January 2023

Harnessing the Power of the Seas

The case for a Marine Energy development strategy

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Introduction

Although there seems to be widespread recognition of the UK potential for generating renewable energy through the ebb and flow of tides, a number of schemes have been suggested but to date no proposals are being implemented.

Current Liberal Democrat policy on the energy mix includes a target of generating 10% of UK energy requirements from tidal energy. This paper aims to provide background information for informing decisions on whether a more ambitious target may be practicable and what steps could be taken to kick-start the introduction of tidal energy schemes in the UK.

Acknowledgement

This paper draws on a presentation with Q and A from Prof George Aggidis, Head of Energy Engineering at Lancaster University, to the conference of the North West Region Liberal Democrats held at the University of Cumbria on October 22, 2002. Prof. Aggidis' permission to make use of slides and notes from that presentation, the provision of access to newly published scientific papers on this topic and his assistance in answering subsequent questions is gratefully acknowledged. Thanks also to David Howard of the UK Centre for Ecology and Hydrology for a helpful response to questions.

1. Executive Summary, Conclusions and Recommendations

i. There are three sources of renewable energy available from the oceans of the world. Tidal stream energy and wave energy are derived from ocean currents and wave motions respectively. Tidal range energy exploits the changing levels of tides as they ebb and flow.

ii. With some of the highest tidal ranges globally, and a multiplicity of sites relatively close to centres of population, including a particular concentration on the West Coast, the UK is the world's most advantageously located country for exploiting tidal range energy.

iii. There are two types of tidal energy scheme, linear barrages across the mouth of an estuary, or tidal lagoons where a curved seawall attached at two points on a coastline forms an approximately 'D'-shaped impoundment of tidal waters. In both cases the flow of the tide drives turbines, generating power in a manner similar to hydroelectric power schemes.

iv. After several years of consideration, proposals for a Severn barrage were ruled out by Government in 2012, leading to a switch of focus to potential lagoon schemes.

v. Since then, improved design options, available for both estuarine barrages and lagoons and which can significantly reduce the impact on the intertidal area behind the seawall have been proposed.

vi. With the ecology of intertidal areas at threat from the consequences of global warming, the construction of tidal range energy seawalls to protect against rising sea levels can provide a positive environmental benefit alongside green energy.

vii. The only operational tidal range energy scheme in Europe, La Rance, in Brittany, operating since 1966, has repaid its capital investment cost many times over and generates the cheapest electricity in France.

viii. Despite this impressive proof of concept, UK schemes have been consistently rejected on value for money grounds. The difficulties appear to lie in the "uncertainty premium" encountered when assessing costs of new forms of power generation, an issue which was successfully addressed in the early days of offshore wind but has given rise to a more questionable financial structure for new nuclear.

ix. Tidal range energy schemes are also unique in their longevity. They incur relatively high capital costs per unit of power generated, but offer low operating costs over a design life of circa 130 years which is potentially extendable through refurbishment. This raises questions as to whether the funding and ownership models applied elsewhere in the energy sector are fit for purpose in the case of tidal range energy.

x. There is also scope for proposing 'hybrid' schemes. These may include; battery and/or other energy storage within the structure of the seawalls, hydrogen production and other uses for energy generated outside of peak times, transport links across the seawall, making use of the grid connection for other green energy schemes, exploiting tourism, leisure or aquaculture opportunities and boosting economic regeneration opportunities in adjacent areas. The added value of associated public benefits achievable at lower cost if incorporated in or associated with a tidal range energy , transforms the business case.

xi. Without Brexit, a UK Tidal Range Energy Strategy would have been a prime candidate for securing financial support via the EIB under the European Green Deal. It is also highly likely that regional economic regeneration opportunities derivable from multi-purpose schemes would have attracted support from EU Structural Funds. This creates an opportunity to demand that the government should put its money where the Brexiteers' mouths are and step into the breach.

xii. In his 2016 report[2] the former Conservative Energy Minister Charles Hendry recommended a very proactive approach to developing and executing a tidal range energy strategy with an arm's-length dedicated resource available to government to harness expertise, drive progress and push down costs. Instead, the Government adopted a 'Micawber strategy' waiting to see what might turn up as the private sector assessed the potential.

xiii. Key to Hendry's approach was support for a "Pathfinder" project, intended as the first of many. Rigorous monitoring and evaluation at each stage of such a project would help to eliminate the uncertainty premium, drive down future costs and establish a regulatory framework for this new industry.

xiv. Hendry identified borrowing costs as a very significant proportion of overall costs, noting government borrowing rates as a benchmark, but stopping short of recommending a direct role for government. He also suggested exploration of alternative ownership models citing the 'not for profit, reinvest surpluses' company Welsh Water which raised finance to purchase its assets through a bond issue, but he reverted to 'leave it to the private sector' Conservative orthodoxy in his conclusions.

xv. Such an ownership model would be consistent with Hendry's precept (below) for a new tidal range energy industry and its UK supply chain;

"I consider it absolutely essential that it should also bring wider and long-term economic benefits to the country, rather than imposing charges on consumers' bills where the economic benefits go to businesses overseas."

xvi. Given that energy policy is a reserved matter the formation of a not-for-profit company, British Marine Power, created to own and manage UK Marine Power assets would be consistent with the analysis above. Publicly owned but independently managed as a commercially focused business it would be committed to reinvesting surpluses and could be capitalised by a special bond issue.

xvii. As owner of the seabed and issuer of exploitation licences, the Crown Estate has supported an environmental data collection and research programme, the Collaborative Offshore Wind Research into the Environment (COWRIE). A similar relationship with the new Tidal Range Energy sector would be desirable. The recent decision by HRH King Charles III to forego a substantial proportion of Crown Estate revenues from offshore wind so that they may be used for “public interest purposes” provides an opportunity to propose that the public interest might best be served by dedicating those surplus revenues to help kickstart this new green energy sector and thereby increase the surplus income available to support the public interest in the future.

xviii. A task force formed to develop and initiate a Tidal Range Energy Strategy should be constructed based on the Hendry recommendation of phased development of a sequential series of projects beginning with a “Pathfinder”. Implementation of the complete programme, and finalising the list of sites to be developed, would be contingent on viability auditing using the data gathered at each stage of the Pathfinder. As hypothetical costs became firm tendering outcomes it is probable that work on a second and then subsequent projects could be authorised before completion of the Pathfinder.

xix. The percentage of UK energy derivable from tidal power would become clearer as the development of the Tidal Range Energy Strategy clarified which sites are exploitable but it is feasible that 15% is achievable[15]and possibly up to 20% especially if a tidal stream energy is included.

xx. The proposed Task Force could evolve into an industry regulator, a Marine Power Development Agency, as the strategy matured and the British Marine Power company became fully operational.

