MARINE POWER SYSTEMS

Making Wave Power Work

June 2017

10%

Wave Power

Up to 4,000 TWh

Energy Resource

Economically exploitable each year

We believe wave power can generate

10% of the world's electricity by 2050

Source: IEA

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1. Introduction

The transition to renewable energy

The world is transitioning to a low carbon future in which clean, affordable, renewable electricity powers our daily lives. Already many countries source at more than 50% of their electricity from renewables. With the right technology, investment and policy in place, we believe the majority of the world will be powered by renewable energy by 2050.[1]

Whilst solar and wind power are presently the UK's main renewable energy sources, waves - an untapped resource - have the potential to form a prominent part of our renewable energy mix. This report outlines how the ocean's waves hold the power to become an important part of the UK's low carbon future, as well as generate renewable electricity for communities, towns and cities across the world.

A brief overview of waves and wave power

Wave power is generated by capturing the movement of seawater caused by waves. Waves tend to be larger and more powerful in deeper water further out to sea. Not to be confused with another marine energy technology tidal power, using the power of water tidal movement.

Waves can be captured to generate energy near the shore, at mid or far offshore, many miles from the coastline. Devices differ in scale, visibility and appearance depending on the size of the wave they're looking to harness and with the amount of power they intend to generate. Concepts developed to-date generally aim to capture the up and down movement of the wave (the heave) or the to and fro movement (the surge) to drive a power-take-off system and generate electricity. Like offshore wind power, this is transferred to shore with an undersea cable.

For decades engineers have been trying to find the very best way to capture the power potential of the ocean. But conditions at sea are harsh and developing resilient technology able to solve the challenges of generating affordable, reliable power is no simple task. But, like any important journey, success is increasingly likely with knowledge, time and persistence.

We believe wave power can generate

10% of the world's electricity by 2050

Source: IEA

10% by 2050: A vision for the future

Our vision is that wave power will generate at least 10% of the world's electricity by 2050. Waves can join the wind and the sun as a reliable, affordable clean energy resource; with Europe's shores alone having the potential to bring electricity to 230 million people, almost half the homes in the EU.[2] We want to see large wave farms built at sea from 2020, increasing year on year as demand for clean power grows.

About the authors of this report

Marine Power Systems Ltd (MPS) is a wave power technology development company. Based in Swansea, South Wales, it was founded in 2008 to develop and bring to market the WaveSub wave energy converter. MPS has dedicated the past nine years to making wave power work, to bring the most affordable, reliable and scalable wave technology to the world.

The WaveSub has the potential to substantially reduce the costs of energy generation from waves and favourably compete with the levelised cost of energy for offshore wind. Funded by a mix of public and private sector investment, MPS has completed two phases of the development of the technology and is currently undertaking Phase three: the design, build and testing of a quarter scale prototype. This will take place at the FaBTest site in Cornwall, UK in autumn 2017.

2. 100% renewable energy // 10% from wave energy

The social, financial, political and corporate shift to 100% renewable energy

> *"The Paris Agreement reflected an unprecedented international determination to act on climate. The focus must be on the decarbonision of the global energy system as it accounts for almost two-thirds of greenhouse gas emissions. Critically, the economic case for the energy transition has never been stronger. Today around the world, new renewable power plants are being built that will generate electricity for less cost than fossil-fuel power plants. And through 2050, the decarbonisation can fuel sustainable economic growth and create more new jobs in renewables."*

Adnan Z. Amin, IRENA Director-General, March 2017

The Paris Climate Change Treaty was signed in September 2016 by 55 of the world's biggest nations to limit global warming to no more than two degrees above pre-industrial temperatures. The world essentially committed to source 40% of its energy from renewable sources by 2030.

Only two months later, it was becoming clear that many countries aimed to exceed these targets. A draft ten-year energy blueprint published by India in December 2016 predicted the country would be generating 57 % of its energy through renewable sources by 2027.

In March 2017 the International Renewable Energy Association (IRENA)[3] reported that global energy-related carbon dioxide (CO_2) emissions could be reduced by 70% by 2050 and completely phased out by 2060. Globally, 32 gigatonnes of energy-related CO_2 were emitted in 2015. Emissions need to fall to 9.5 gigatonnes by 2050 to meet The Paris Agreement target.

