Lost at sea? Charting wave energy’s difficult innovation journey towards commercialisation in the UK

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ECCI seminar 4th November 2016

Structure

- Introducing wave energy
- International comparison of UK's wave energy innovation performance
- Factors contributing to wave energy's slow progress in the UK
- Policy recommendations
- Conclusions
- Recommendations for future work

Wave energy – the prize

UK could practically extract **70 TWh/yr** of wave energy, accounting for approx. **21% of UK electricity generation** (2014)

BUT technology is not yet commercially viable

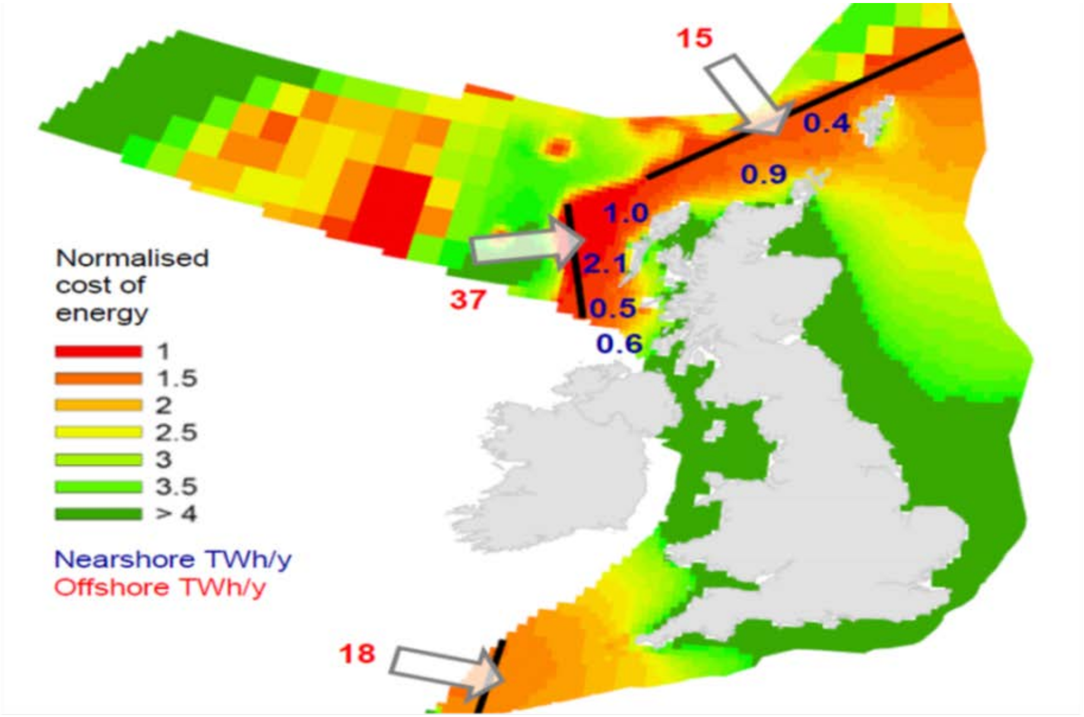
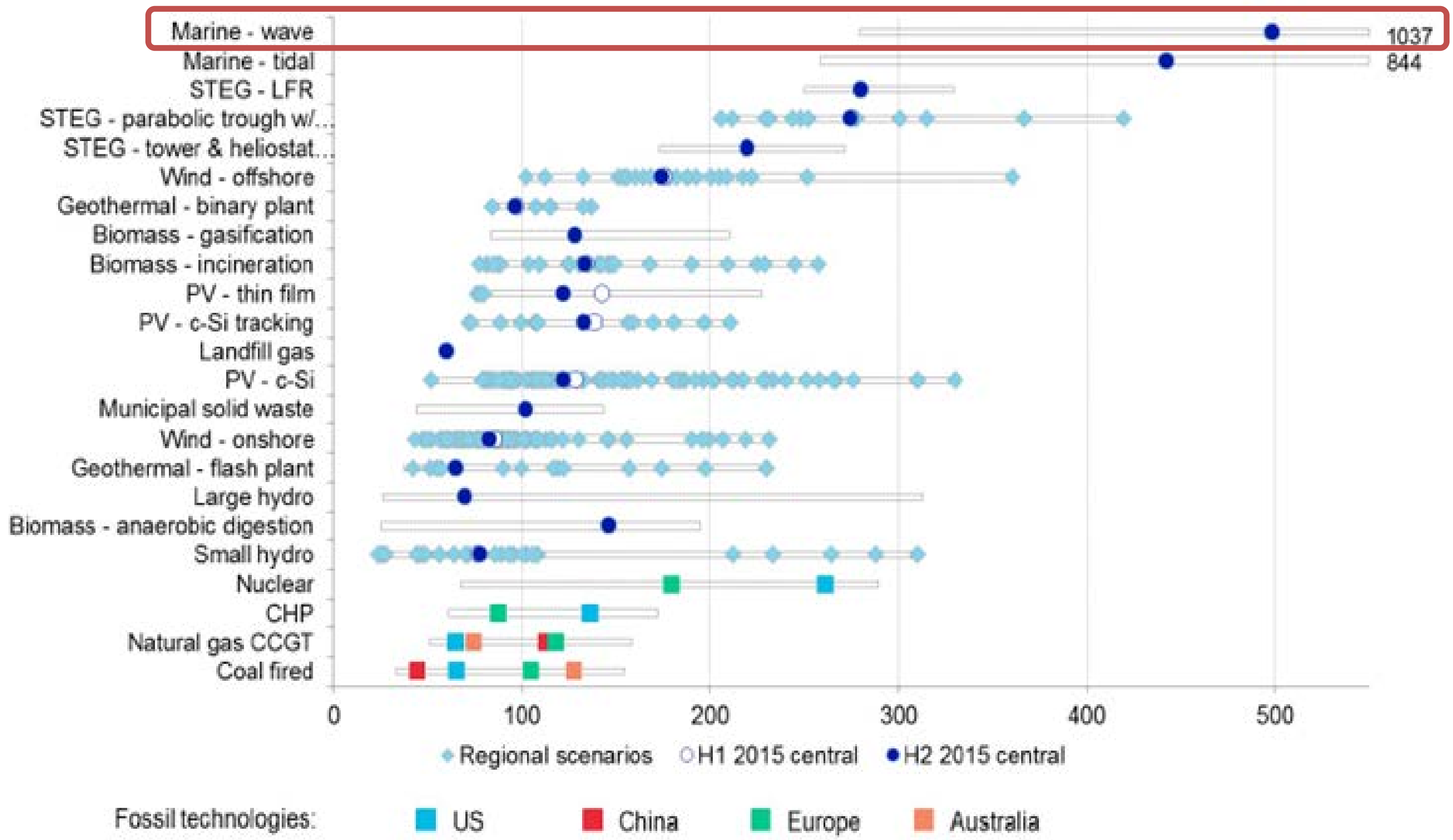


Figure 1: Practical UK wave energy resource (source: AMEC & Carbon Trust 2012)