2. Harnessing the Power of the Seas

There are three principal sources of energy from the seas available for exploitation as elements as part of the UK’s energy mix, wave energy, tidal stream energy and tidal range energy.

2.1. Wave Energy

Wave Energy; derived by capturing the kinetic energy in the motion of waves is perhaps the most conspicuous source of potential power from the seas around our coasts. Waves, being produced by winds, can vary significantly in their intensity and direction.

The oscillatory motion of waves, which can seem quite powerful, is relatively slow for the purposes of conversion into useful power. The variability of height and periodicity presents a challenge for conversion into a smooth electrical signal and offshore power converters need to be sufficiently robust to survive storm conditions[8]. Wave energy remains a relatively immature industry compared to some other renewables but has high global potential. Wave energy plant muffles the power of the waves, a potentially useful effect in combatting erosion[8].

2.2. Tidal Stream Energy

Tidal Stream Energy; utilises the kinetic energy from the currents generated by tidal flows around our coastline. The current is harnessed to generate power through floated or anchored turbines (some of which are conceptually similar to wind turbines with blades below sea level), or via hydrofoil devices. There are many locations around the coast of the UK with strong tidal streams (See Figure 1 below).

At the Fall of Warness, off the Isle of Eday in the Orkneys, there is an especially strong stream which can travel at up to 4 m/s in spring tides. In 2003 this became the site of the world’s first marine energy test facility, The European Marine Energy Centre (EMEC). EMEC provides a test site and grid conductivity for a range of partners seeking to develop tidal stream energy or wave energy generation equipment.

After the collapse into administration of a Scottish company, Pelamis Wave Power, in 2014 the Scottish government was instrumental in establishing Wave Energy Scotland, a subsidiary of Highlands and Islands Enterprise with the aim of establishing Scotland as a leader in this technology.

Others with greater resources also have an interest in these technologies.

For example, in 2016 a Chinese company launched a product very similar to that which Pelamis had been developing. Prior to its liquidation Pelamis had been the victim of a break-in during which five laptops were stolen, an incident occurring two months after the visit of a Chinese delegation[10].

While EMEC industrial partners enjoy an excellent test site their objective is to develop tidal stream and wave energy technologies replicable elsewhere in the UK or globally.

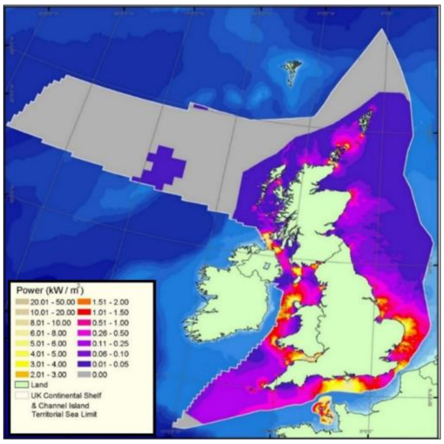

Figure1. Tidal stream energy availability in UK waters (Source – DTI Atlas of Marine Renewable Energy)

There are already seven tidal stream energy projects with a total capacity of 9.1 MW in operation. Schemes for generating a further 2.5 MW are in progress and proposals for generating an additional 390 MW have been approved for development with £20 million per year ring fenced for tidal stream energy under the Government’s Contracts for Difference scheme[13].

2.3. Tidal Range Energy

“The country does not have a more substantial resource of energy that is not being utilised than our tidal range, which is world-class.”

(Hendry report[2] “The Role of Tidal Lagoons”, 2016, p.1)

Tidal Range Energy utilises the potential energy arising from the ebb and flow of tides. This can be achieved through the construction of either estuarine barrages or tidal lagoons bounded by a sea wall such that the seawater flows through turbines to generate electricity in a manner similar to the generation of hydroelectric power. The UK has some of the highest tidal ranges in the world. Tides from the south-west, having gained momentum across the Atlantic are then funnelled between landmasses of Ireland and Europe. The effect is most pronounced on the west coast of mainland UK but there are a number of other locations where tidal energy schemes may be viable.

A 2018 study[9] listed 30 tidal range energy schemes across the world which had been identified as technically feasible of which 10 were in the UK and of these four were barrages and six lagoons. It is possible that this could prove to be an underestimate. The Hendry report[2] identified 18 potential locations for lagoons and his list of potential sites for barrages did not include The Wash where a scheme has recently been mooted.

The tidal range is the difference in height between low tide and high tide. It is caused by the interaction between the gravities of the Earth, Sun and Moon with the lunar cycle. This means that the amount of electricity generated from estuarine barrages or tidal lagoons will vary during the day according to the state of the tide and the position and phases of the moon. These variations are highly predictable enabling balancing adjustments to the energy mix on any given day to be planned in advance.

Also, the times of high and low tide vary at different points on the UK coastline where tidal range energy schemes may be feasible providing opportunities to achieve an element of output balance through the positioning of schemes at different locations.

Figure 2a below illustrates the global distribution of sites with tidal ranges suitable for exploiting these technologies, highlighting the concentration of such sites in UK waters.

Figure 2a; Global Distribution of tidal ranges

Figure 2b below shows that while opportunities exist on the south and east coasts of mainland UK there is a concentration of sites on the west coast.