At the beginning of June 2017, President Trump announced he would withdraw the USA from the Paris Climate Treaty on the basis that it would undermine the US economy. It was a move that was widely criticised by global leaders. However, within weeks of its withdrawal, representatives of American cities, states and companies had drafted a plan

to be sent to the United Nations, pledging to meet the United States' greenhouse gas emission targets under the Paris agreement.

What the US's withdrawal from the Climate Treaty showed us is the business community is leading by example when it comes to climate change. Many corporate companies have already committed to targets of 100% renewable energy. To date, nearly 100 of the world's most influential companies have now joined RE100[4] - an initiative from The Climate Group and CDP to shift the world to renewable power. The global renewable energy pledge has commitments from global brand names like Google, IKEA, Unilever and Tata Motors. This corporate community is vital in the transition to clean power - just 90 companies around the world are responsible for two-thirds of CO2 emissions.[5]

The resource potential to achieve 10% from wave

Global

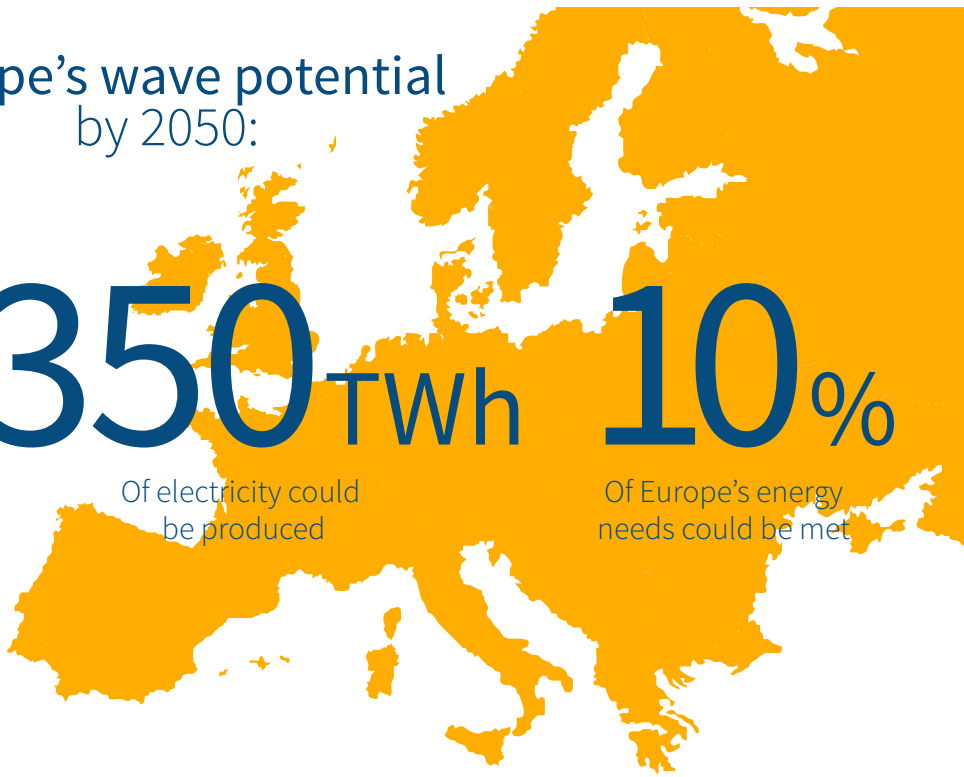
The main industry body Ocean Energy Europe has stated that 337GW of marine renewables can be deployed globally by 2050, with the global marine industry market set to grow to £76 billion.[6]

Wave power represents a significant opportunity for clean renewable energy supply, with the total wave resource across the globe of up to 80,000 TWh / year[7], out of which up to 4,000TWh / year is considered economically exploitable. [8]

The total global electricity consumption is circa 21,000 TWh / year.[9] This is set to potentially double by 2050 depending on the trajectory of population growth, energy efficiency and the rise of electric transport; with the most accurate projections produced by the International Energy Agency's annual 'World Energy Outlook' report.

