THE ROLE OF TIDAL LAGOONS

FINAL REPORT

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DECEMBER 2016

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Foreword

I am pleased to conclude my review into tidal lagoons and to submit this report to Greg Clark, the Secretary of State for Business, Energy and Industrial Strategy.

In this Foreword I set out some of the key themes and thoughts that emerged as part of the Review.

The UK has the second largest tidal range in the world (after Canada) and it is hard to find an energy source where people are more instinctively supportive than tidal power. In my time as a Minister, I constantly heard people speak negatively about most sources of electricity generation but rarely, if ever, about the principles of harnessing the power of the tides (allowing of course for opposition to individual projects such as the Severn barrage). The 2016 annual public attitudes tracking survey by the former Department of Energy and Climate Change[1] showed that the public is strongly supportive of (wave and) tidal renewable energy, with 76% of those polled supporting the use of this form of renewable energy. In comparison, 84% were supportive of solar, 76% offshore wind, 69% onshore wind, 63% biomass, 55% CCS, 38% nuclear, and 19% shale gas.

This is also the general impression which has come through in the many meetings and pieces of evidence that have formed the basis for this Review. It was perhaps put most succinctly by one independent stakeholder: "The country does not have a more substantial resource of energy that is not being utilised than our tidal range, which is world-class."

Nevertheless, tidal lagoons face very considerable challenges, particularly in relation to their role in the UK's energy mix and potential environmental impact. These challenges, and others, are explored in depth in my report.

In particular, there will be continuing debate about value for money of tidal lagoons, and here the decision ultimately is also strategic rather than purely economic.

Greg Clark as the new Secretary of State for BEIS has, quite rightly, spoken about the fundamental responsibility on politicians to make decisions for the longer term.

[1] https://www.gov.uk/government/statistics/public-attitudes-tracking-survey-wave-17

> "Planning for the long-term is nothing to be embarrassed about. In any other walk of life, it is essential. Every business here forms a view of how you are going to earn your living in the future. I've never understood why it has been considered controversial for a government to do the same.
>
> "A government that fails to look ahead and make the right long-term decisions on tax, infrastructure, research, education and skills, is one that has abdicated responsibility.
>
> *Greg Clark, speech to the Institute of Directors annual conference, 27 September 2016*

I share his views that planning long-term for necessary infrastructure is fundamental to creating an environment in which investment can be made and business can grow most effectively; that industrial strategy should maximise the different opportunities available in different parts of the country; and that industrial strategy should recognise that well-implemented policies will be cross-cutting, rather than attempting to act in isolation to benefit this or that sector or industry.

Historically, too, that was the way decisions were made – looking at the long-term interests of the country.

Our energy landscape is full of examples of power plants which would never have been built on a purely commercial basis, but for which we have had grounds to be extremely grateful for decades that they were constructed. Many of the hydro plants in Scotland were initially built to provide power for the aluminium industry, but are still in regular use today 70-80 years on.

Dinorwig in Wales was built as a pumped storage facility in the 1970s/80s (and to a lesser extent Cruachan in Scotland back in the 1960s) to fill a perceived need for back-up. They too would never have been built on straightforward commercial terms, but even now they play a critical role in balancing the electricity system.

Building the first tidal lagoon today is in the same category. But when the wind turbines and solar panels it is often compared to, have long since been decommissioned in a few decades time, the tidal lagoons will still be capable of delivering some of the cheapest, lowest carbon power available. This is both the greatest attraction of tidal lagoons, and ironically also their greatest challenge, as it is precisely this longevity which makes comparisons with other technologies so difficult.

It is difficult to compare the value of tidal lagoons with this potential for a long operating life to other low carbon projects with considerably shorter operating lives (25 to 60 years). The economic modelling I have seen provided some very helpful illustrations, but I found none to be entirely satisfactory or conclusive. There is no final answer fully reflecting the attributes different technologies bring to addressing the energy trilemma, and hence the strategic dimension to the issue - ultimately

Government must pursue the energy mix which most closely reflects its relative priorities for security of supply, low carbon and affordability.

That also means deciding whether it is right for energy consumers to pay for tidal lagoon projects within a short timeframe or would a longer timeframe be most conducive to achieving value for money for consumers?

In essence it comes down to a number of binary choices. Do we want to build long-lasting facilities now, which may initially cost more, but which would be cheaper over the long-term, or do we want the cheapest power available for today's consumers regardless of the longer-term? Do we want to kick start an industry where the UK can reasonably expect (and plan) to be a global leader or technologies where the economic gain often goes abroad? Do we want to take advantage of a resource which we know for certain will be available for as far ahead as we can see, or to leave the debate still rumbling on with our grandchildren asking why we did not harness the power of the tides, when we knew how to and had the opportunity?

During the Review, I have considered a proposal by TLP for tidal lagoons to have an operating life of around 120 years. I accept this, although I can see no reason why its operating life would not actually be even longer – the Holyhead Breakwater on the Isle of Anglesey has a similar seawall structure and remains in-place after 140 years. However significant capital works and turbine refurbishment will be required periodically.