The cost of wave energy

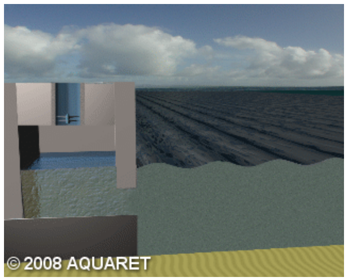


Note: STEG = solar thermal electric generation

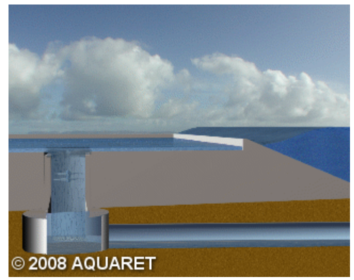
Source: Bloomberg New Energy Financ

Wave energy – its various forms

Onshore

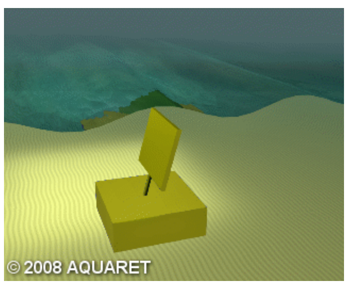


OSCILLATING WATER COLUMN

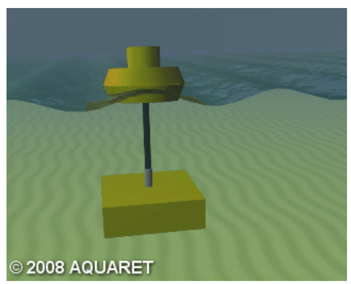


OVERTOPPING/TERMINATOR DEVICE

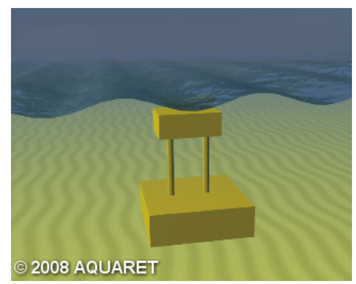
Nearshore



OSCILLATING WAVE SURGE CONVERTER



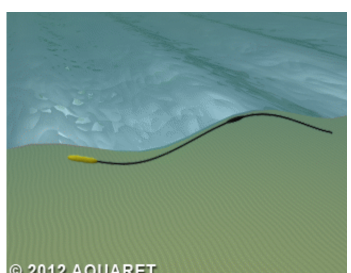
POINT ABSORBER



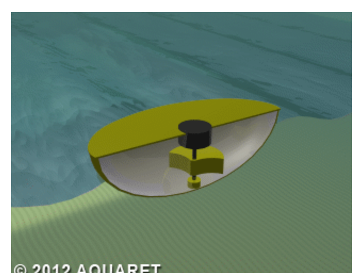
SUBMERGED PRESSURE DIFFERENTIAL

Offshore

ATTENUATOR



BULGE WAVE

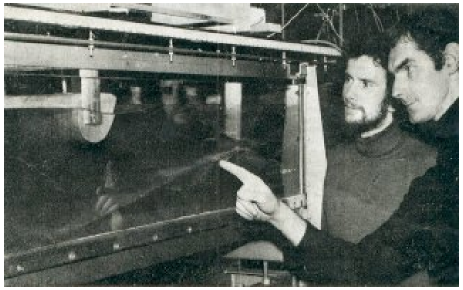


ROTATING MASS

Both the lack of technological convergence and high LCOE indicates a **need for further energy technology innovation**

BUT rich history of UK wave energy

- **1973** – Oil crisis hits and Salter begins work on his Duck
- **1975** – 7 year long £51m (£ 2014) programme for wave energy
- **1982** - Energy Technology Support Unit (ETSU) report on cost of renewables leads to suspension of funding
- **1990s** – Piecemeal EU funding continues UK wave energy research
- **Late 90s** – New & Renewable Energy Programme committed £43m (3 years) and Scottish Renewables Order 3
- **2000** – Limpet on Islay is 1st commercial wave energy generator
- **2003** - DTI's Our Energy Future recognises marine as priority research area and Marine SuperGen established
- **2004** - European Marine Energy Centre (EMEC) established. Pelamis first offshore wave-power device to generate electricity into a grid system.
- **2008** - 1st wave energy array with 3 Pelamis devices (2.25MW) installed in Aguçadoura, Portugal
- **2011** – Banding of Renewable Obligation - 5 ROCs per Megawatt hour
- **2014/5** – Pelamis and Aquamarine enter administration. Wave Energy Scotland established



Stephen Salter and his duck

Limpet on Islay

Pelamis at Aguçadoura

Research Questions and Methods

Research Questions

1) What level of innovation support has the UK committed to wave energy?
2) What level of innovation output has this investment delivered?
3) How effective has this investment been in supporting innovation and how does this compare internationally?
4) To what extent has the design of UK wave energy innovation policy contributed to its slow progress?

Methods and Data

- IEA RD&D budget database for 29 countries 1974-2013
- Patents from European Patent Office (EPO) for 180 countries 1979-2011
- Ocean Energy System (OES) database and reports for installed capacity for 25 countries 2007-2016
- Analysis of approximately 650 UK marine energy grants 2000-2015
- 32 interviews (March – Oct 2015).

RQ1 - What level of public support has the UK committed to wave energy?

Public ocean energy RD&D 1974-2013 (INPUT)

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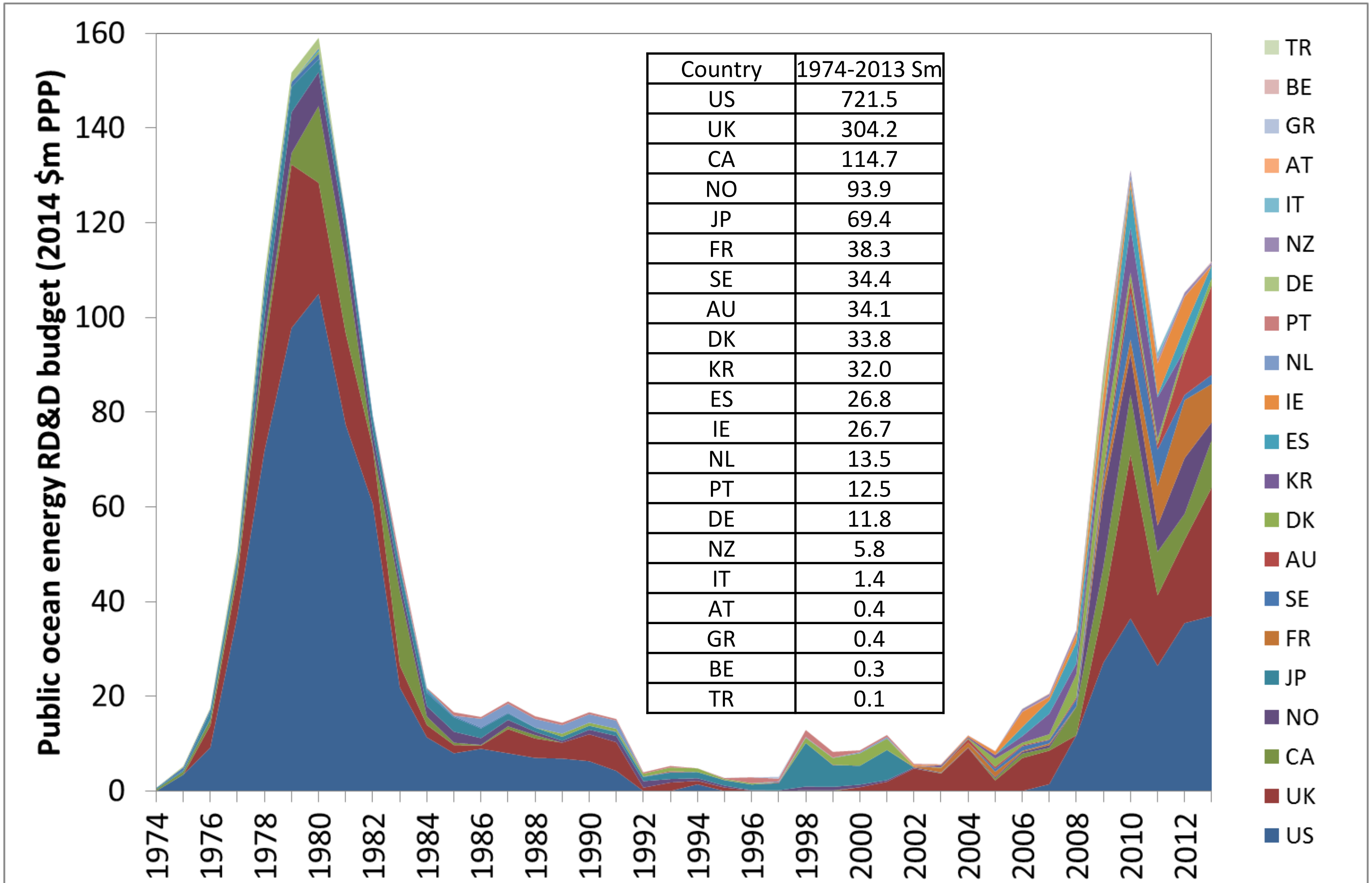

Country	1974-2013 Sm
US	721.5
UK	304.2
CA	114.7
NO	93.9
JP	69.4
FR	38.3
SE	34.4
AU	34.1
DK	33.8
KR	32.0
ES	26.8
IE	26.7
NL	13.5
PT	12.5
DE	11.8
NZ	5.8
IT	1.4
AT	0.4
GR	0.4
BE	0.3
TR	0.1

(Source: IEA)

NOTE: Excludes private RD&D. Public budgets not actual spend. All ocean energy, including tidal range but most components drawn from hydro RD&D

Public ocean energy RD&D 1974-2013 (INPUT)