On this basis, MPS has a vision to see wave power provide 10% of the world's electricity by 2050. Both because we believe it's possible and because the industry should set ambitious goals around which to rally and focus in the long term. Having such a vision is vital to the success of wave power. By way of comparison, hydropower generated 16% of the world's electricity in 2015, with biomass and waste producing 10%.[10]

Europe

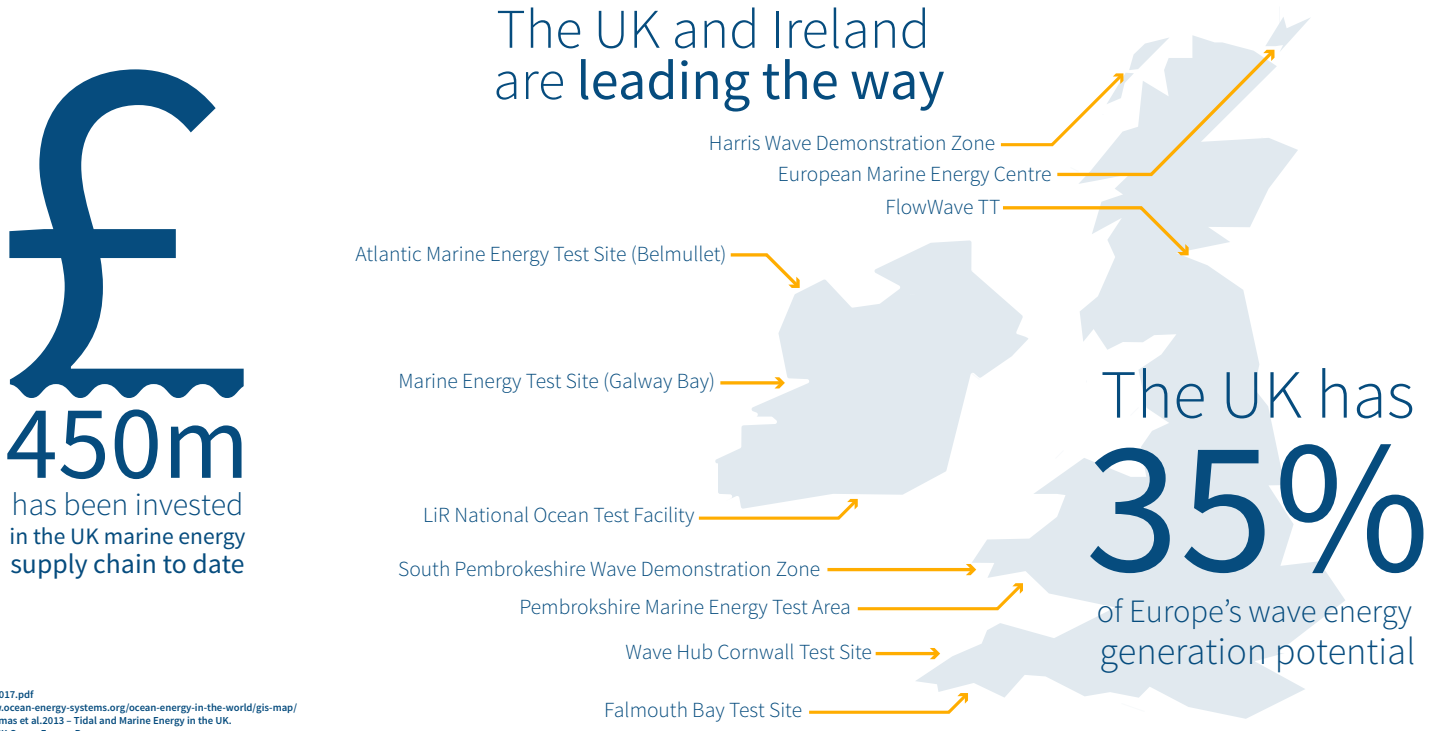


Source:
Ocean Energy Europe

Ocean energy is abundant, geographically diverse and renewable. Developing technology to exploit this potential offers opportunities for Europe, in particular, to develop a new industrial sector, create jobs and capitalise on its first mover status to cultivate significant export opportunities.