The challenge of creating a genuinely new industry is formidable, with many uncertainties to be addressed. We can either stand back and watch other countries take the lead (or watch a resource left permanently unused) or we can decide that we should do what the UK has done so well in the past - spotting an opportunity, developing the technology and creating an industry. As Britain moves into a post-Brexit world, we need to ask if we want to be leaders or followers. If the answer is that we should be leaders, as mine unequivocally is, then tidal lagoons offer an early, achievable and long-term opportunity.

There is a 'chicken and egg' issue. Should government energy policy be led by a developer who comes forward with a particular concept? Or should it be managed in a more strategic way, with government taking the lead?

I think in a competitive market economy, Government should always want to encourage entrepreneurialism and innovation and a top-down Government-led approach would be likely to stifle this, so an approach which encourages new ideas and developments is essential, but once new technologies start to be considered actively, especially on the scale of tidal lagoons, then Government must consider whether a more strategic approach to that industry would be most beneficial.

I have therefore sought to ensure that this Review looks to identify a clear way forward, and to chart a course through some of the challenges and obstacles –

financial, administrative and commercial – with clear recommendations. I have therefore also sought to give an answer to those binary questions where a fudge would only add further delay and uncertainty. This is often referred to as a traffic light approach – red, amber or green giving the appropriate signals for moving forward. In this case, however, I consider an amber signal to be the same as red, as we all recognise that the projects being explored cannot survive endless delays and debate.

The fact that tidal power has not been delivered at scale already does not mean that it cannot be done now. However, there are very significant questions as to whether tidal lagoons can be cost effective, particularly as to whether tidal lagoons may be able to compete with other renewable energy and low carbon technologies to deliver low cost electricity.

I have assessed the contribution tidal lagoons could make to our national energy security and decarbonising the power sector in a cost-effective way. I have taken a view that such an industry must also bring wider economic benefits and I have sought to set a way forward which would ensure that all those separate but important interests would be served.

The proposed first of a kind project Swansea Bay Tidal Lagoon would be a billion-pound national infrastructure project. I make a number of recommendations with a bearing on its future, including that it would be very beneficial for TLP to secure a delivery partner with a track record in building major energy or infrastructure projects.

Greg Clark has rightly highlighted that Government must make difficult choices between technologies as subsidy support cannot simply be made available to all those technologies which seek it. He highlights that the support should be focussed on those which are scaleable and where costs can be brought down. The evidence I have seen puts tidal lagoons fall fairly and squarely within this category.

In retrospect, I started this process with interest but sceptical. The more evidence I have seen, the more persuaded I have become that tidal lagoons do have an important role to play and there should be a government strategy in place to help this happen.

Charles Hendry

CHARLES HENDRY

6 December 2016

1. Introduction

The Review was initiated by Government following proposals for tidal lagoon projects, in particular a proposal by the company Tidal Lagoon Power (TLP) for a tidal lagoon in Swansea Bay. The focus of the Review is not on specific proposals but on the general principles of tidal lagoons. However much of my consideration necessarily started with work which has already been done for Swansea Bay: as it is by far the most developed proposal, it is also the best source of data concerning many issues covered.

I have divided the task facing the Review into two parts. Part One is to assess whether tidal lagoons can, and should, play a cost effective role as part of the UK's energy mix – the 'existentialist question'. Part Two is to consider circumstances in which this might happen by exploring how the technology and the new industry might be developed and financed, and how the optimum national interest can be achieved.

At the start of the Review I issued a call for evidence, which can be found in Annex B, to help to secure a broad evidence base for the Review. The call for evidence was emailed to those who were in our stakeholder list and also to those who expressed an interest in feeding into the Review. The Call for Evidence was published on our dedicated website: https://hendryreview.com/. Updates were provided on Twitter at @hendry_review.

The Call for Evidence ran from 25 May 2016 to 31 July 2016, although I accepted a number of submissions later than this date. We had an excellent response, receiving almost 200 submissions from a wide range of stakeholders, including financiers, investors, developers, supply chain companies, NGOs, academics, as well as many individuals. **I recommend that the Department for Business, Energy and Industrial Strategy considers publishing as much of the material received as possible, as a valuable resource for a range of interested parties.**

We also had excellent engagement from a wide range of stakeholders in the short time available. We held meetings with developers, financiers, supply chain companies, Government delivery partners and Government stakeholders. I also met academics, community organisations, investors, business leaders and representatives from a number of Local Authorities on visits to Swansea, Cardiff, Newport, Liverpool, Bristol and Sheffield.

Stakeholder Themes

Certainly, in relation to Swansea it would be hard to overstate the overwhelming apparent support for a tidal lagoon in Swansea Bay. This included all Sections of the community – local councils, businesses, universities and colleges, and community groups. TLP's commitment to developing a positive local relationship has been exceptional. The tidal lagoon is seen to be the investment which would lead to a transformation of many aspects of the city and its future economic opportunities. To a smaller extent (in part because they are later in the process) a similar programme of community engagement is being undertaken in other 'host communities'.

It has to be recognised that a decision not to proceed with a tidal lagoon in Swansea Bay would be seen as a very serious blow indeed to the city and community (and some would say to Wales more generally). That is not in itself a reason for agreeing to it, but that consequence needs to be appreciated.

On the other hand, I found more cautious views from those who might take a role in financing future projects, or might be taking construction or operational risks.

I heard from current investors and others of their frustration at the length of time it is taking to move any of these projects forward and I understand that. Uncertainty is the biggest threat to investment in any project, but as this report shows there are complex issues to consider.