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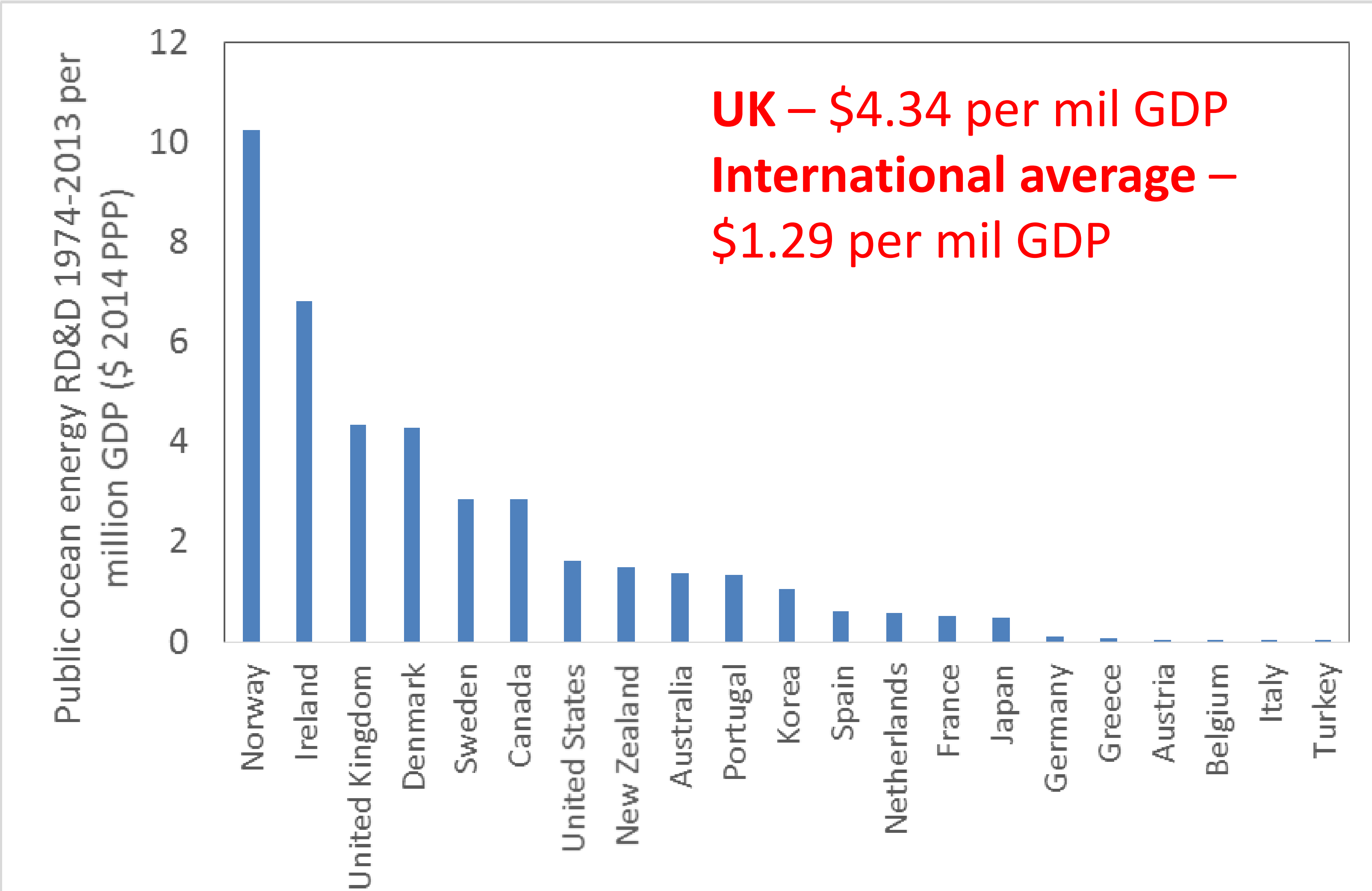

(Source: IEA)

NOTE: Excludes private RD&D. Public budgets not actual spend. All ocean energy, including tidal range but most components drawn from hydro RD&D

RQ2 - What level of innovation output has this investment delivered?

Patents 1979-2011 (OUTPUT)

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Rank	Total Ocean			Wave		
	Country	Patent filings	%	Country	Patent filings	%
1	US	242	18%	US	118	17%
2	UK	228	17%	UK	118	16%
3	DE	154	11%	DE	71	10%
4	FR	79	6%	NO	49	7%
5	NO	78	6%	AU	34	5%
6	IE	52	4%	SE	34	5%
7	JP	50	4%	FR	33	5%
8	SE	49	4%	IE	30	4%
9	AU	47	3%	IT	27	4%
10	IT	45	3%	ES	27	4%
	Global	**1368**	**-**	**Global**	**717**	**52%**

NOTE: This study takes the following Y02E patent classifications specific to ocean energy: (10/28) Tidal stream or damless hydropower, (10/32) Oscillating water column (OWC), (10/34) Ocean thermal energy conversion (OTEC), (10/36) Salinity gradient and (10/38) Wave energy or tidal swell.

(Source: EPO)

Deployment 2007-16 (OUTPUT)

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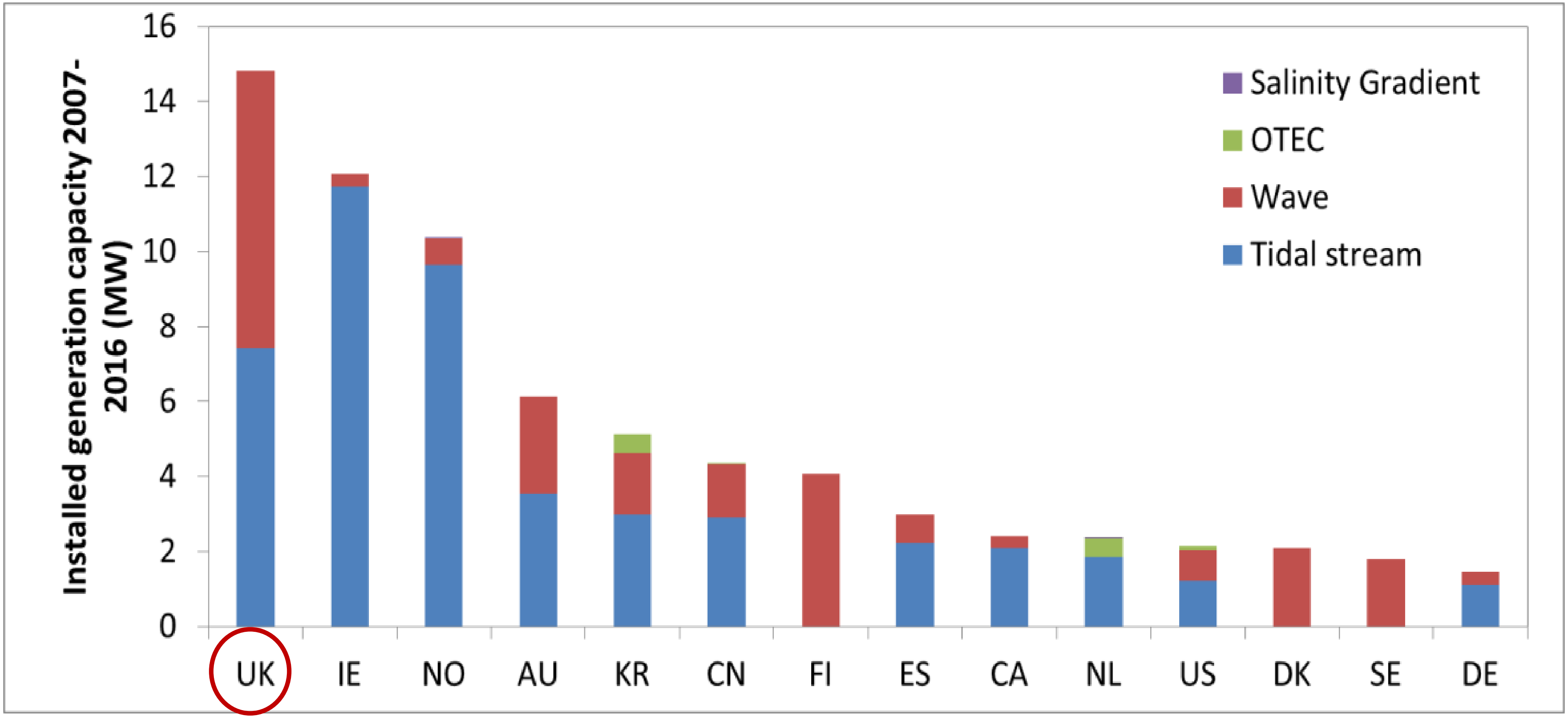