Ocean Energy Europe (OEE) has estimated that 100 GW of ocean energy capacity could be deployed in Europe by 2050, meeting 10% of Europe's energy needs, producing around 350TWh of electricity.[11] 100GW of deployed ocean energy technology in Europe will generate an annual market of 53 billion Euro. [12]
If Europe's wave forecast deployment targets are reached, by 2050 enough power will be produced from waves to meet the electricity demand for almost half the homes in the EU. [13]

The example of the United Kingdom



Sources:
oes-vision-2017.pdf
https://www.ocean-energy-systems.org/ocean-energy-in-the-world/gis-map/
Andrew Thomas et al.2013 – Tidal and Marine Energy in the UK.
RenewableUK Ocean Energy Race

The UK has 35% of Europe's wave energy generation potential. [14]

To date, nearly £450 million has been invested in the UK marine energy supply chain; mainly from private investment motivated to drive science, engineering and operations. [15]

This resource and interest from the government and investment communities has resulted in new industrial clusters in the coastal regions of Cornwall, the Solent, Isle of Wight, Scottish Highlands and Wales. [16]

The end of March 2017 saw a flurry of activity in the Welsh marine sector. The Prime Minister arrived in Swansea, signing the Swansea City Bay Regional Deal, pledging to mobilise up to £1.3 billion in a host of low carbon and sustainable initiatives along the south Wales coast including the £76 million Pembroke Dock Marine project. Then followed the £324,000 backing of what will be the world's largest wave energy site, the Pembrokeshire Demonstration Zone, by the Welsh Government.

Marine Energy Wales claim that marine developers active in Wales will invest £1.4 billion over the next five years if the right incentives are in place. Published ahead of the Marine Energy Wales Conference in Swansea, the *'Marine Energy in Wales: Investment, Jobs, Supply Chain 2017'* report forecasts major growth for wave, tidal stream and tidal lagoons with appropriate market and development incentives. The report states total direct investment in marine in Wales has risen to £68.3m. That represents an increase of over £23m from 2015.

The marine sector directly supports 137 full time equivalent jobs, 101 more jobs than two years ago.

In February 2017, the UK's lead renewable energy trade body Renewable UK launched a new report on the state of wave and tidal power: *'Ocean Energy Race'.* It stated that wave and tidal energy has the potential to deliver 20% of the UK's present electricity needs at a 30-50GW installed capacity. Unsurprisingly perhaps, it stressed the importance of industry and government working together to achieve this.

Wave power from 2020: the coming together of natural resources; politics; technology and finance

As referenced by the 2017 Energy Technology Institute report on marine energy, for wave power to be a success it must provide the highest performance guarantee at the lowest cost per kWh. Providing power at the right levilised cost, it would:

- Maximise investment returns in the long term
- Increase energy security, with nation states becoming less vulnerable to geopolitical uncertainty and wider energy price increases
- Cut CO_2 emissions and meet Climate Change targets globally and across Europe, agreed as 80% renewable energy by 2050
- Create much needed skilled jobs in low carbon manufacturing.

3. A short history of capturing energy from waves

The market backdrop of wave power has not historically been simple nor stable. Like any emerging industry, wave power has seen many start up technology development companies attempt to produce a scalable and cost effective solution to energy production.

Due to wave power's potential as a global energy resource, it has seen growing regional investment interest on the back of national renewable energy targets and policy, in particular financial backing in the UK from the Scottish and Welsh governments. A number of testing sites have been established in the UK, namely The European Marine Energy Centre (Orkney) and Wave Hub (Cornwall), to facilitate the development of scalable technology. This activity is being emulated across the world.

The industry is gradually maturing with second generation technology developers learning much from the early day pioneers of wave energy. Financial, legal and technical difficulties initially hit the sector, but the market picture is changing fast with an increasing number of organisations and test sites emerging across the world.

The key operational organisations developing large multi-MW wave power technology are presently MPS (Swansea); AW-Energy (Finland); Wello (Finland); GWave (USA) and Carnegie Clean Energy (Australia); who recently announced the development of their EU RDF funded 1MW project in 2018 at WaveHub in Cornwall.

4. The technology challenges: Harnessing powerful and uncompromising waves

Simply because of the amount of energy stored by the ocean and its variable conditions, the marine environment is an incredibly challenging environment for technology. This is particularly the case for multi-MW, far offshore wave devices, as being developed by MPS.