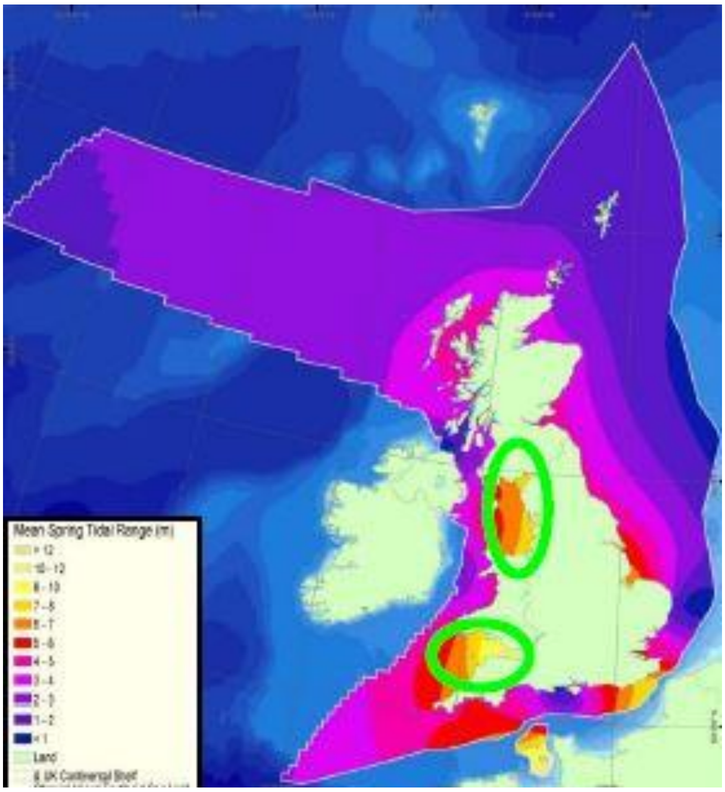

Figure 2b; UK Mean Spring Tide Ranges

The UK is unique not only in the number of potential tidal range energy sites around its coastline, but we are a densely populated nation with most people relatively close to the coast compared to many sites in other countries which are relatively remote from main centres of population.

Despite these apparent advantages the UK currently has thus far failed to construct any tidal range energy plant. The first in the world at La Rance in Brittany was opened by President Charles de Gaulle in 1966. Other schemes have mostly been small scale, an exception being, the Sihwa Lake Tidal Power Station in South Korea, constructed in 2011 and currently the largest in the world. While other countries may have less compelling reasons to adopt tidal range energy than the UK successful development of this new industry could provide new global business opportunities for those involved[1,2].

Despite the relatively small number of schemes the output of tidal range energy schemes globally considerably exceeds other forms of marine energy generation. The International Renewable Energy Agency (2020) stated the global generating capacity from tidal barrages as 521.5 MW versus 10.6 MW for tidal stream and 2.31 for wave energy. By absorbing kinetic energy from high velocity currents the use of tidal stream equipment could alleviate potentially undesirable flows of sediment adjacent to outfalls from tidal range schemes or elsewhere[1,9]. Exploiting this synergy between the two different forms of tidal energy could further strengthen the case for new tidal range schemes.

3. The Story so Far

3.1. The Severn Estuary

The scope for harnessing for power generation from high UK tidal ranges such as those in the Severn Estuary has attracted attention from Victorian times and was the subject of a detailed study by the Sustainable Development Commission culminating in the report "Turning the Tide; Tidal power in the UK "published in 2007[3]. This report concluded that a Severn Barrage should not be proceeded with for cost and environmental reasons (with Parliament subsequently reaching the same conclusion) and drew attention to opportunities for creating coastal lagoon schemes in the Severn estuary and elsewhere. This prompted interest from the private sector including Tidal Lagoon Power Plc. who investigated 5 sites with a Swansea Bay Lagoon seen as the likely first scheme for development.

The interest in lagoons led to the commissioning by government of a review, led by Charles Hendry, whose report[2] "The Role of Tidal Lagoons" was presented to the then Secretary of State for BEIS in 2016. Restricting Hendry's brief to Tidal Lagoons is a little puzzling given his recognition that lagoons and barrages, from an engineering and construction perspective, are broadly the same thing and that in rejecting a Severn Barrage the Sustainable Development Commission had recommended continuing investigation of potential estuarine barrage projects elsewhere.

For this reason, when examining the continuing relevance of many of Hendry's ideas and conclusions to this document they are treated as applicable to both potential barrage and potential lagoon projects.

3.2. The Uncertainty Premium

Hendry found some difficulty in assessing likely costs of tidal range energy, finding the economic modelling he had seen as providing helpful illustrations, but not being entirely satisfactory or conclusive. He identified significant difficulties in the estimation of both capital and operational expenditure. Using a proposed tidal lagoon in the Bridgwater area as an illustration, modelling available to him at the time suggested that that could generate electricity at a cost in the range of £75-90 per MWh. Uncertainty can be very expensive. For example, 38% of the price loaded onto bill payers for construction of Hinkley Point C nuclear power station is the "construction uncertainty premium". Hendry also proposed ways of reducing the level of uncertainty, identifying the need for a "Pathfinder" project to clarify issues and set in train the process of driving costs down. While new costing models have since become available[5] Hendry's argument for gaining experience via a Pathfinder to help drive down costs of subsequent schemes remains persuasive.

3.3. The Micawber Strategy

The Government response to the Hendry report was simply to hope that "something would turn up", sitting back to see if interest identified and stimulated during engagement with stakeholders as the report was formulated might yield a viable proposal. In these circumstances any private sector organisation would need to base the uncertainty premium on worst-case scenarios and formulate a proposal which would ensure that bill payers pick up the tab for the uncertainty. The objective would be for the company to be as certain as possible of profits in all circumstances, profits which, should the best-case cost scenario transpire, may prove substantial. While many of the UK sites attracted interest from potential promoters, proposals often lacked the technical and financial detail necessary for reaching a clear judgement of viability[5].