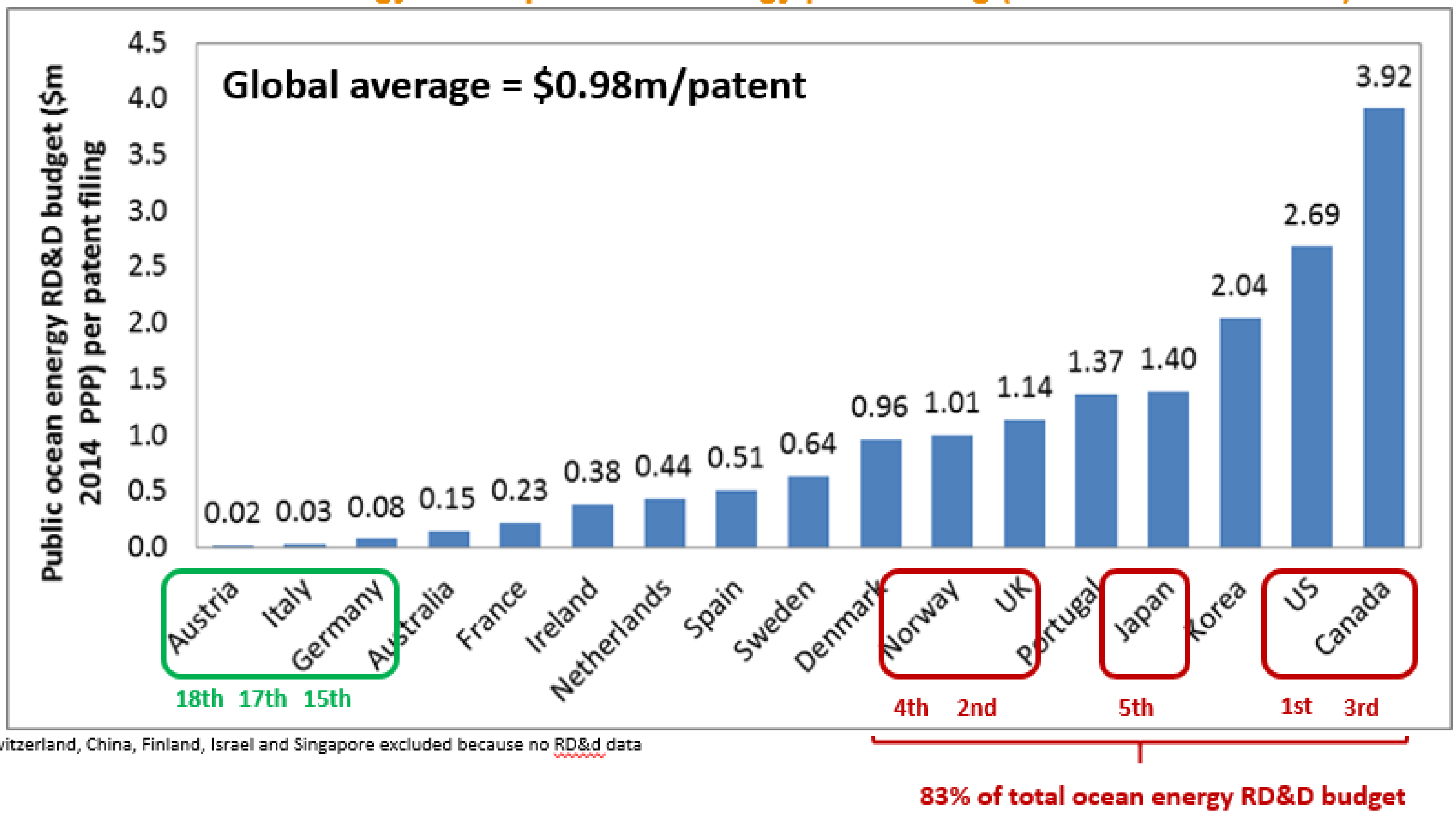
NOTE: Nationality by origin of the developer. Includes both pre-commercial demonstration and commercial deployment between 2007 and 2016, therefore some deployments may have been temporary.

(Source: OES)

RQ 3 - How effective has this investment been in supporting innovation and how does this compare internationally?

Performance: $ RD&D per patent

Public ocean energy RD&D per ocean energy patent filing (Source: IEA and EPO)



NOTE: Switzerland, China, Finland, Israel and Singapore excluded because no RD&d data

Performance: $ RD&D per MW

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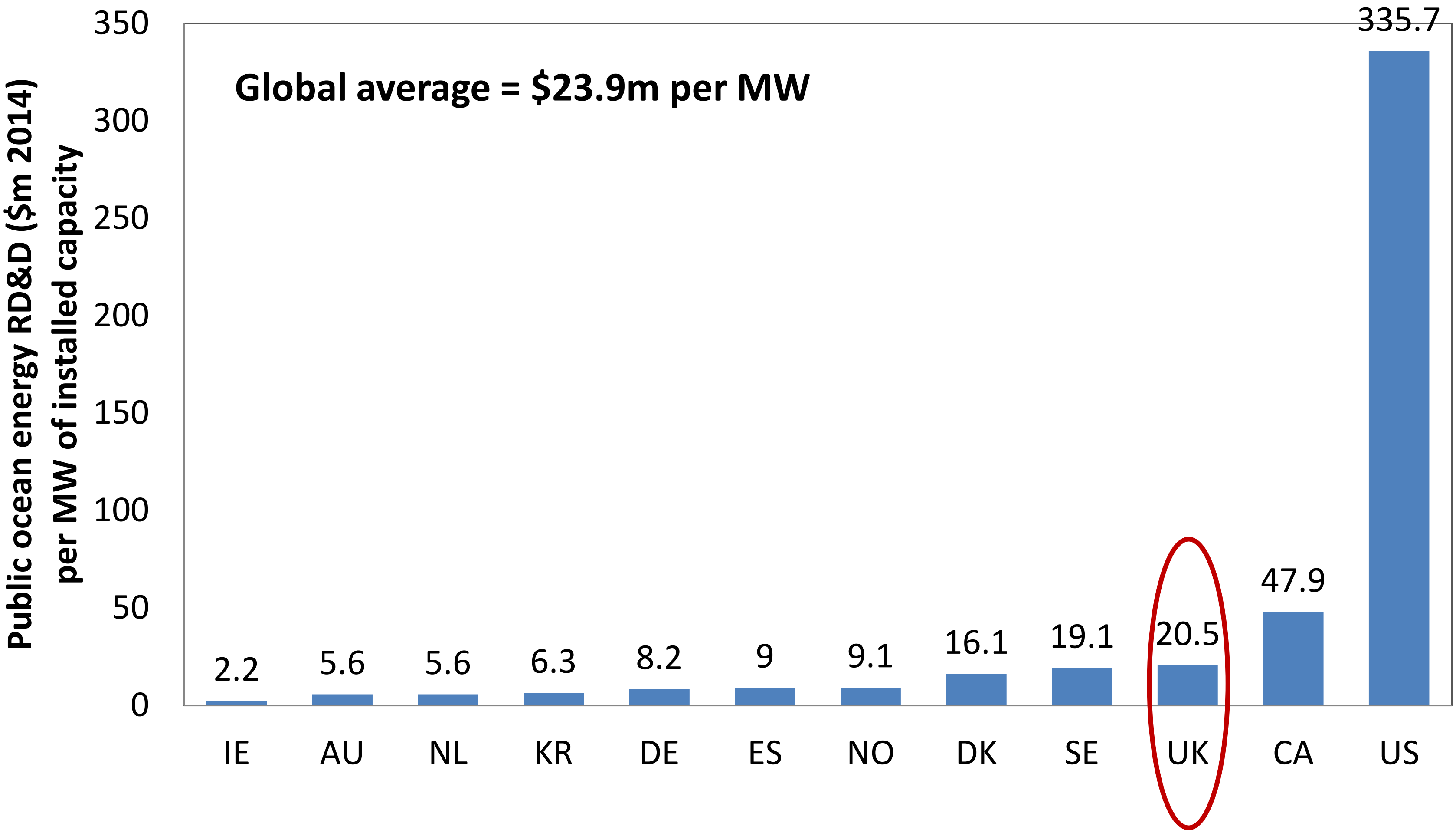

NOTE: Nationality by origin of developer. Excludes countries that have delivered less than 150kW of capacity. Also missing Finland and China due to lack of RD&D data. Public ocean energy RD&D is for ocean energy and thus incorporates tidal range, tidal stream, OTEC, salinity gradient etc.