"Moving a new power generating concept to an industrial reality, and feeding substantial amounts of electricity into the grid, requires decades of investment, innovation and applied learning. Ocean energy development has advanced significantly, and follows a similar development timeline to that of other energy industries [such as wind]."

"To harness different resources viably, the ocean energy industry is developing concepts, including: small wave devices for calmer seas such as the Mediterranean; smaller tidal turbines for slower currents or near-shore areas; and devices that can be attached to harbour walls, dams, bridges and other existing infrastructure. A range of ocean energy devices must be developed to take into account the range of different sea conditions."

Ocean Energy Europe, March 2017

To date wave technology has not been able to deliver energy at a low cost due to four main challenges, as identified by Marine Power Systems (MPS):

1. Energy Capture
Subsurface orbital energy flow is powerful but difficult to harness

2. Survivability
The marine environment is extremely harsh, forces on any device must be limited at times

3. Transportation, Operation & Maintenance
Devices need to be quick and simple to deploy, recover and service

4. Capital Costs
Devices need to be cheap to build in relation to the power they produce

5. 10% Wave: How to reach our wave energy potential

With the industry focused on developing technology for testing over the coming years, the main call is for policy support to bridge a short gap between now and deployment, to increase the scale and speed of impact. But there are other challenges, namely public perception, technological progress and funding. All are interlinked.

It's crucial to be clear on how wave energy meets its potential. The prize is big in terms of economic development and clean, affordable and reliable energy growth.

Public perception and social engagement

Whilst 10% of global electricity from waves is possible, at present there is a lack of information for government, investors, industry and the public at large to understand how wave power works and it's potential as a low carbon electricity source. This must and will change for wave to reach its full potential. Whilst more mature renewable energy technologies such as solar photovoltaics and wind have seen increasing success in public perception, wave power is seen as a second generation renewable energy technology grouped with tidal power as 'marine energy'. Yet, a promising 77% of the British public support wave power.[17] Over time, we're likely to see more industry joined up thinking and communication on the benefits of wave power.

Finance provision and positive return on investment

IRENA is advocating that the share of renewable energy in the world's primary energy supply would need to increase to 65 per cent in 2050 from 15 per cent in 2015 to stay within a two degree warming limit. An additional $29 trillion of energy investment would be needed to 2050, equivalent to 0.4 per cent of global gross domestic product (GDP). Such investment should provide stimulus that, with other policies supporting growth, would boost global GDP by 0.8 per cent in 2050.[18]

Commenting on the European market alone, Ocean Energy Europe states that today 45% of wave energy companies and 50% of tidal energy companies are from the EU.[19] The right support over the coming decade will enable Europe to maintain leadership in a global market, worth a potential €653 billion (cumulative, undiscounted) for 2010-2050, and an annual market of up to €53 billion, hugely benefiting the European economy. Investment will come from a wide mix of private and public bodies, supported by the wider finance and banking industry.

With this backdrop, the wider impetus for investors, government and industry to back renewable energy is strong, but the conversation on wave power is dominated by its high price, ie. the proven cost of electricity production or levelised cost of energy; plus performance and reliability, otherwise known as long-term profit. Today, it is challenging for investors to understand the interplay of these important factors. Therefore 'cost per kWh' often becomes the single point of differentiation between renewable energy technologies.

According to Ocean Energy Europe lack of empirical experience and deployment data results in uncertainties about ocean energy projects operation and production.[20] This means that ocean energies bear a higher technological and financial risk compared to more mature energy technologies. At present there is only limited protection available from the commercial insurance market or from manufacturer warranties. At project level, this risk is currently overwhelmingly borne by the project developers, both limiting their pool of potential equity finance and making it difficult to leverage their funds to access commercial project finance, something the industry is looking to change to help shift the investment picture. As technologies such as WaveSub begin to reduce the cost of electricity from wave power, this investment landscape will simplify.

6. Technological solutions: The example of the WaveSub

How it works

The WaveSub is immensely efficient in power generation, construction and installation, creating the potential for a substantially lower energy cost than has been achieved by other renewable energy technologies. The technology directly addresses the fundamental challenges facing devices that try to exploit wave energy.

