewable energy farms' jointly with UCL and CEFAS, total value £1,200k, of which 50% is at QUB. (Elsaesser B., Senior Lecturer at Queen's)

(5) EPSRC-EP/J010197/1, 2012-2015, 'Modelling marine renewable energy devices; Designing for survivability', £1,039,617, of which 33% is at QUB. (Whittaker T.J.T.)

4. Details of the impact (indicative maximum 750 words)

The output of **grant 1**, which was the conceptual design of a nearshore wave power farm comprising bottom hinged flaps directly connected to the sea bed with hydraulic power take off led directly to the creation of Aquamarine Power, ***source 1***. The company was specifically formed to develop this technology and continues to do so today. Owing to the track record of the Queen's team in conceiving device concepts, undertaking the basic research and taking them to prototype

demonstration, as was demonstrated by the 75kW and LIMPET devices on the Isle of Islay, private investors backed the new company initially with £3 million and the Oyster project was born leading to the first prototype. The company's website clearly states the role of the Queen's team and Professor Whittaker in the birth of the company. The following is a direct quote from the Aquamarine Power website –

"Our story first started in 2001 when Professor Trevor Whittaker's research and development team at Queen's University, Belfast began to research flap-type wave power devices with a view to reducing the cost of energy. The R&D team's research ultimately led to the development of the Oyster wave energy device. The innovative design of the Oyster wave energy converter attracted the interest of Allan Thomson, the retired founder of WaveGen, the UK's first ever wave power company. Allan went on to co-fund further R&D into the Oyster wave power device. In 2005, Allan set up Aquamarine Power to bring Oyster wave power technology to the commercial market.

"In 2008 we completed our senior management team and our company rapidly expanded as we went from four employees to a team of 15 in only three months. We continue to grow rapidly. We now employ over 60 staff who are all working towards our vision of making marine renewable energy mainstream. SSE remains a major shareholder in Aquamarine Power. In 2010, we also secured major investment from ABB, one of the world's largest power and automation companies."

To date the total funds raised from both private finance and public grants are in excess of £60 million. Two prototypes have been deployed at sea. Oyster 1 was commissioned at the European Marine Test site on Orkney in 2009 and Oyster 800 was commissioned spring 2013.

The research team at Queen's continues to support the development of Oyster from hydrodynamic modelling in our two wave tanks, shown in ***sources 2 and 3***, to numerical simulation of both the hydrodynamics and projected electrical production. The third and fourth generations of the Oyster machines are currently under development by Aquamarine with support from the Queen's team. This complements the fundamental research being conducted under grants 3, 4 and 5. In addition the team is supporting wave and tidal power research throughout Europe through MARINET which is funded by the European Union under framework 7 and enables trans-national access to both our wave tank and tidal test facilities (***source 4***).

The success of the team in attracting grant income for fundamental research in combination with the industrial exploitation of technology developed at Queen's is testament to the standing of the group and the impact it has had on the marine renewable energy industry.

European Marine Energy Centre (EMEC) Ltd (www.emec.org.uk) is the world's only accredited testing laboratory for the performance assessments of wave and tidal facilities. Its endorsement (***source 5***) perhaps best summarises the impact of this research by Queen's team:

…Oyster is based on the original oscillating wave surge convertor developed at Queens University by Professor Trevor Whittaker.

The wave energy industry is still in it infancy, however even at this early stage the benefits generated from the development, installation, commissioning and performance testing of the different machines are apparent. Both EMEC and Orkney have benefited from these early stage activities and expect to benefit still further as the industry develops…

In my opinion the fledgling industry and the associated economic activity results directly from the long established, high quality academic work undertaken at Queens University Belfast and other universities over many years. In the case of Oyster I see this as a direct result of the research undertaken by Professor Whittaker and his team.

A further impact has been the expansion of the Queen's marine renewable team and the inward investment in both academic staff and facilities. In 2009 Dr Elsaesser with extensive experience of numerical modelling coastal processes was employed as a senior lecturer and in 2012 Dr

O'Driscoll, an oceanographer was employed as a lecturer. They have expanded the capabilities of the group by interfacing numerical modelling with marine biological science to quantify the impact of marine renewable structures as well manmade pollutants in the seas and oceans.

In 2009 a £1 million investment in facilities at Queen's was completed. This included a 600 m^2 building housing a 16m × 18m coastal wave basin with variable bathymetry, 24 computer controlled wave generators and multi directional current generation. The investment also financed equipment to measure waves and tidal currents at sea. This has led to the development of a 1/10th scale tidal stream test site in Strangford narrows which is being used by device developers from across Europe under the PF7 funded MARINET project. To date the tidal work has generated £1.1 million of research income. The international standing of the group is demonstrated by the staff profile with researchers from USA, New Zealand, Australia, South Africa, Germany, France and Italy.

5. Sources to corroborate the impact (indicative maximum of 10 references)

(1) Company web sites – www.wavegen.co.uk, www.aquamarinepower.com which describe the commercial development of technology which originated with the QUB team.

(2) Queen's University making waves in Portaferry (BBC, April 2010) – http://news.bbc.co.uk/1/hi/northern_ireland/8626468.stm

(3) Royal visit gives 'green' light to world-leading research at Queen's (QTV, May 2010) – http://www.qub.ac.uk/home/TheUniversity/GeneralServices/News/Qtv/Life/stories/Name,191708,en.html

(4) Seagen to benefit from £7 million pledge to sea power (BBC, July 2010) – http://news.bbc.co.uk/1/hi/northern_ireland/8865504.stm

(5) Managing Director, European Marine Energy Centre (EMEC)