(Source: IEA and OES)

RQ 4 - To what extent has the design of UK wave energy innovation policy contributed to its slow progress?

Diagnosing the UK’s wave energy innovation performance

- UK leader in wave energy innovation inputs ($ RD&D) and outputs (patents, deployment)
- Despite above average performance (output per $ RD&D) it generates less **‘*bang for its buck*’** versus many of its peers.
- UK not delivered a commercial wave array, with main developers (Pelamis, Aquamarine) in administration.
- We examine **whether the design of the UK’s innovation support policy (2000-2015) could have constrained the pace of wave energy technology innovation?**
- **Why? –** To learn lessons to accelerate wave energy innovation in the future. Also wider innovation policy…

Strengths of wave energy innovation support system

UK wave energy innovation system considered to be working well in a number of ways…

- World-leading research capabilities (e.g. Uni of Edinburgh) and test infrastructure (e.g. EMEC)
- Strong supply of highly skilled individuals (e.g. IDCORE)
- Consecutive RD&D schemes some delivering major demonstration (e.g. MRPF)
- Government funding has provided strong market signals (e.g. ROCs) and raised significant private sector funds
- Strong offshore energy sector for cross-fertilisation
- Multi-institution and international university collaboration (e.g. H2020)

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Wave energy RD&D faces distinct challenges

- Testing conditions very hostile and wave energy devices extremely large and heavy in order to capture energy, making them very costly. Breeds conservatism
- Relatively few clear opportunities for cross-sector fertilisation unlike tidal from wind.
- Wave resource typically very remote, needing significant investment in grid

"You need devices that have got dimensions comparable to wave lengths…typically about 150, 160 metres long" - Developer

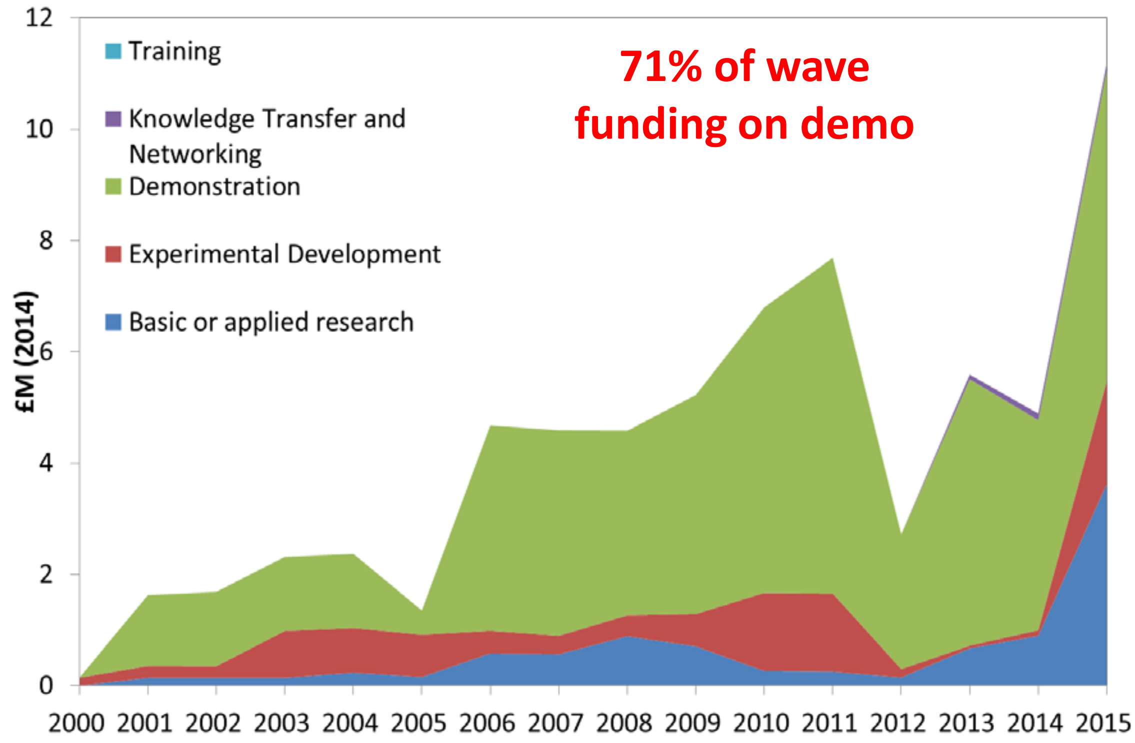
"We just didn't let [our machines] see anything bigger than 10m waves. They're still big waves, but we made a risk-based decision not to do it because it was too likely they would all would get smashed up" – Developer

"These guys are able to learn from what's already been done in the wind industry, so there's a much more rapid sense of convergence. They're standing on the shoulders of giants…in the wave industry it's very hard to find a parallel" Consultant

Source: Atlantis

Problem #1 – Overpromising and under-delivering

- Unrealistic expectations wave energy could be ‘fast-tracked’
- Funding made available for full-scale and array demonstration
- Developers overpromised but then under-delivered
- Trust eroded and leading to scaling back of VCs and government



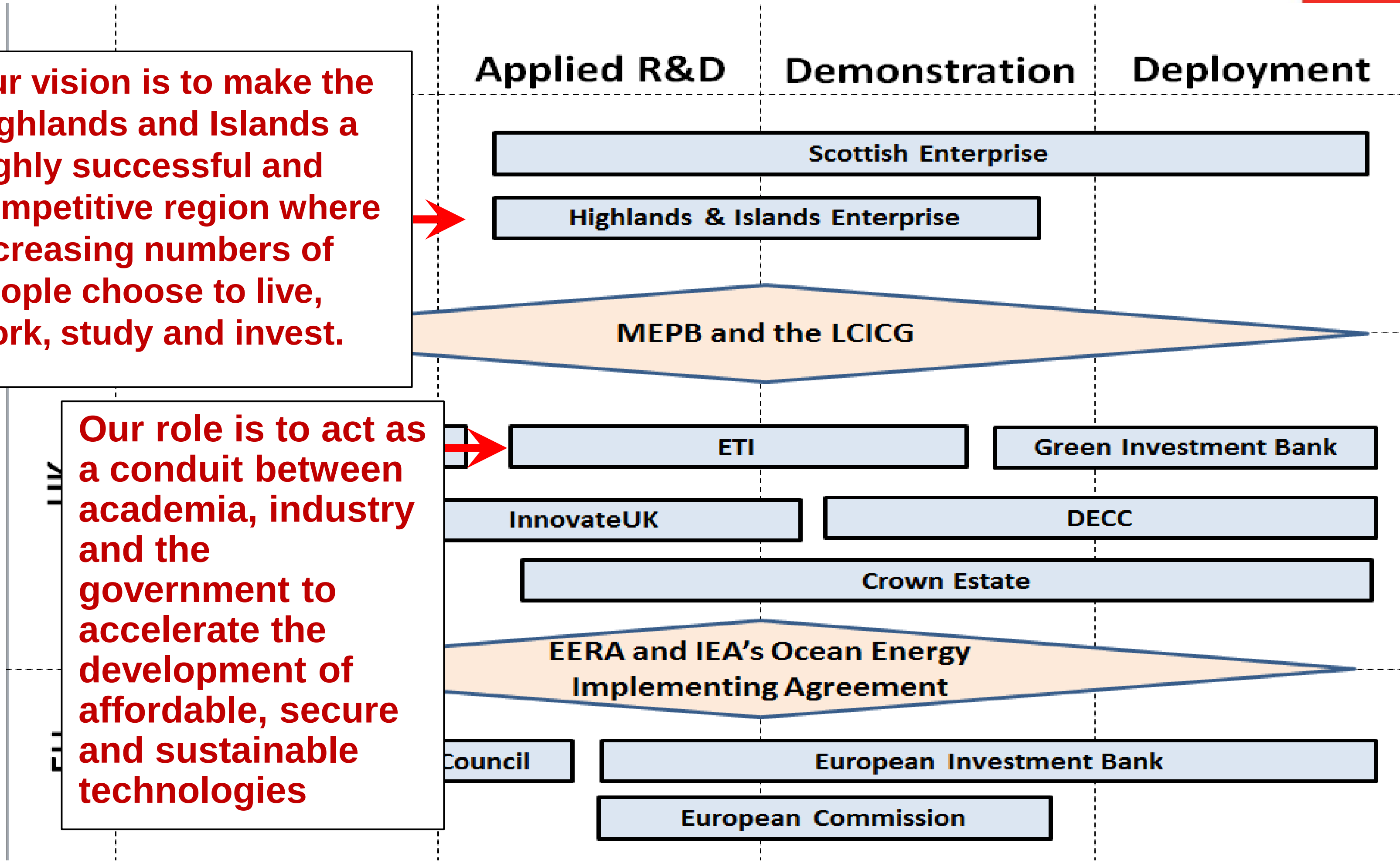
“It’s been people like me…guilty of thinking that we could get this to kick-start, like wind energy, off the back of a couple of prototypes on a small farm being demonstrated” – Consultant