The WaveSub has undergone significant computational modeling, small scale sea trials and tank testing each year since 2009, in 2017 completing five weeks testing alone.The company also recently compiled a detailed project to model the cost of energy. The conclusion was that the WaveSub has the potential to compete favourably with other renewable technologies and ultimately be competitive with conventional energy generation.

Reliable Energy

The WaveSub captures wave energy mid to far offshore by utilising the continual orbital motion of waves to drive a sophisticated power-take-off (PTO) system. Crucially it is able to 'hide' during storms, minimising the stress put on the device. At 100 metres long, rated at 5MW, each device can power approximately 5,000 homes. This is a similar power output to a large offshore wind turbine.

Affordable Energy

Devices are cost effective to build, using largely off-the-shelf equipment with minimal bespoke engineering; significantly de-risking WaveSub**.** This means parts are simple to find and replace in the long term. Deployed by boat, the WaveSub is low cost and able to be recovered and serviced with relative ease.

The WaveSub farm potential

Once fully commercialised a 500MW WaveSub wave farm has the potential to power around 500,000 homes. The farm would be 5-10km from the shore and be made up of 100 WaveSubs rated at 5MW. With minimal environmental impact, from the air the only objects visible would be small buoys on the surface of the sea, marking the area of the wave farm.

Cost per kWh

The levilised cost of electricity from the WaveSub is projected to compete favourably with offshore wind once matured. MPS has produced detailed models that allow the cost of energy and other cost and performance metrics to be evaluated. The assumptions and metrics used in MPS' cost model are very similar to those outlined in the cost estimation methodology described in the Carbon Trust's Marine Energy Challenge.[21]