3.4. A fair crack of the whip?

In 2018 the government rejected a proposal for a tidal lagoon project in Swansea Bay. This was arguably not the best choice for a Tidal Range Energy "Pathfinder" Project. Having been identified as an option in the "Turning the Tide" report it attracted interest from the Local Authority and the Welsh Government in view of local regeneration opportunities ancillary to its development and the opportunity for Wales to take a leading role in developing a new form of green energy. The Welsh Government were also willing to provide a subsidy.

It was rejected on the grounds that the capital cost per unit of electricity generated compared unfavourably with both nuclear and offshore wind[6]. Aspects of the basis for comparison are questionable.

The comparison with nuclear was based on a 60-year operating period. At the end of 60 years a tidal range energy project would be almost half-way through its planned operating life of circa 130 years with the potential for that life to be considerably extended through refurbishment. At the end of 60 years a new nuclear plant has uncalculated and potentially open-ended decommissioning costs with problems of storing highly toxic waste for the foreseeable future.

The comparison with offshore was based on the anticipated cost of wind at 2024 prices. There was no recognition of the comparatively high cost of pioneering offshore wind farms. Drawing on high-level modelling, the Hendry report made a well-reasoned case for the scope to reduce significantly the cost of future schemes, based on the experience of a first "Pathfinder" project, in a manner similar to the progressive reduction in offshore wind costs.

Without providing evidence, the Government claimed that no cost reductions would accrue through experience of building tidal range energy schemes, although it still claimed that a downward cost trajectory would apply to the additional future nuclear plants it aspires to. In the comparison with offshore wind the Government applied a correction for the shorter lifetime of wind, stating that offshore wind farms would need to be renewed 2.4 times to cover a 60 year timeframe. In fact wind farms would need to be renewed five times to cover the planned lifetime of a tidal range energy scheme. There would be decommissioning as well as rebuild costs involved in renewing offshore wind farms.

There are also political considerations. If the scope for driving down costs subsequent to the commissioning of a Pathfinder tidal range energy project could be more accurately quantified, and improved more viable proposals for a series of tidal range energy schemes were to emerge, this might raise doubts about the pricing structure applied to new nuclear and the proportion of nuclear needed within the UK's energy mix. Hendry also identified scope for exploring alternative ownership models which might prove unpalatable in comparison to right-wing economic orthodoxy.

4. The Future for UK Tidal Range Energy

4.1. What's new?

4.1.1. New perspectives on environmental impact

In the 15 years since an initial unfavourable report[1] on the feasibility of a Severn barrage, times have changed. Civil and Electrical Engineers, in industry and in academia, have continued to develop expertise relevant to the construction of tidal range energy projects.

During that period the consequences of climate change with rising sea levels and increasing likelihood of storm surges have provided an additional rationale for the construction of both lagoons and barrages. A major objection in the past has been the projected impact on wildlife habitats within the intertidal areas impounded behind the new seawalls. These habitats, together with the coastal and estuarine towns and villages nearby, are now increasingly under threat from extreme weather events.

Recent research has indicated how what was previously a negative consideration could now be deemed a positive attribute. Counterintuitive though it may seem, the potential damage through sea-level rise and storm surges could be far greater than the short-term impacts of development.[4]

Tidal range energy seawalls can provide coastal defences, the cost of which could not possibly be justified were that their sole purpose. They can be constructed taller than the minimum necessary for electricity generation purposes to provide even greater protection from extreme weather events and take account of future sea level rises.

When using turbines to generate power on both the ebb and flow of the tide, efficiency can be improved by pumping seawater into the impoundment to give an improved head of water at slack tide. Pumping can also contribute to retaining intertidal areas in a similar state to that prior to construction or be used to reduce intertidal water levels when rivers emptying into them are in spate. Environmental impact mitigation, and some habitat adaptation or replacement, would continue to be part of the planning and design process.

A seawall constructed to the minimum height necessary for its prime purpose of power generation would offer significant protection from storm surges. Although it might be over-topped during an extreme weather event, the volume, power and impact of the water entering the intertidal area would be significantly reduced. The height of the sea wall could also be increased to offer greater protection and to take account of future climate change impacts.

The Government may have an obligation to protect some of the coastal habitats under threat from climate change, but the construction of coastal defences purely for this purpose would seem unlikely. Although the coastal defence public interest benefit could be seen as a by-product of tidal range energy schemes, it is nevertheless a significant benefit that should be accounted for in any cost-benefit analysis of a project.

4.1.2. Improving the energy mix

Concerns from the recent past regarding the potential cost of tidal range energy need to be considered in a different context as global energy costs and energy security concerns have increased and recent figures published in "Energy Monitor" suggest that tidal power construction costs compare favourably with new nuclear[7].

Location	Power (GW)	Cost (£bn)
West Somerset	4	10
North Wales	2.5	8.5
Mersey	3	8.1
Morecambe/Duddon	2.3	7
Wyre	1	3
Swansea	0.3	1.3
Cardiff	0.1	0.4
Hinkley Point	3.2	25
La Rance, Brittany (built 1966)	0.24	0.88 (estimated cost at 2022 prices)

Table 3; Projected cost and capacity of tidal range energy vs. Hinkley Point nuclear (Energy Monitor[7])

The above is not a fully comprehensive list of potential sites for the exploitation of tidal range energy. Other potential sites include Solway Firth, Firth of Forth, Firth of Tay, Humber estuary, The Wash, Rye Bay, Dymchurch, Kirkcudbright Bay and Wigtown Bay.