I also found some views that were mutually exclusive. Whilst some, especially in the financial and environmental communities, argue that a smaller tidal lagoon in Swansea Bay needs to be operational before a commitment can be made to larger projects on the most competitive terms; others, in the supply chain, academia and those pushing for faster action on climate change, argue that the cumulative economic and industrial benefits of a programme of tidal lagoons would inevitably be lost by such a delay.

Industrial Strategy

During the course of my Review an industrial strategy for the UK has gained new prominence. This report is submitted early in the development of this strategy, but I have taken note of indications from the Secretary of State for Business, Energy and Industrial Strategy about the direction of travel.

> "I believe that it is time for this country to have an upgrade. An upgrade in our infrastructure. An upgrade in the resilience and the cleanness of our energy supplies. An upgrade in our education and training. An upgrade in the development and regeneration of our towns and cities. Upwards to a country that invests. Upwards to a country of opportunity and enterprise. Upwards to an economy country that works for everyone.
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> *Greg Clark, speech to the Conservative Party Conference, 3 October 2016*

This agenda is a key component of the role tidal lagoons might play, taking into consideration innovation, skills, education and other topics I will address in the report. Part of the challenge, however, is that the proposed tidal lagoons do not fit into a neat box where they can be considered alongside other energy generation projects. They are hybrid projects, which would generate power but could also provide additional benefits such as economic regeneration, recreational facilities or flood protection. They have a lifespan of two to three times that of other sources of power generation, which makes direct comparisons extremely difficult. That means that the evidence in favour of tidal lagoons in the non-economic aspects – security of supply, decarbonisation and job creation – have to be all the more substantial. And I believe they are.

Other projects and technologies

The Review did not look at other electricity generation technologies apart from making essential comparisons to assess the relevance of tidal lagoons.

I have been made aware of a number of potential tidal lagoon projects in different parts of the country. Some of these have been developed to a position where very detailed work has been undertaken on the engineering design, environmental consequences and costings. Others are rather more aspirational. I note that for proposals such as Tidal Lagoon Cardiff, the City Council is considering setting up a task group to look at independent expert advice on the opportunities and issues that a tidal lagoon could bring to the area[2]. This is a useful step in ensuring areas identified for potential tidal lagoons fully understand the opportunities and implications of these types of projects.

Given the significant difficulties in estimating capital expenditure (capex) and operational expenditure (opex) accurately, I have concluded that it is reasonable to consider in detail those projects where developers have made substantial investment in, and commitment to, the development of their business plans. This is not to say that the more aspirational projects could not have real prospects of success, but that it would be premature to make that conclusion at this stage based on the information available.

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[2] http://www.cardiffnewsroom.co.uk/r/13366/tidal_lagoon_for_cardiff_bay

Working assumptions

The Review has a clear set of Terms of Reference, which are set out in Annex A, and I have therefore made a number of assumptions about the wider policy framework, within which the scope for tidal lagoons should be considered. They are as follows:

- The Government will remain committed to the decarbonisation targets set out in the Climate Change Act 2008, and the UK therefore needs an energy mix which will contribute to meeting these.
- The Levy Control Framework approach (which sets the total amount of funding available for low carbon generation projects) will remain in place, with a Government-determined cap on costs that may be passed on to energy consumers.
- The Government will not look to pursue Carbon Capture and Storage in the near future.
- The Government is looking for an approach which delivers energy security, affordability, low carbon and wider economic benefits to the UK in terms of jobs and industrial benefits.
- There is no change in the Government's position regarding the Severn Barrage, which is essentially off the agenda.
- It remains the Government's goal to bring competition into the process of 'bidding' for financial support for energy projects.

The result of the referendum on British membership of the European Union also occurred during the course of the Review. It is still too early to know what the consequences of Brexit will be and it is certainly beyond the remit of this Review to estimate what it means in terms of securing new investment into the UK's infrastructure. Whilst Brexit will have inevitable consequences for projects such as tidal lagoons, it is not yet possible to establish what they will be and what impact they will have.

Conduct of the Review

I could not have asked for a more active and constructive engagement from the many people and organisations who engaged with the Review. I recognise the very significant demands which so many requests for information and clarifications have imposed, especially on TLP, which have all been responded to with speed, thoroughness and enthusiasm.

I am grateful too to all the people and organisations who have submitted evidence to the Review. I recognise that it is an issue with diverging but sincerely held views and this Report is not intended to précis those submissions but to offer my personal judgement, based upon the material provided.

Finally, I would like to be clear about some areas I have not covered. I have not interpreted my Terms of Reference to include considering the pros and cons of various engineering solutions. Nor do they include assessing the environmental impacts of individual tidal lagoons, for which there are clear processes in place already. Where I have touched upon environmental impacts, it is at a strategic level that relates to whether and how a programme of tidal lagoons might be realistic, and what obstacles might lay in the path towards that goal.

I was asked to produce a report which sets out my own views having read the documentation and interviewed people from all perspectives, so the report is not a summary or précis of the evidence submitted. The conclusions are therefore very much my own, but I could not have done this work without the dedicated and tireless work of a small team of excellent civil servants, seconded to the Review team for its duration – Chris Barrett, Ifediba Egwuatu, Alex Hudson and Cynthia Pereira, ably led by Thomas Wood. I am immensely grateful to all of them for the work they have done.