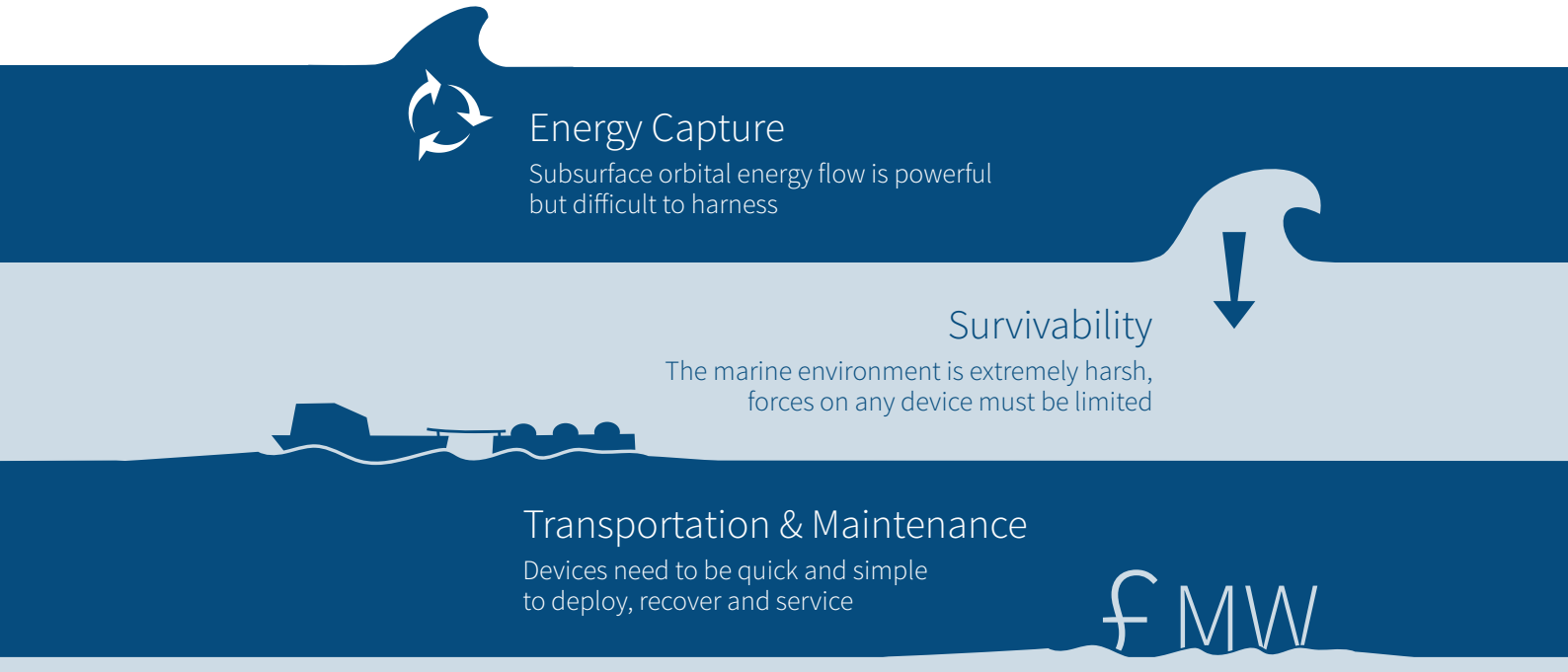
Investment and supporters to date

Founded in 2008, MPS quickly raised sufficient capital to develop and test a small scale model of their WaveSub. This enabled 'Phase one' of their journey. MPS worked on a proof of principle prototype device that underwent successful sea trials and energy generation tests in 2009 at the National Renewable Energy Centre (NaREC) in Newcastle. The operating principles and ability to generate energy were proven by this prototype. In 2010 MPS secured their first wave of private investment and match funding of £200,000 from the Welsh Government for further testing and research. Following cost of energy modelling in 2011, their first development phase was complete in 2012 with solid conceptual modelling.

In 2013 'Phase two' was underway with £500k from the Welsh Government, matched by private investors, to develop the design for a quarter scale prototype. The MPS team began to grow with a focus on design and tank testing. In 2014 another investment push was underway, by 2015 raising a further £2 million and European Regional Development Funds of £2.4 million. At this stage the company continued its work in manufacturing and testing to bring the quarter scale prototype to sea trials.

In 2016 MPS received a highly competitive Innovate UK Grant of £200,000 for computational modelling and the tank scale testing of a full size WaveSub device. In August 2016, the device was tested at Plymouth University's Coastal, Ocean and Sediment Transport (COAST) laboratory, in partnership with the University of Bath. To date Marine Power Systems has raised over £5 million of financial support from a range of different organisations. MPS has an IP portfolio to protect the WaveSub innovations across all relevant territories.

In autumn 2017, 'Phase three' will see the testing of a quarter scale model of WaveSub at sea at the FaBTest site in Falmouth for 12 months.



7. On the horizon: What to expect in 2017 and beyond

The future for wave power and large-scale wave farms is promising with the right long-term outlook from governments, a stable policy framework together with sound and sustained communications efforts from industry. We believe wave power technology has the potential to supply around 10% of the world's electricity demand by 2050, but in the meantime there is much to be done.

Perhaps the most poignant words of late have been from David Jones, Director of Marine Energy Wales in March 2017 who offered a word of caution amongst the enthusiasm for ocean power. He recalled a time when the UK led the burgeoning wind power market and was set to become a world leader in an emerging tech. However, policy support was withdrawn at a critical stage Denmark is now in the lead, with a workforce of 28,000 generating £5 billion a year in exports.

We agree. We have witnessed the ups and downs of both the wind and solar sector across the world, and it's time for the marine sector to learn the lessons and go forward with purpose and knowledge. Echoing the words of Ocean Energy Europe and RenewableUK,[22] to provide long term jobs and reliable, low cost electricity we need:

1. **Policy stability and consistent financial support, with marine energy firmly in national energy and industrial strategies.**
2. **Joined up communications across the industry and meaningful public support.**
3. **Investor confidence and action.**

Here at MPS we're now focused on the testing of WaveSub at the FaBTest site in Cornwall in autumn 2017. At this point we will open a new round of fundraising to develop the full-scale, multi-MW technology required for the deployment of large wave farms from 2020.

Our mission is to make affordable, reliable and scalable wave energy technology to power communities across the world. We're doing this by addressing the core challenges facing the industry: energy capture, survivability, transportation, operation and maintenance and reduced capital costs. Whilst we're driving hard at cost reductions to hit our target of being competitive with offshore wind energy, which we believe is fully achievable, within the wider market, investment confidence and policy framework remains more important than ever.

Support for wave energy must remain. Once this is in place, investment should equal jobs and a meaningful industry: bringing prosperity to Wales, the UK and communities across the globe.