	La Rance Barrage*	Present day French Nuclear*	Hinkley Point New Nuclear	Swansea tidal lagoon	Offshore wind built 2017-19	Offshore wind built 2021-23	Wylfa nuclear (proposed)
Price £/MWh	15.94	22.14	92.50 (indexed)	150	117.7	62.14	77.5
Contract (yrs)	N/A	N/A	35	30	15	15	35

Source: Electricity Market Reform, Delivery body, House of Commons, reported in “The Guardian” 25/06/18
Source*: Energy Monitor[7]

Table 4; Price Comparison between Alternative Methods of Power Generation

While attitudes to public finance in 1960s France may have been worlds apart from attitudes to public finance in 2020s UK, the gulf between real prices for French tidal range energy and projected prices for UK tidal range energy are so stark that cast doubt on the cost projections themselves. The issues which relate to the hefty front-end loading of costs, for an admittedly high capital outlay method of green energy generation, albeit one capable of low-cost operation for many generations to come, are elaborated below.

4.1.3. The Application of Innovation

Opportunities exist to reduce construction times and costs, some of which illustrate the scope for economies of scale which drive down the cost of a series of schemes as opposed to a one-off project.

An example of this is the use of pre-fabricated caissons to construct the sea wall, sluices, and turbine halls. While the use of caissons is a well proven technology those used in the construction of barrages would be larger those used for other civil engineering projects and Hendry noted that no manufacturing facility for ‘mega-caissons’ currently exists in the UK.

Engineering advances relevant to tidal range energy schemes[5] include recent developments in the use of precast sections for underwater tunnels which proved that large structures can be prefabricated on land, floated into place, then joined and sealed. These projects used temporary dry docks and casting facilities, but there is scope for one or more semi-permanent facilities in the UK to reduce the cost of a developing multiple schemes in sequence. Large prefabricated vertical caissons

using a floating barge have been deployed by a Spanish company for constructing breakwaters and docks.
Plans for the pre-fabrication on land of sections of tidal energy seawall with turbines, generators, or other equipment pre-installed and then floated into position can therefore be seen as realistic. Another example of an opportunity to deploy and advance the state-of-the-art is to be found in the manufacture of turbines, these include advances both in the efficiency of electricity generation during both directions of the tide and ecological benefits in the reduction of harm to fish which may pass through them.

4.1.4. Finance and ownership models

A tidal range energy scheme commissioned today should still be providing cheap electricity to the great-great grandchildren of those who promote, design and develop such schemes. La Rance in France, less than half-way through its expected lifetime, is currently providing that country's cheapest electricity to the great grandchildren of those who built it and yet such schemes are repeatedly deemed uneconomic by UK governments. This raises questions as to whether the problem lies with the technology or with the ownership models, business models and funding models deployed for its development. Should we be asking whether the "Contract for Difference" model, originally deployed to guarantee a price sufficient to attract private investment into pioneering offshore wind projects is the best vehicle for kick-starting a UK tidal energy industry?

We live in a world where venture capital is directed toward projects where there is an opportunity for short-term capital gains with an exit after around four years. Our European neighbours are less constrained in securing finance for the long term. A consequence of Brexit is that the European Green Deal, which is helping to transform energy security and the quest for net zero within the EU, together with the source of finance underpinning it, the EIB are no longer available to us. Among the many hitherto empty promises made during the referendum campaign and the 2019 general election campaign were assurances that the UK Government would step into the breach. Perhaps in the case of tidal range energy we should be demanding that they do so.

Hendry recognised that tidal range energy projects, requiring significant initial capital funding but with a lifespan of circa 130 years of relatively low operating costs, make comparisons difficult.

He acknowledged that the cost of capital for investors and financiers has a very significant impact on the overall costs of projects. By way of illustration, the cost of capital in the case of Hinkley Point C makes up 12% of the cost to electricity consumers and a further 29% of the price we will pay is accounted for by "other finance costs."

Clearly any means of driving down the cost of borrowing major has implications for the tidal energy business model. Hendry also recognised that by some margin the cheapest borrowing is government borrowing. Whether from his own conviction, or that of the Conservative ministers receiving his report, he decided that the procurement model which he felt this implied should be disregarded in favour of a totally private sector ownership and management model. However, no tidal energy specialist civil and electrical engineering conglomerate companies exist. Companies such as Tidal Lagoon Power Plc., who have promoted schemes, would themselves be, in effect, adopting a procurement model. The uncertainty premium they seek in advance, via a long-term guaranteed surcharge to bill payers, is therefore based on their estimated outcomes of a future tendering process and they would of necessity need to build in an ample safety margin.

It should be noted that the French tidal range project, which when judged 57 years on from its completion appears successful on any measure, was commissioned by a nationalised industry which, prior to recent re-nationalisation in response to the energy crisis, became a publicly owned company whose profits were ploughed back into the business. This includes substantial profits made from UK customers, with those future profits guaranteed by subsidies and by high prices for new nuclear energy from Hinkley point C and Sizewell C.

Hendry drew attention to evidence received which suggested that a very low cost of capital for a large-scale tidal range energy programme could be achieved by introducing an alternative ownership model. While seen as an example for consideration rather than a recommended definitive model for replication, he drew attention to Welsh Water. Welsh Water is owned and financed by Glas Cymru, a not-for-profit company that acquired the utility in 2001. This ownership model was cited by Hendry as an illustration of how a capital-intensive industry with low-risk and long-term income generation characteristics can be funded at low cost. It is also noteworthy, that despite its continuing Thatcherite rhetoric in relation to public ownership, the Government is a 50% shareholder in Sizewell C and may need to be a direct investor in any other new nuclear it may wish to commission. Its long-term income generation prospects enabled Glas Cymru to purchase the assets it manages through the issue of bonds on favourable interest terms. The establishment of UK Ocean Energy as a publicly owned, but independently managed, business committed to re-investing its surpluses might not appeal to right-wing Conservative orthodoxy and might further foment public discontent with the privatisation models adopted in the UK. However, Government backing would enable such an entity to be financed at the lowest practicable cost, a factor identified by Hendry as having a major impact on the overall cost structure.
A British Marine Power company, publicly owned, but independently operated and with its surpluses reinvested, could raise capital via a government-backed bond issue. Once firmly established, a bond issue for expansion of its business might be constructed in such a way as to provide an opportunity for small investors.