PART ONE

2. What are Tidal Lagoons?

2.1. Technology Overview

Tidal lagoons are a tidal range technology. Tidal range technologies use a barrage or other barrier to generate electricity from the height difference between high and low tide.

Tidal lagoons work by using a wall to impound a body of water in the sea or a tidal estuary and use the difference in the rise and fall of the water to drive turbines in the wall, and so generate electricity.

Tidal lagoons are similar to tidal barrages, although the distinction between a barrage and a tidal lagoon in technical terms relates primarily to whether an estuary is blocked (using a barrage) or whether the resource is captured using a barrier or seawall attached to two parts of the shore. In common parlance, the distinction often relates more to the very clear geography and history of proposals associated with the Severn Estuary and the historic proposals for barrages. There is a significant and important overlap in the technology, construction and skills associated with tidal lagoons and barrages. Outside the Severn I consider the distinction to be less clear and some tidal lagoon projects I have heard of might also be called a barrage by virtue of also impounding the mouth of a river.

By contrast, tidal stream technology[3] (which is not within my terms of reference) uses turbines often comparable to wind turbines, with blades positioned either in parallel (horizontal) or perpendicular (vertical) to the direction of the flow of water[4].

Tidal lagoon and barrage schemes mainly use bulb turbines, which are similar to hydropower turbines used in dams (a run of the river hydro power plant). They also have three methods of generating power: ebb generation, flood generation, or ebb and flood generation, as set out in the table below[5].

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[3] In some instances referenced for clarification and comparison reasons only.
[4] Definition of tidal stream taken from IRENA Tidal Energy Technology Brief June 2014.
[5] Taken from IRENA Tidal Energy Technology Brief June 2014

One way generation at ebb tide	This form of generation uses the outgoing tide to generate electricity. The lagoon basin is filled at flood tide (incoming tide) through sluice gates that are closed once the tide has reached its highest level. At the ebb tide, the water in the basin is released through the turbines and power is generated.
One way generation at flood tide	This form of generation uses the incoming tide to generate electricity. At flood tide the sluice gates are kept closed to isolate the basin while at its lowest level. When the tide is high, the water from the sea-side flows into the basin via the turbines, thus generating power. This cycle is less efficient than generating electricity during ebb generation, as the amount of kinetic energy is less during flood generation compared to ebb generation.
Two way generation	This form of generation uses both the incoming and outgoing tides to generate electricity. This two-way generation is in general less efficient than one-way flood or ebb generation as the required head height is much smaller which reduces the period over which normal one-way generation might have otherwise occurred.

Table 1

2.2. Characteristics of sites suitable for tidal lagoons

There are a number of physical factors that determine whether a site is suitable for a tidal lagoon. It is considered by some that the minimum 'head' to make tidal lagoons economically viable is five metres. However, some turbine manufacturers have submitted evidence that current bulb technology can work with a nominal head of water as low as four metres. This is an example of where technological change could deliver greater efficiencies over time.

Seabed geology

The geology of the seabed will affect the location, type and design of the foundations for the seawall and the powerhouse. Seawalls must be high enough to impound the required volume of water, whilst being suitably robust for expected weather and sea level conditions. Non-ideal seabed conditions (such as silts and soft deposits subject to scour) will require increasing civil engineering interventions and more material.

Bathymetry: depth and profile of the seabed

The depth and profile of the seabed is a dominant factor in determining the viability of a tidal range project. Ideally a site would have an area of shallow seabed in a convenient location for the seawall and powerhouse to be built in order to reduce cost and construction risks, and an adjacent large area of deeper seabed to impound as large a volume of water as possible, minimising pre-works such as dredging.

Tidal velocity

Tidal velocity at a site is a function of the depth and profile of the seabed, and wind, wave and sediment characteristics. Flows around the structure can increase scour of the seabed, potentially undermining the seawall. This could be addressed by the inclusion of scour protection, but this would increase capital costs. The tidal regime will dictate the orientation and location of turbines, and the efficiency of the filling and emptying of the water volume.

Sedimentation

Tidal range structures can influence, and be influenced by, sediment flows (broadly defined as flows of mud and sand). This can affect the morphology of adjacent coastal areas and the requirements for dredging (and hence operational costs). Sediment trapped by tidal range structures can reduce the effective difference in water heights, reducing the amount of head available for the generation of electricity.

Wave regime

The direction, strength and height of waves will affect the design requirements of embankment walls and powerhouses. The eroding impacts of higher stronger waves can be mitigated by shallower-angled seawall and a higher crest, but this increases the footprint of structures, the amount of material required to construct them and capital costs. Future changes in wave regimes and sea levels as a function of climate change must also be considered.

Location in relation to the National Grid

The proximity of tidal range sites to national grid infrastructure suitable for electrical connections influences capital costs, with more remote sites requiring costly long cable routes to connection points. Reinforcement of existing networks may also be required. National Grid levies Transmission Network Use of System charges to recover the cost of installing and maintaining the transmission system. Charges are a function of the size of generation capacity to be connected and the ‘geographical zone’ generation assets are located in. Issues relating to connecting to the Grid will be exacerbated if multiple tidal lagoons are constructed close together.