“‘Developers have chased the money that’s been available…the money was there for demonstration projects…and so the fault doesn’t all just lie at the door of the developer, it’s that the funding was designed to go too big, too soon” Senior researcher

Problem #2 – Poorly coordinated & complex innovation system

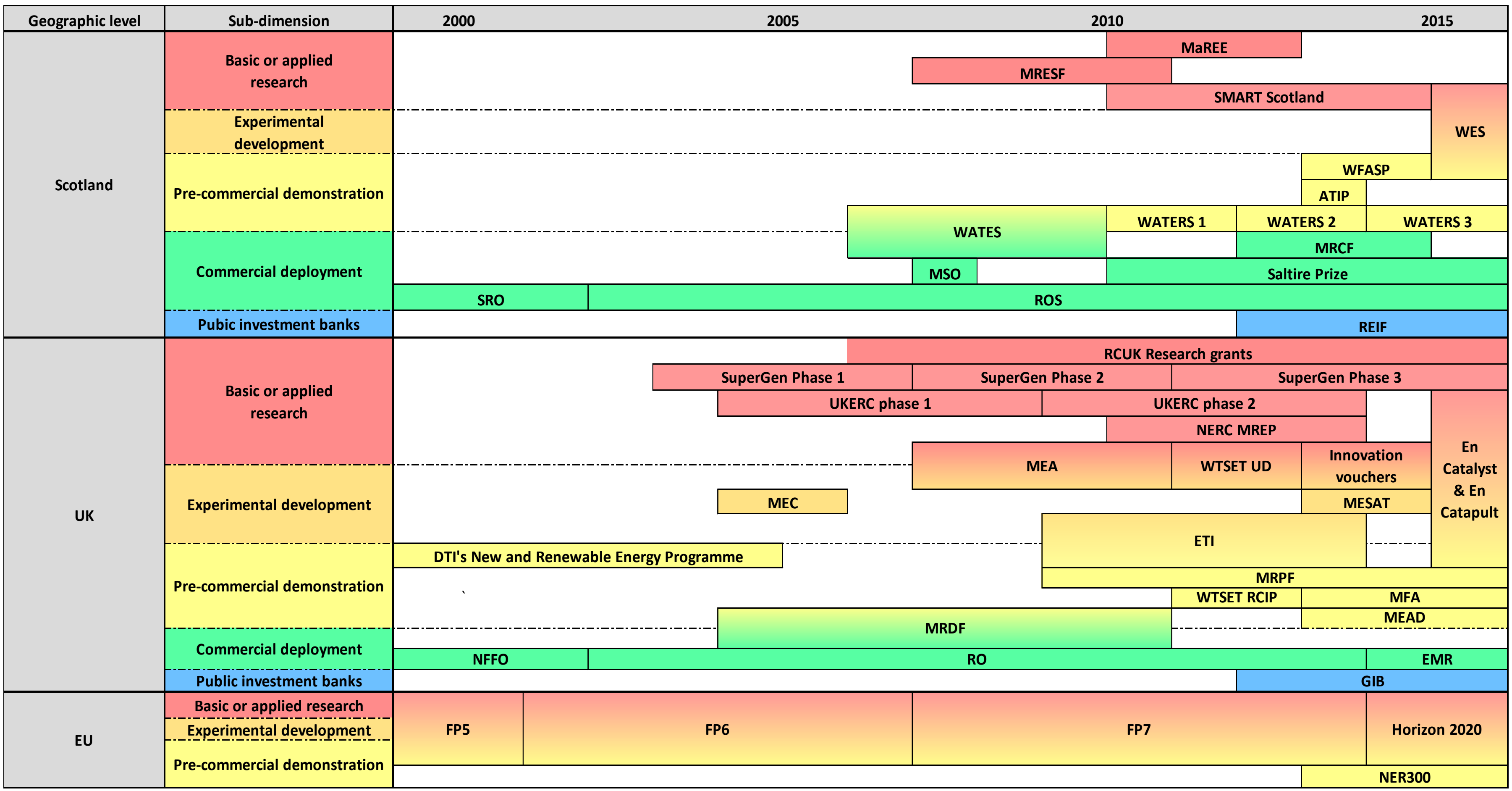
Our vision is to make the Highlands and Islands a highly successful and competitive region where increasing numbers of people choose to live, work, study and invest.

Our role is to act as a conduit between academia, industry and the government to accelerate the development of affordable, secure and sustainable technologies

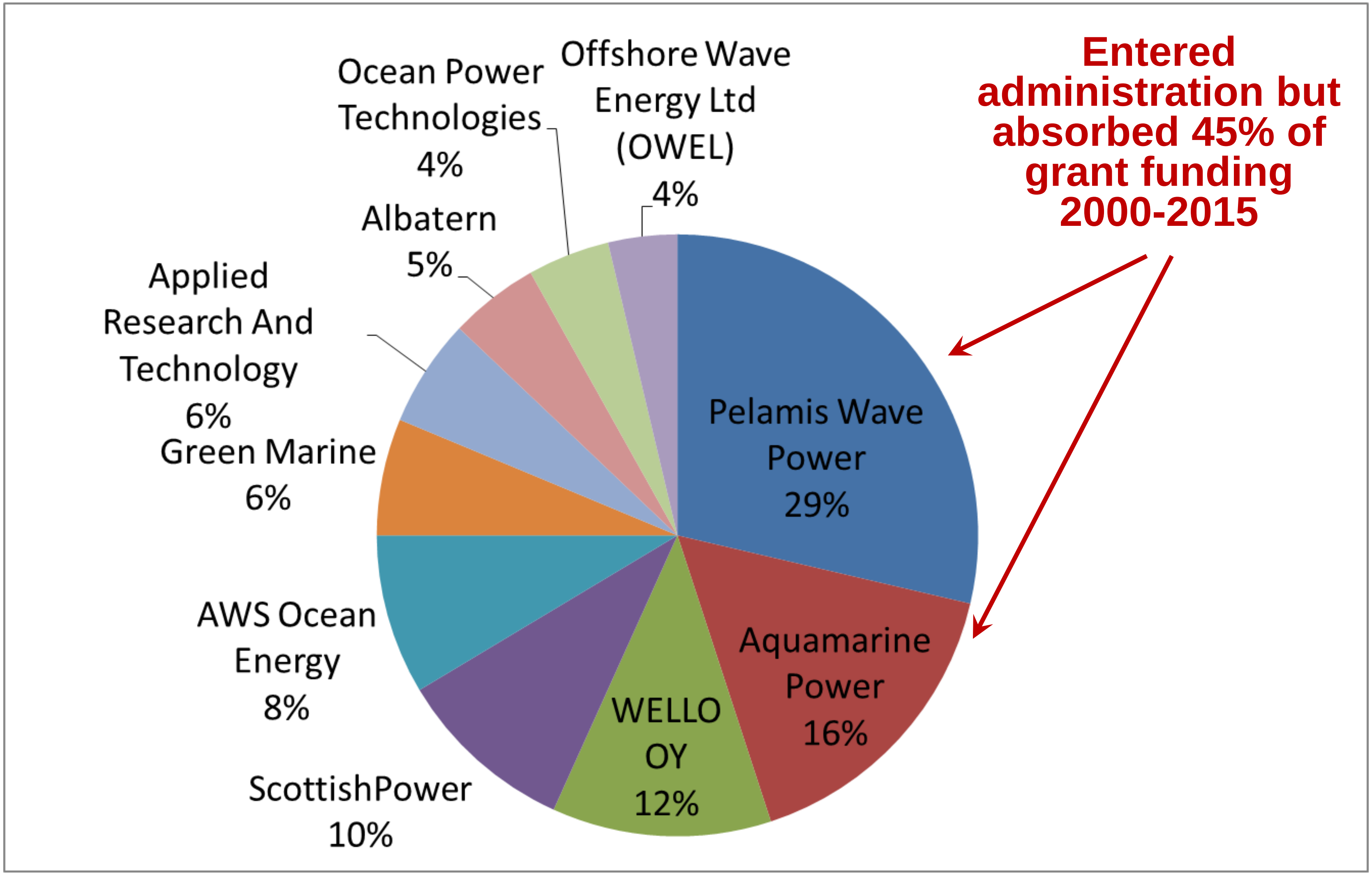


"There were a number of different streams that were all coming out with different sources of funding to try and tackle the same problem" – Developer CEO