Together, we can achieve 10% of our electricity from waves.

marinepowersystems.co.uk

About the authors of this report

Marine Power Systems Ltd (MPS) is a wave power technology development company. Based in South Wales (UK) the company was co-founded in 2008 by Swansea University engineering graduates Dr Gareth Stockman and Dr Graham Foster to develop and bring to market its WaveSub wave energy converter.

MPS has dedicated the past eight years to developing a device which can offer the most affordable, reliable and scalable mid-far offshore wave technology in the world. The WaveSub, which is designed and built in Wales, has the potential to substantially reduce the costs of energy generation from waves.

Funded by a mix of public and private sector investment, MPS has completed the first and second phases of development and is currently undertaking Phase Three; the build and testing of a quarter-scale prototype. This 12-month test programme will take place at FaBTest in Falmouth Cornwall.

The project is being conducted with support from many local Welsh businesses in the local supply chain including Marine Energy Pembrokeshire, Swansea University, Pembrokeshire Port and the Welsh Government as well as business and academic institutions throughout Europe.

MPS's long-term vision is to take its product to a commercial market and become one of the world's leading manufacturers of multi-megawatt wave energy devices which can generate clean, affordable, reliable energy for countries around the globe.

www.marinepowersystems.co.uk

Further reading and references

1. UNFCC: The Paris Agreement, 2016

2. Ocean Energy Europe (OEE): Ocean Energy Roadmap 2016 http://www.oceanenergy-europe.eu/en/communication/publications/ocean-energy-roadmap

3. IRENA: Perspectives for the Energy Transition: Investment Needs for a Low-Carbon Energy Transition, March 2017

4. CDP and The Climate Group: RE100 http://there100.org/re100

5. The Guardian, November 2013 https://www.theguardian.com/environment/2013/nov/20/90-companies-man-made-global-warming-emissions-climate-change

6. Highlands and Islands Enterprise, RegenSW and Marine Energy Pembrokeshire: ***Marine Energy key steps to maintaining a Great British success story***, 2016

7. International Energy Agency (IEA) / Ocean Energy Systems: www.ocean-energy-systems.org Implementing Agreement on Ocean Energy Systems (IEA-OES), Annual Report 2007 (PDF). International Energy Agency, Jochen Bard ISET. 2007. p. 5. Archived from the original on 1 July 2015. https://en.wikipedia.org/wiki/Marine_energy.

8. Building Options for UK Renewable Energy indicated a practical worldwide wave energy resource of between 2000 and 4000 TWh/year. Ref: Future Marine Energy Results of the Marine Energy Challenge: Cost competitiveness and growth of wave and tidal stream energy

9. Global Electricity Consumption: https://yearbook.enerdata.net/electricity-domestic-consumption-data-by-region.html

10. International Energy Agency (IEAfile://localhost/)/ www.tsp-data-portal.org:Historical-Electricity-Generation-Statistics - tspQvChart

11. Ocean Energy Europe (OEE): Ocean Energy Roadmap 2016 http://www.oceanenergy-europe.eu/en/communication/publications/ocean-energy-roadmap

12. Ocean Energy Europe (OEE): https://www.oceanenergy-europe.eu/images/OEF/140037-SI_Ocean_-_Market_Deployment_Strategy.pdf

13. IEA: World Energy Statistics, 2015

14. Andrew Thomas et al: Tidal and Marine Energy in the UK. Identifying Future Challenges for supply chain development, 2013

15. Highlands and Islands Enterprise, RegenSW and Marine Energy Pembrokeshire: Marine Energy, key steps to maintaining a Great British success story, 2016.

16 .RenewableUK: Member Survey, 2016

17. Department for Energy and Climate Change (DECC): Public support for renewable energy survey, 2014

18. IRENA: Perspectives for the Energy Transition: Investment Needs for a Low-Carbon Energy Transition, March 2017

19. Ocean Energy Europe (OEE): Ocean Energy Forum Report, 2017

20. Ocean Energy Europe (OEE): Ocean Energy Forum Report, 2017

21. The Carbon Trust: Accelerating Marine Energy Report, 2011 http://www.carbontrust.com/resources/reports/technology/marine-energy

22. RenewableUK: Ocean Energy Race Report, 2017 http://www.renewableuk.com/news/332280/Ocean-Energy-Race-report.htm