2.3. History of Tidal Power

There is a long history of proposals to harness marine energy at scale in the UK, in particular with proposals for a Severn Barrage dating back to 1849. The tide mills at Eling and Woodbridge date back to the $17^{th}/18^{th}$ centuries with evidence of tidal power being used on site for centuries before that.

To date, there are no tidal lagoons in operation in the world and currently the only tidal range technology in operation is tidal barrages. The largest of these are in La Rance in France, Annapolis in Canada and most recently Sihwa in South Korea.

La Rance, France

La Rance Barrage is the world's oldest tidal power station, located on the estuary of the Rance River in Brittany, France. It opened on 26 November 1966 and is currently operated by Électricité de France (EDF). It was the largest tidal power station in the world, based on an installed capacity of 240 MW until 2011, when it was surpassed by the South Korean Sihwa Lake Tidal Power Station.

I am advised that the Barrage has caused some silting of the Rance ecosystem, but that this has been 'manageable'. Tides still flow in the estuary and EDF adjust their levels to minimise biological impact. The facility attracts between 40,000- 70,000 visitors per year.

As there are no operating tidal lagoons to date and due to similarities with barrage technology, the extensive experience from the La Rance Barrage is commonly used as a learning case for general understanding of how tidal range technology works, in particular turbine operation and maintenance and operational processes. Work has also been done to assess the environmental impact of the barrage.

Annapolis Royal Generating Station, Canada

The Annapolis Royal Generating Station is the first and only operating Tidal Power Plant in North America. It opened in 1984 and is currently operated by Nova Scotia Power (an Emera Company). Initially designed as a pilot project, it has an installed capacity of 20 MW, which equates to enough energy to power 4,000 homes and includes a visitor information centre which attracts around 40,000 visitors annually.

Sihwa Lake Tidal Power Station, South Korea

The Sihwa Lake Tidal Power Station is the largest operating tidal range barrage scheme in the world, with an installed capacity of 254 MW. It was built in 2011, as a way to develop clean, renewable energy supplies and improve water quality of the region. It is operated by Korea Water Resources Corporation and includes an eco-park area consisting of a culture and arts area; recreation area and eco-environmental area.

Other operating tidal power stations

There are other smaller operating tidal power schemes, such as the Jiangxia Tidal Power Station in China with an installed capacity of 3.2 MW and the Kislaya Guba Tidal Power Station in Russia with an installed capacity of 1.2 MW.

The Severn

As mentioned above there have been many proposals for tidal range schemes in the Severn. A two-year cross-Government feasibility study was conducted to inform a decision on whether or not to promote a tidal range scheme in the Severn Estuary. The study looked at five options in outline and assessed their costs, benefits and risks. In 2010 the study concluded that there was not a strategic case to bring forward a Severn tidal power scheme at that time.

In 2012 the Energy and Climate Change Select Committee launched an enquiry into one of the most well-known proposals for a Severn Barrage – the Hafren Power proposal. Based on the evidence provided, the inquiry concluded that the case for the Hafren Power Barrage proposal failed to demonstrate economic, environmental and public acceptability.