4.2. Renewable Energy Plus- Economic development benefits

In addition to their value as a major new source of green energy, tidal range energy schemes provide significant economic opportunities. For example[2], turbines and generators account for between 25-35 percent of total cost and present an opportunity to develop and deploy innovative products. Hendry reported that in the course of the preparation of detailed proposals for a Swansea Bay Lagoon over 1000 geographically dispersed UK businesses had registered an interest in supplying parts and skills. For this single relatively small project it was forecast that over a five-year period circa 2300 direct jobs would be supported. Almost half would be in metal fabrication, 20% in steel casting and 11% in forging/damping metals with around three quarters of jobs requiring skills at level 3 or above. The predictable nature of peak energy generation with some peaks at night-time and other off-peak times, provides opportunities to make scheduled use of that energy by high consumption industries, for example hydrogen generation or the use of electric arc technology for green steel production.
There is also the opportunity to create a new industry in the onshore pre-fabrication of concrete caissons to form sections of the sea wall, including the pre-installation of turbines and other components.

4.3. Renewable Energy Plus- Coastal defences

As outlined previously, the construction of a sea wall offers flood protection to the impounded coastline through the reduction in the impact of wind and wave action. Increasing the height of the sea wall beyond the minimum required for a tidal range energy scheme itself could provide enhanced protection against rising sea levels and other consequences of climate change.
Hendry identified the following benefits which would accrue primarily to the land behind the sea wall;

- Reduction in storm surges,
- Reduction in the peak size of waves
- Reduction in peak tide levels
- Reduced erosion of existing defences
- Reduced tide-locking at high-water.

A two-way generating tidal range scheme can reduce the peak water elevation within the impounded coastline reducing the risk of flooding from rivers emptying into the impoundment[4]. Pumping to adjust levels within the impounded area can enhance this effect.

The effects of water volumes creating changes to flows of water and sediment need to be assessed during the design stages to avoid adverse consequences elsewhere. Improved modelling techniques, deploying the ever-increasing computer power available today can be utilised for this purpose.

A number of locations that are potential sites for tidal range energy schemes have an existing coastal defence need the meeting of which would otherwise be prohibitive. One example is the North Wales coast where coastal communities and major transport links are at risk from future storm surges on a plausible scale[4]. The Somerset Levels could benefit less from a lagoon in the Bridgwater Bay area than one might intuitively expect[2] since the 2014 flooding was the result of water overtopping embankments upstream of the tidally influenced area.

With one third of the Fens below sea level the threat of future inundation is clear. With about 88% of the land cultivated, including around half the most fertile Grade 1 agricultural land in the country they make a major contribution to food security. The recent proposal for an 11-mile barrage across the mouth of The Wash[11] between Hunstanton in Norfolk and Gibraltar point in Lincolnshire, incorporating a road link and port facilities might seem intuitively appealing. The high tide times in this area could also help with balancing output from other locations. It is unclear however how far substantial port facilities, constructed to take advantage of the deepest channel, might reduce the length of sea wall available for power generation facilities. Furthermore, the Fenlands are a major carbon sink and since they, and the coastline involved, boast unique wildlife habitats ecological objections to any project are to be expected[12]. The extensive river systems emptying into The Wash deposit large quantities of silt which could create practical problems for the operation of a tidal range energy facility and the impact of changed tidal flows on a North Norfolk coastline with adjacent low-lying communities is a further issue that would need to be addressed.

4.4. Renewable Energy Plus- Energy Storage

The predictability of tidal range energy and the opportunity to construct multiple schemes at locations with different high tide times provide an opportunity to make a meaningful contribution to baseload power generation. However, tides continue to ebb and flow overnight when electricity usage is low. The use of prefabricated caissons in construction offers scope for the preinstallation of a variety of electricity storage options, including batteries, pumping systems and gas compression. There is also the option of hydrogen generation, or the use of night-time generated power to service high power usage industries such as 'green steel' electric arc scrap recycling. Night-time generated tidal range energy power could be accessed via the grid or where schemes are sited adjacent to an area in need of economic regeneration direct local connectivity may be an option.

4.5. Renewable Energy Plus-Transport links

Some feasible estuarine barrage locations may benefit from the construction of transport links along the top of the sea wall. Perhaps the most striking of these opportunities is the Northern Tidal Power Gateways Project across Morecambe Bay and the Duddon estuary. A dual carriageway linking North Lancashire and West Cumbria is estimated as attracting 4.5 million annual crossings, reducing distance by 50% and journey times by 75% with an estimated quarter of a million litres of fuel saved annually. A beneficial improvement in transport links could also prove a benefit of any future barrage across the Wash. While any estuarine barrage could provide a shortcut between points on opposite sides of an estuary the value of this in relation to existing transport links and traffic flows between the points in question mean that each would need to be judged on its merits. While some vehicular access along a barrage would be necessary for servicing reasons providing sufficient width to accommodate a road or rail link would incur extra costs over and above that needed for a sea wall constructed purely for tidal-range energy generation purposes.

4.6. Renewable Energy Plus-Tourism, Leisure and Regeneration

The estuary barrage at La Rance, which incorporates a dual carriageway road, reputedly attracts around 40,000 tourists per year. There would appear to be scope for enhancing the tourism experience for those curious to see any similar UK facility and, where a road or other public access is included in the scheme, to enjoy the new unique sea view perspective that a long sea wall across what had previously been part of the ocean can provide.

The regeneration potential has been inherent in the development of Swansea Bay Lagoon proposals. The economic transformation of the Cardiff Bay area subsequent to its enclosure by a sea wall with swathes of derelict brownfield sites redeveloped for housing, commerce and the home of the Welsh Parliament (Senedd) provided a visible exemplar. (The Cardiff Bay barrage has no power generation function but was created for environmental improvement purposes.)