Problem #2 – Poorly coordinated & complex innovation system

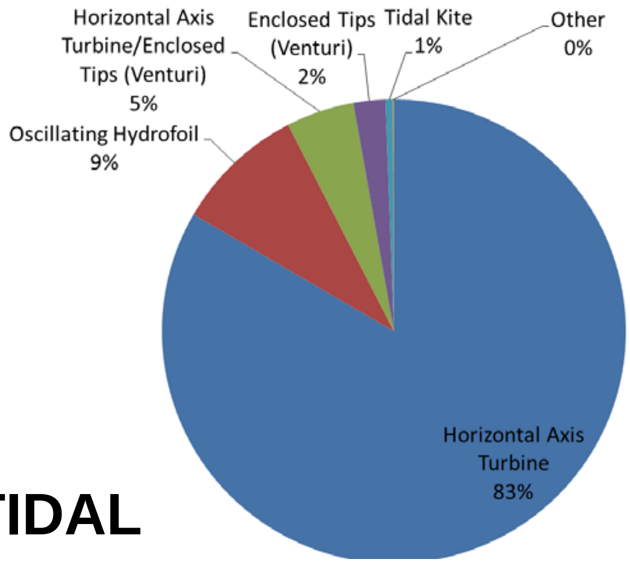


Problem #3 – Majority of funding awarded to failed companies

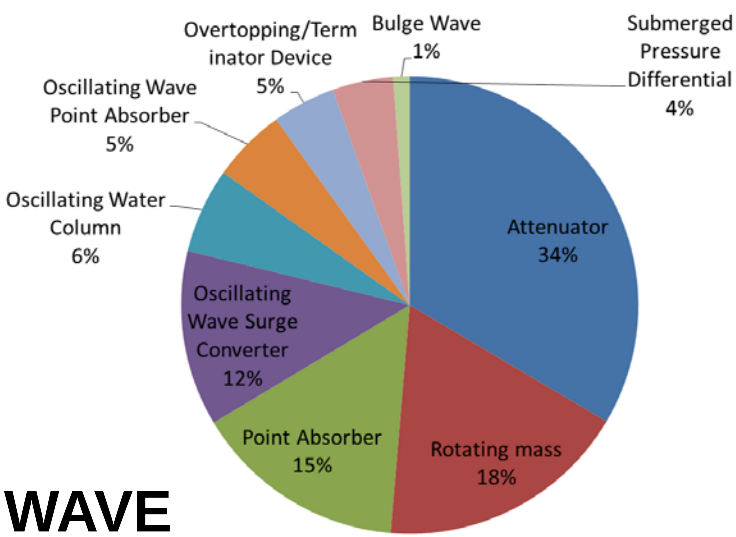


Top wave energy demonstration grant awardees in the UK 2000-2015

Problem #4 – Bundling wave into same schemes with tidal stream

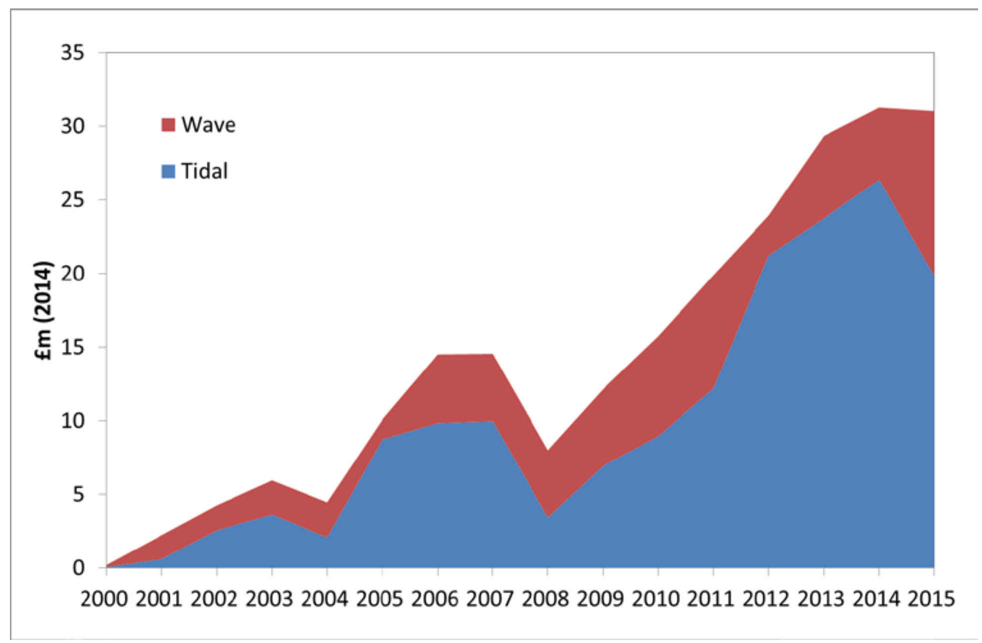


TIDAL



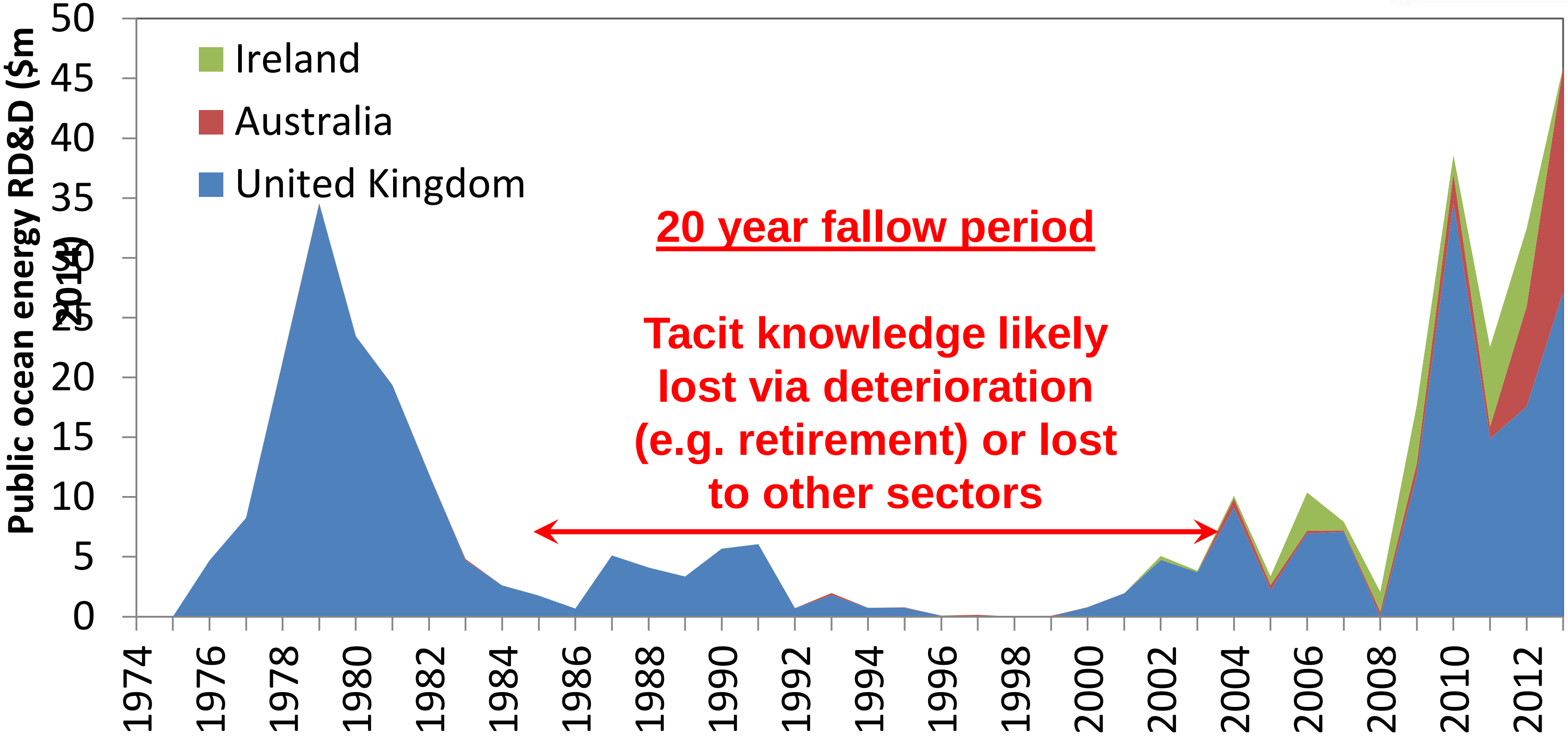
WAVE

"There's a sense of convergence around the axial flow turbine which looks a little bit like a Danish wind turbine…They're standing on the shoulders of giants…whereas in the wave industry it's very hard to find a parallel" - Funder



Tidal stream received x2 funding

Problem #5 – Funding hiatus - knowledge depreciation & skills leakage



MW per $ RD&D - Bottom 5 performers (US, UK, Canada, Sweden and Denmark) committed 87% ($782m) of global RD&D budget between 1974-1995 vs. 59% ($401m) between 1996-2013.