2.4. The opportunity in the UK

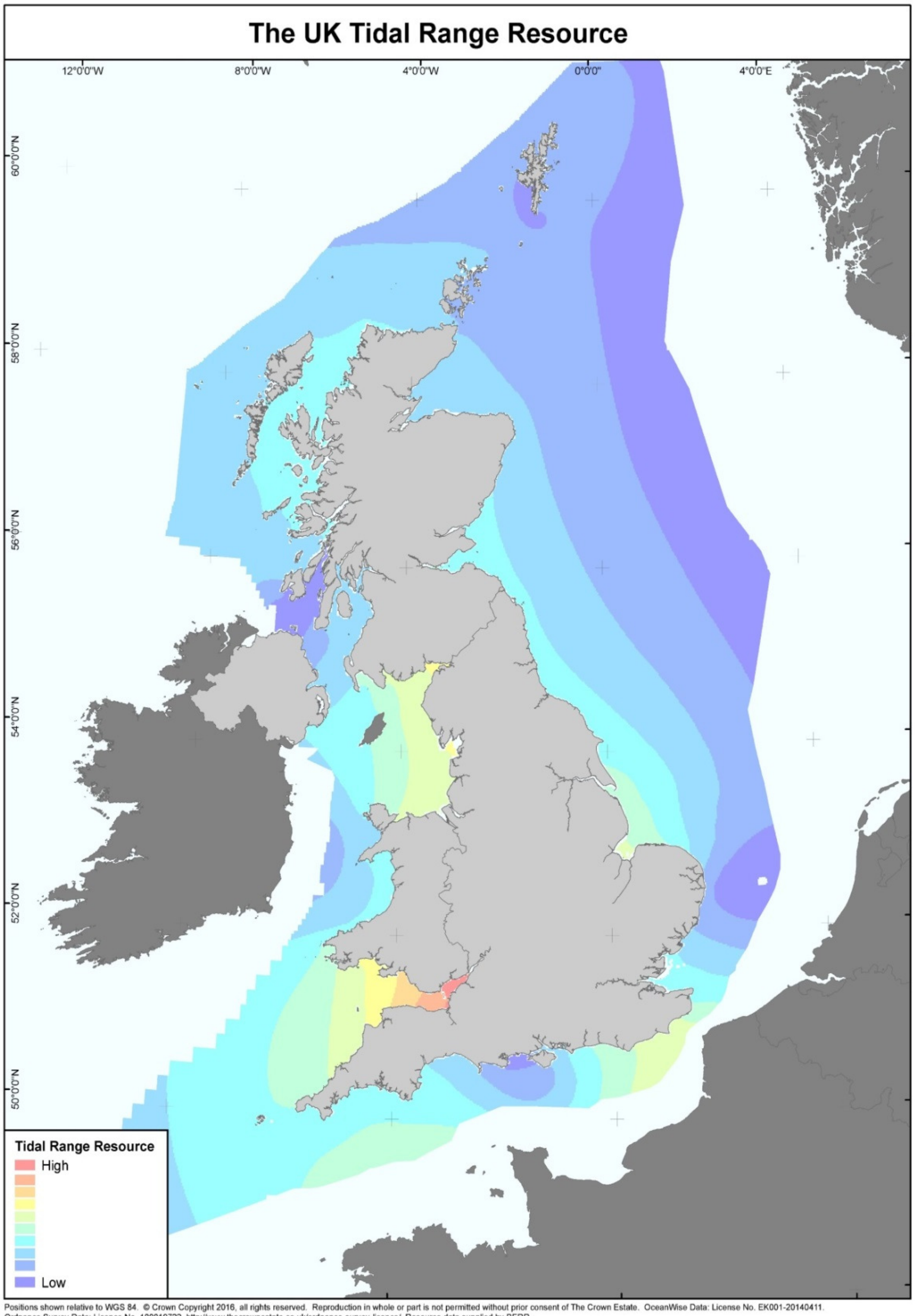

Figure 1: UK tidal range resource
Source: Crown Estate

In 2012 the Crown Estate published findings[6] of a study of the UK's wave and tidal energy resources. The study concluded that there is the potential for a significant quantity of tidal lagoon generation in the waters around the UK. It also identified areas of high resource for each technology. Generally speaking tidal range technologies are deployed on the West Coast, as a result of the UK's geographical position in the north-east Atlantic: tides arriving from the south-west, having built momentum across the Atlantic, are funnelled between the land masses of Ireland and Europe. The unique shape of the Severn Estuary leads to particularly high tidal ranges. An updated map from The Crown Estate's areas of high resource for tidal range technologies is shown on the previous page.

The Bristol Channel and Severn Estuary is the largest single area of tidal range resources. The Solway Firth has the second highest tidal range after the Severn Estuary (and is the third largest estuary in the UK). Other potential sites include Liverpool Bay, North Wales and the North West of England.

Further assessment of the potential for tidal lagoons, commissioned for the Review concludes that the theoretical scale of opportunity in the UK is around 37 GW of installed capacity, from a tidal lagoon programme of 18 potentially feasible schemes, generating 55 TWh of electricity per year.

However, this theoretical assessment does not take into account potential negative interactions between tidal lagoons that could reduce output, or a number of other possible limitations, including financial viability.

An optimal programme would therefore include a significantly smaller number of tidal lagoons. A number of illustrative portfolios for an optimal programme were analysed. These were compared with TLP's proposed programme of six tidal lagoons. This analysis indicated that a programme of the top seven schemes (in terms of comparative cost per annual energy production) would provide 30 TWh of low carbon electricity per year from, a total installed capacity of 18 GW.

In preparing these assessments, out technical advisers ITP have grouped together a number of tidal lagoons with certain characteristics, to assess which grouping might be optimum.

[6] https://www.thecrownestate.co.uk/media/5476/uk-wave-and-tidal-key-resource-areas-project.pdf

Comparison of illustrative portfolios of tidal lagoons			
Portfolio name	**Capacity**	**Capex**	**AEP**
	GW	**£bn**	**TWh**
Value for money[7]	17.9	54.8	30.0
Generation output phasing[8]	13.5	44.4	21.5
Lowest impact[9]	11.2	36.6	16.5
TLP's programme[10]	18.2	51.4	29.0

Table 2
Source: ITP's Technical Report for the Review

2.5. Tidal lagoon projects under development in the UK

Despite the considerable resource available, relatively few developers have begun to develop tidal range projects. In my view this is due in part to the absence of a clear Government policy, and therefore a high level of political risk. The following developers are the most advanced at the present time.

Tidal Lagoon Power

Tidal Lagoon Power (TLP) was set up in 2011 to develop, construct and operate tidal lagoon power stations in the UK and internationally. They are currently developing proposals for a fleet of six tidal lagoons around the country.

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[7] Includes the six tidal lagoons ITP believe would have the lowest ratio of capex to annual energy production (Bridgwater Bay, Newport, Cardiff, Wyre, Blackpool, and Stepping Stones) plus TLSB.

[8] Models eight tidal lagoons (at Swansea, Cardiff, Wyre, Sussex Coast, Sheerness, Conwy, Thames Estuary, and East Lincolnshire Coast) whose high and low tides would be at different times of the day, due to being at different locations on the UK's coast. This difference in tidal phasing could provide a more constant overall electricity supply, with fewer hours of zero power output or power consumption due to pumping.

[9] Comprising seven tidal lagoons (Swansea, Wyre, Stepping Stones, Liverpool Bay, Sheerness, East Lincolnshire Coast, and West Cumbria (Solway Firth)) which are thought would have both low environmental impact and cumulative impacts on energy yield.