The most recent iteration of a hybrid scheme for a Swansea Bay lagoon, branded "Blue Eden", includes installation of high-volume battery storage for power generated outside peak use times. This would serve as the launch customer for an adjacent new battery manufacturing facility. The proposed scheme also includes a 72,000 sqm floating solar power farm, the creation of an oceanic and climate change research centre, floating dome structures for cultural/scientific centres, 5,000 waterside homes and a 94,000 sqm data centre linked to its own uninterruptible renewable energy supply. While there is some synergy between the lagoon and other developments, the early priority for Blue Eden appears to be a regeneration of the Docklands and adjoining areas. Since the scheme is to be constructed in phases substantial progress could be made before the issue of the lagoon and the cost of its electricity is re-addressed.

4.7. Renewable Energy Plus- More renewable energy

Large offshore wind farms enjoy some economies of scale in the development of their connectivity to the shoreline and thence to the National Grid. Offshore wave power and tidal stream energy schemes, hitherto on a relatively small scale also require connectivity. In preparing any business plan for a tidal range energy scheme the possibility of wave power development on the seaward side of the sea wall should be considered. A wave energy farm in this location would benefit from the tidal range scheme's connectivity to the grid. The channelling of tidal flow through narrow turbine apertures increases the velocity of currents in the vicinity of the seawall. Once the water has passed through the turbines the kinetic energy in that current serves no further purpose and could potentially drive tidal stream turbines. If modelling demonstrates this symbiotic relationship to be feasible the use of tidal stream turbines in the 'surplus 'currents could mitigate potential deposition of sediments elsewhere. There may also be opportunities to mount solar panels or wind turbines on and near the sea wall.

4.8. Value for Money

Assessing the value for money of tidal range energy proposals is a complex process. In addition to its primary purpose of providing a new form of green energy, tidal range energy is unique in its longevity, its ability to contribute to baseload, and for its hybridisation potential which can generate other forms of public interest benefit. Some of these benefits could be provided through other means, but at greater costs that would often prove prohibitive. It would be invidious to load the cost of these additional benefits onto electricity bill payers and they must therefore be funded directly from the public purse. However, it would be fair, when judging the capital cost of tidal range energy schemes, to recognise that significant public interest benefit add-ons can be provided at a very substantial discount compared to stand alone costs.

In addition to UK tidal range energy having been evicted from what could have been its natural home in the European Green Deal, the wider societal and economic regeneration benefits which public interest add-ons can yield would have made these schemes attractive propositions for securing a significant financial contribution from EU Structural Funds. Prior to Brexit, tidal stream energy had benefitted from EU support[13]. To date we have no credible bridge across the yawning levelling-up chasm created by our severance from EU support. We have instead the pitiful spectacle of local authorities spending scarce resources on bids to what is, apart from the minimum window dressing, necessary to sustain an extremely tenuous claim to the contrary, The Pre-Election Sweetener Fund. The public interest to be derived from the enhancement of tidal range energy schemes beyond the minimum specification required purely for power generation purposes could be seen as a test case for demanding that the government steps into the Brexit Breach and provides genuine, levelling-up investment to fill the void where EU Structural Fund Support should be.

5. Implementation

5.1. Role of the Crown Estate

As the owner of the seabed, the Crown Estate would have an important role within the strategic planning and consenting framework overseen by Government, and in granting of leases for tidal range energy schemes. Within the offshore wind programme it has taken on an additional role in supporting an environmental data collection and research programme, the Collaborative Offshore Wind Research into the Environment (COWRIE). In the exploitation of marine energy in general, and tidal range energy in particular, an equivalent body could play an important role from the earliest stages of strategy formulation and implementation. This could include the development and monitoring of good practice from the design stage, ensuring the realisation of positive benefits in terms of coastal defence and exploiting fully the scope for the protection of habitats within the intertidal areas. Within a phased rolling programme there is also a public interest case for independent monitoring and evaluation of early schemes to develop a continuous improvement mindset. In understanding and potentially mitigating the impacts of climate change there is also a need for further work in the application of state-of-the-art computing methods to the modelling of current and sediment flows in relation to the positioning and design of seawalls. This could include further research into how far the absorption of kinetic energy by tidal stream and wave energy schemes may have potential to impact erosion.

In the light of HM King Charles' recent statement regarding his wish that surplus revenues from the Crown Estate could be used for purposes that benefit the common good there is a strong case for creating an "Marine Energy Development Fund" to help kickstart new schemes for generating power from the ocean focusing initially on tidal range energy. Such a fund could be used to cover at least part of the "uncertainty premium" inherent in the earliest projects enabling a multi-project strategy to be formulated with confidence that it could be delivered. There are also some "start-up" costs related to the initiation of a new form of green energy, for example, the establishment of manufacturing facilities for the onshore fabrication of caissons and the installation of turbines and generators etc. within these sub-structures.

5.2. A Marine Power Development Agency

In order to move things forward as quickly as possible it may be necessary to establish in the first instance a task force of civil servants augmented by external experts. This could evolve into an oversight and regulatory body, the MPDA, once the Pathfinder was at a sufficiently mature stage for a more comprehensive strategy involving the sequential development of a full programme of tidal range energy schemes to proceed. As indicated above, any Agency participating in an initiative equivalent to that of COWRIE in the offshore wind sector, but applied to the generation of energy from the seas, would have a remit adjusted to the needs of its sector. Hendry identified the need for a body analogous to the Olympic Delivery Authority (but without its planning powers) to formulate a strategy and drive it forward. This would include development and monitoring of a regulatory framework to help ensure an overall benign impact on the marine environment. In the almost seven years which have elapsed since the delivery of his report the opportunity to establish a new form of green energy that can make an impact on the achievement of net zero has drifted. In addition to the decision to proceed new sense of urgency for delivery is required. Operating at arm's length would be desirable, especially since the role of an MPDA would overlap with the functions of BIES and DEFRA.

The 1996 French example provides a value for money benchmark which modern methods of design and construction ought to be able to match. Deciding what price should be charged for tidal range energy for decades to come should not be based on even a well-informed guess as to the scale of the 'uncertainty premium' that is required. It should be based on reality; a project with all design details in place, all preconstruction seabed preparation completed, a real cost for establishing a prefabrication facility for caissons with preinstalled sluices, generation, pumping and power storage units to serve it (and subsequent projects), together with real competitive tenders for construction and a real strategy for driving down costs as further schemes are implemented.