Patents per $ RD&D - Bottom 5 performers (Japan, Portugal, Korea, US and Canada) committed 73% ($657m) of global budget between 1974-1995 vs. 43% ($293m) between 1996-2013.

Problem #6 – Poor level of collaboration

Low levels of collaboration and knowledge exchange

Business-to-business – private sector investment and value of IP in pre-commercial sector breeds secrecy. Public funding centred on devices not components.

Business-to-university – Mismatching incentives and timeframes, which was not accommodated for by funding support.

University-to-university – Seen to be much stronger through things like Supergen

'I think the other thing is that the developers have worked too much in their own box. They've been so frightened about somebody stealing their IP that they've lost out on the benefits of collaboration' Test facility executive

"The same mistakes have been repeatedly made because there hasn't been the exchange of information" Senior researcher

"Academia was having to convince their funders that the questions were still being uncovered" Senior researcher

Other important barriers

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- Lack of objective and rigorous **stage-gating process** for innovation funding
- Lack of **business acumen** amongst the wave energy sector
- **High entry costs** for developers to use UK marine energy test infrastructure
- **Struggling to retain foreign expertise** honed at test facilities
- **Duplication of funds** e.g. WaveHub and EMEC
- **Modest funding split between numerous developers**

'Previously nobody knew where they were on this. [The developer would] say there were TRL 7 and actually they're nowhere near it' Programme coordinator

'Everybody involved is an engineering bod…they haven't got any business acumen at all' (Consultant)

"It should be – "Here you are, here's a facility, it's funded, here's a voucher, go and use it" or we pay it" Facility executive

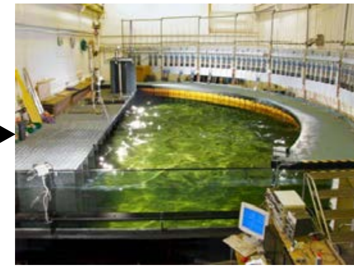
"They pay to go into EMEC and they are gone. Not a lot of knowledge is retained in the UK as a result of that project" Developer

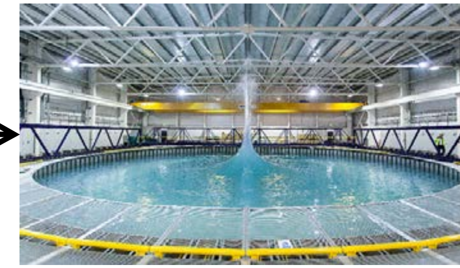
UK wave energy innovation support being re-calibrated

Following Scottish Government's Wave Summit (2014) lessons learnt leading to major changes in wave energy innovation support system, not least **Wave Energy Scotland**:

- **P#1** - 100% funding avoids need for private sector match funding
- **P#2** – WES board comprised of reps from other funders
- **P#2, P#3** - Stage-gating criteria to ensure promising tech receives more funding
- **P#4** - Decoupling tidal stream and wave energy funding
- **P#4** - Refocusing at sub-component level to promote convergence
- **P#5** – Capturing knowledge e.g. Quoceant and Pelamis
- **P#6** – Multi-institution teams and allows for university-business collaboration

New infrastructure also important





Narrow tank (1974)
- 1/150 – 1/100
- 0.2m wave height
- Single unidirectional wave maker
- Rectangular

Wide tank (1977)
- 1/150 - 1/100
- 0.3m wave height
- 89 multi-directional wave makers (180°)
- Rectangular

Curved tank (2003)
- 1/70 - 1/100
- 0.12m wave height
- 48 multi-directional wave makers (90° arc)
- Curved

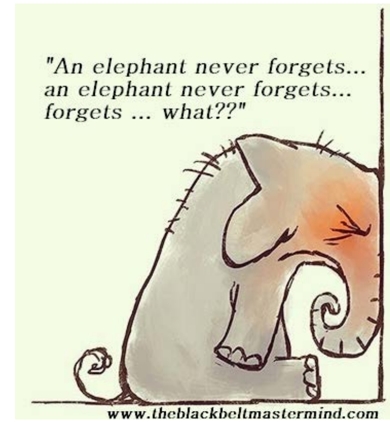
FloWaveTT (2014)
- 1/20
- 0.7m wave
- 168 multi-directional wave makers 360° arc
- 28 flow-drive submerged units simulate current
- Circular

Basic research → Applied R&D → Real world demonstration

“Facilities like FloWave are a last step before you step off the beach. The rule of thumb is that when you step off the beach you put a zero onto the end of any number with a pound on the front. When you go to the bottom of the sea you put another zero on the end” – Facility manager

Wider lessons for innovation studies

- **Institutional learning capacity** – Learning not restricted to technology innovation but also policy about what works and doesn't
- **Secondary technology innovation** – The ability to develop a new technology relies on the necessary tools and testing facilities already being available. Steward's 'systems of innovation'
- **Devolution and innovation** – Tiered governance structure may lead to duplication or contrasting innovation strategies BUT smaller governments more nimble and able to change track?
- **Innovation timelines** – Supports view that gestation period is approx. 40 years



Policy recommendations

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- **Consistent funding** – Intermittent funds don't help
- **Cross-fertilisation** – Accelerate innovation by learning from other sectors (e.g. ship building, sub-sea mining, aviation)
- **Greater international collaboration** – New entrants challenging UK e.g. Sweden, Australia, China.
- **Cultivate niche markets** e.g. aquaculture, islands
- **Strengthen links between developers and researchers**, e.g. joint-body and medium-term funding
- **UK-wide programme** that broadens out Wave Energy Scotland model to UK
- **Public investment banks** - Scotland's REIF helped tidal reach commercialisation. GIB could follow suit
- **Innovation vouchers scheme** to improve access to test facilities

Conclusions

- UK is a leader of ocean energy innovation outputs but lags behind other countries in terms of effectiveness i.e. 'bang for its buck'
- **Why?** Weaknesses identified in the UK's wave energy innovation support system: **(1)** going too fast too soon; **(2)** poorly coordinated and complex landscape; **(3)** backing the wrong 'winners'; **(4)** bundling technologies together at different TRLs; **(5)** intermittent support and **(6)** low levels of knowledge exchange/collaboration
- BUT effective learning and system re-configuration has taken place following policy learning, embodied by Wave Energy Scotland
- **Policy recommendations** include more consistent support, cross-fertilization; international and private-public collaboration, UK-wide coordination and affordable access to test infrastructure

Next Steps?

- **PUBLISH, PUBLISH, PUBLISH!!!!!!!**
- **Future Research?**
  1. Compare wave vs. tidal stream in UK – How has tidal stream 'stolen a march'?
  2. Explore best and worst international performers. UK compared against 'strong' (e.g Ireland, Australia) and 'weak' (e.g. US) performers
  3. Additional innovation indicators e.g. private $ (Bloomberg), generation (MWh) and LCOE
  4. Understand nature of innovation policy learning
  5. Examine innovation process from perspective of the energy entrepreneur (e.g. Richard Yemm, Adam Norris)

Preliminary Outputs

- Hannon, M., van Diemen, Renee. (2016) An International Assessment of Ocean Energy Innovation Performance, 23rd World Energy Congress, Istanbul October 2016
- Hannon, M. Griffiths, J. Vantoch-Wood, A., Carcas, M., Bradley, S., Boud, R., Wyatt, S. (2016) Marine Energy, chapter in World Energy Resources 2016

The Fighting Temeraire. 1839, by J. M. W Turner

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