[10] Assumes a programme of six tidal lagoons at Swansea, Newport, Cardiff, Colwyn Bay, West Cumbria, and Bridgwater.

The first of these, Tidal Lagoon Swansea Bay (TLSB), received development consent from the then Secretary of State for Energy and Climate Change on 9 June 2015. First-stage negotiations on the terms of a Contract for Difference are currently ongoing on a bilateral basis.

The proposed TLSB project would have an installed capacity of 320 MW, providing power to over 155,000 homes. A 9.5 km U-shaped seawall would be constructed running from Swansea docks to near Swansea University's new campus.

According to the developer, the proposed TLSB would offer community and tourism opportunities in sports, recreation, education and culture, including use for local, national and international sports, such as cycling, walking and running around the lagoon wall, in addition to sea angling, open water swimming, canoeing, rowing and sailing within the lagoon.

TLP are also looking to develop a further five additional tidal lagoons at sites in Cardiff, Newport, West Cumbria, Colwyn Bay and Bridgwater Bay. The proposal for Cardiff is the most advanced of the five.

The currently proposed tidal lagoon at Cardiff would have an installed capacity of c.3 GW and an annual output of around 5.5 TWh, while the proposed tidal lagoon at Newport would have an installed capacity of between 1.4-1.8 GW and an annual output of between 2 TWh and 3 TWh. It is suggested the Cardiff project would offer improved flood protection for the area as well as opportunities for sports and nature conservation. The developer anticipates submitting its Cardiff proposal for development consent in 2018.

It should be observed how much work has been carried out, and to a very high and detailed standard, by the TLP team.

North Wales Tidal Energy and Coastal Protection Ltd

North West Tidal Energy and Coastal Protection (abbreviated to NWTE by the developers) is a local company based in North Wales, which is proposing to develop what they describe as a tidal energy impoundment and coastal protection system.

NWTE is at an early stage in its corporate and financial development and are currently developing a single project – a 32-km long seawall from Prestatyn to Llandudno, enclosing a surface area of around 150 sq km that will reduce the flooding risk to 30 km of coastline and over 100,000 people. The installed capacity of the project would be 2 to 2.5 GW with pumped storage, generating approximately 4.5 TWh pa of power using roughly 125 turbines. The cost of the project is expected to be in the region of £7bn over a six-year build period. While still at an early stage of development they have received significant support from a range of stakeholders and are in the process of engaging with GE and Andritz Hydro regarding the supply of turbines, in addition to working with Welsh universities regarding research and training plans for the future to help the project and region prepare for the requirements of project.

2.6. Other Tidal Range Projects in the UK

In addition I received evidence about other tidal range technology projects. For example, Natural Energy Wyre (NEW) is proposing a tidal barrage project on the River Wyre in Fleetwood. NEW are currently working on validating the feasibility of the project. The project would be expected to cost c. £250 million with an installed capacity of 120 MW, generating around 225 GWh pa using six turbines. NEW have been engaging with Andritz Hydro regarding the turbine design, in addition to civil engineering; environmental and engineering design and planning consultants.

Given the significant overlap in the technology required to build tidal lagoons and barrages, small projects like NEW's Tidal Hydro-Energy Project could help sustain the momentum of a tidal lagoon supply chain.

I also heard about less developed and more aspirational tidal lagoon projects and noted that many of these projects have the potential to innovate through potential cost reductions and construction methodologies used. The table below summarises some details of such projects.

I have also been made aware of other tidal range technologies, such as tidal reefs and tidal fences. Whilst these are outside the scope of the review, some of my recommendations would be relevant to their potential development.

Project name	LongBay SeaPower/ Halcyon Tidal Power	Ecotricity	Tidal Electric Limited	North West Energy Squared (NWE^2)
Location	West Somerset coastal area of the Severn Estuary from the west of Minehead to Weston-super-Mare in the UK	Various	Solway Firth	Morecambe Bay and the Duddon
Installed capacity	Ranging from 1.5 to 4.5 GW	Ranging from 0.36 to 0.9 GW	0.2 GW	5 GW
Seawall length and turbine quantities	Ranging from 21 to 37 km, with 480 to 1440 turbines.	Ranging from 4.6 to 10km, with 12 to 30 turbines	Ranging from 19 to 21 km, with 20 turbines	Unspecified seawall length with 230 turbines
Innovation	Developing construction techniques that could bring down costs and might allow cost effective tidal lagoon facilities in deeper water than would be the case with other approaches.	Construction cost reduction and tidal lagoon design.	Unspecified	Incorporating dual carriageways, providing improved connectivity and transport.
Other benefits	Flood protection, tourist and recreational facilities and other local commercial opportunities.	None proposed.	Tourism, recreation and regeneration.	Tourism, recreation and transport support.

Table 3: Other tidal range projects

3. What role might Tidal lagoons play?

Key findings

- Tidal lagoons would contribute to the UK's security of supply.
- Tidal lagoons would contribute to the UK's decarbonisation goals.
- If tidal lagoons were to be built, ongoing monitoring of any environmental impacts should take place to allow effective mitigation.
- Tidal lagoons would bring wider benefits beyond those of power generation, but these are unlikely to generate significant revenues.