In parallel with the commissioning and monitoring of a Pathfinder project, the task force would review all previous schemes in collaboration with the various promoters and stakeholders, revisit cost profiles and develop a strategy based on sequential implementation of chosen schemes.

It should initiate the establishment of a not-for-profit company UK Marine Power and once this was established the MPDA would serve as its regulator. UK Marine Power would be publicly owned but independently managed as a commercially focused business committed to reinvesting surpluses and capitalised by a special bond issue underwritten by government to ensure lowest possible financing costs. Its first employees would be tasked with establishing relationships with local stakeholders and contractors for delivering the Pathfinder. Its board would have additional responsibility for finalising the wider Tidal Range Energy Strategy and the projects to be included within it. Its business plan would quantify cost reduction targets achievable in subsequent schemes as a result of the data emerging from the Pathfinder. The rollout of the complete tidal range energy strategy would be contingent on a viability audit based on this improved data, resulting in business plan for the generation of electricity at realistic and affordable prices when compared to other means of providing a contribution to both net zero and to the UK power generation baseload.

5.3. Which Pathfinder?

5.3.1. Why choose an Estuary?

As reasoned above, in the years since the rejection of a Severn barrage the picture has changed radically in relation to the ecological issues which were a major cause of that rejection. Carefully designed tidal range energy schemes can limit the changes to the intertidal area which have been a cause of concern while also serving a coastal defence function. Estuarine barrages typically impound a larger body of water and a longer stretch of coastline per mile of seawall compared to the roughly 'D'-shaped wall of a lagoon. Thus, more coastline is protected per mile of estuary seawall and estuaries have also historically attracted settlements.

There is therefore a logic in selecting an estuarine scheme as the Pathfinder to a tidal range energy strategy that would include other estuary schemes and lagoons. Certain potential lagoon sites would enhance the protection of stretches of coastline at high risk of flooding. For example, a North Wales coastal lagoon would protect towns like St Asaph, with a history of flooding, and also the main London-Holyhead railway line[4].

The Severn estuary remains the biggest prize. It includes potential lagoon sites[2] and more than one option for a barrage. The experience of conducting the earlier phases of a national tidal range energy strategy in other locations would provide data which would help to clarify optimal solutions for exploiting tidal range energy within the Severn estuary.

5.3.2. The case for Morecambe Bay

A barrage across Morecambe Bay and the Duddon estuary has much to commend it. A Preliminary Information Memorandum (PIM) commissioned by Northern Tidal Power Gateways project[14] has provided evidence that such project could be viable and could deliver a transformational impact on the surrounding areas and beyond.

Years of inaction and prevarication mean that the period during which a smaller scale Pathfinder may have been the best option has passed. Morecambe is of a sufficient scale to make a meaningful contribution in terms of electricity generation and provide a convincing demonstrator.

- There is a clear need for a hybrid project at this location with a convincing need for the new road link which could be constructed along the sea wall.
- The "Energy Coast" at the Cumbrian end is an area in need of regeneration with a skills base that could be repurposed to the needs of the project and North Lancashire is also in need of a boost to the local economy.
- There is scope for enhancement of the existing tourism and leisure industries at both ends of the barrage.
- There is good connectivity with the National Grid as a consequence of nuclear power stations at Heysham and Sellafield.
- Should the connectivity at the northern end come under pressure through growth in offshore wind and proposed new nuclear at Moorside then new cabling could be accommodated within the structure of the barrage obviating the need for new pylons in a scenic area.
- It is sufficiently close to other potential sites for construction assets to be transferred to other locations within a phased programme.
- This proximity would also offer potential for providing a sub- structure prefabrication facility, developed for the Pathfinder, but which could also serve other schemes.
- A barrage across Morecambe Bay will offer protection from tidal flooding to Ulverston, Grange-over-Sands, Milnthorpe, Carnforth, Morecambe, parts of Lancaster and several villages[4].

5.4. The evolution of a UK Tidal Range Energy Strategy

It is suggested that the development of a UK tidal range energy strategy proceed in parallel with the fleshing out of a comprehensive UK Tidal Range Energy Strategy the evolution of which would be informed by the development of the Pathfinder, a process which would include;

I. Discussions with the Crown Estate both for licensing purposes and for the establishment of a collaborative environmental research programme for tidal range energy similar to COWRIE in the offshore wind sector.
II. A design competition for a multi-functional Morecambe Bay barrage that would serve a coastal defence need, include a dual carriageway road connecting West Cumbria and North Lancashire and incorporate features such as energy storage facilities within and adjacent to the structure.
III. A call for proposals for developing an environmental impact assessment and strategy for Morecambe Bay.
IV. A call for proposals for the establishment in the North West of a facility for prefabrication of concrete substructures.
V. The development of a substantive levelling up strategy to identify and pursue economic regeneration and tourism/opportunities arising from or enhanced by the construction of a Morecambe Bay tidal range energy scheme.
VI. An evaluation and monitoring strategy for each stage of the Pathfinder to inform the development of subsequent schemes and drive down construction costs.
VII. Clarification of the percentage of UK energy derivable from tidal range power as the number of sites viably exploitable is finalised. It is feasible that 15% is achievable[15]and possibly up to 20% especially if complemented by a tidal stream energy programme.
VIII. A commitment from Government to provide financial support for the Pathfinder's wider public interest benefits; coastal defence, environmental protection, transport link and economic regeneration.
IX. The dedication of surplus funding to be from Crown Estate offshore wind licences toward support that would mitigate the 'uncertainty premium' associated with the early phases of a tidal range energy programme.
X. The percentage of UK energy derivable from tidal power would become clearer as the development of the Tidal Range Energy Strategy clarified which sites are exploitable but it is feasible that 15% is achievable[15]and possibly up to 20% especially if a tidal stream energy is included.

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