3.1 Energy Policy

All forms of generation need to be considered in relation to how they help the UK meet its energy objectives.

In recent years, this has been thought of in terms of the energy trilemma – security of supply, affordability and low carbon. In reality, the trilemma is far from static – the relative importance of each element changes according to domestic and international circumstances. It can probably now be most correctly summarised as being security of supply, low-carbon in the most affordable ways, with a new added emphasis on wider UK economic, industrial and employment impacts.

The UK continues to need baseload generation – power that can be guaranteed to provide the minimum levels of electricity supply that the country needs. As more power from renewables comes on stream, it also requires flexible elements either to manage demand more effectively at times of lower generation, or to provide extra supply at times of greater demand.

This has broadly broken down in to a mix where the major elements are nuclear, offshore wind, interconnection and gas generation.

Looking forward, we know that much existing capacity will close, as the plant is ageing or too polluting, and this will see the full closure of all coal plant by 2025 (under Government policy). The UK currently has eight operational nuclear plants with a combined capacity of 8.9 GW, and all but one of these is scheduled to close by 2030.

Notwithstanding the substantial progress that can be (and has been) made with energy efficiency and demand management/demand-side response, the UK still needs significant new generating capacity to be provided, especially as we see the move to greater use of electricity in transportation, if we are to meet our carbon reduction commitments.

To achieve this, there needs to be a further step change in the power that we obtain from low carbon sources. The Committee on Climate Change estimates[11] that solar could provide around 5% of our electricity supply by 2030, and that wind could provide just over 30%. With the current renewables mix, it estimates that low carbon could reach over 60% in total, but this could rise considerably if tidal power was also harnessed.

In the following Sections of this Chapter, I make an assessment of the extent to which tidal lagoons could contribute to two of the three horns of the energy trilemma: security of supply and decarbonisation. Other Sections of this Chapter look at two sets of issues that have been raised repeatedly in the evidence to the Review: the potential environmental impacts of tidal lagoons, and the question of whether tidal lagoons should be treated solely as electricity generation assets, or whether their unique features mean they should be treated as examples of 'hybrid' infrastructure. The third element of the energy trilemma, affordability, is the subject of a separate Chapter later in this report. Other issues, relating to supply chain opportunities and export potential, are also dealt with in subsequent Chapters.

3.2. Security of supply

Security of supply has three principle elements:

- the indigenous nature of the generation/fuel
- its predictability
- its dispatchability (the ability to provide power when it is called for).

Indigenous generation has security of supply advantages over those which depend on imported fuel supplies. Where we rely on either imported power or imported fuel stocks, there is inevitably a greater risk of interruption than for domestic alternatives.

Tidal lagoons are UK sources of generation, using a UK resource. The same can be said of most sources of renewables. Nuclear provides UK generation but uses imported uranium; gas again provides UK generation, but now also mostly uses imported gas. In time, UK shale gas resources could change this, but the extent which this could replace imported gas and at what price is not yet established, and

[11] https://www.theccc.org.uk/publication/fifth-carbon-budget-dataset/

throughout this time, the gas we can recover from our own resources in the North Sea is expected to decline.

The power generated by the tides is not constant each day because of different levels of output according to where we are in the moon’s cycle.

Tidal cycles and their effect on generation

The tides are a regular and predictable phenomenon caused by the gravitational attraction of the moon and the sun acting on the oceans of the rotating earth. Most locations around the UK experience the familiar two high and two low waters each day (the average interval between successive high waters is approximately 12 hours 25 minutes which leads to only 3 turning points on every 7-8th day.

The relative motions of the Earth, Moon and Sun cause the tides to vary in numerous tidal cycles – the two most important ones being:

- The spring-neap cycle – a 14.77 day cycle resulting from the tidal influence of the sun and moon either reinforcing each other (called spring tides, although this has nothing to do with the season) or partially cancelling each other (neap tides).
- The equinoctial cycle – a half yearly cycle caused by the tilt of the earth, and its orbit around the Sun which leads to higher than average spring tides around the time of the equinoxes (March and September) and lower than average spring tides in June and December. [12]

Since the amount of electricity tidal lagoons could generate is a function of the difference in height between low and high tides, these tidal cycles mean that the amount of generation from tidal lagoons would vary in cycles too.

The second aspect of security of supply is predictability. The movements and strengths of the tides are known with certainty. This gives tidal technologies a significant benefit over other fluctuating sources of renewable generation. Whilst National Grid can use increasingly sophisticated ways of predicting levels of wind and solar generation, that does not deliver the absolute assurances on generation that tidal power can provide.

The third element of security of supply is dispatchability. Whilst tidal power delivers well on predictability, it inevitably falls short of some other technologies in its ability to dispatch power when required.

[12] http://noc.ac.uk/f/content/using-science/Info_Intro_to_Tides_and_Tidal_Numerical_Modelling.pdf

Following the tidal cycle, tidal lagoons would be capable of delivering the greatest output shortly after high and low tide (but this could be at 2:00am, well ahead of the morning peak demand). It would be possible for the operators of tidal lagoons to delay the start-time of generation on any given cycle, offering some ability to respond to grid demands. In their evidence to the Review, National Grid have noted the potential benefits in the ability of tidal lagoons to shed load easily or even take up load (by pumping) at times when this is needed to balance the system.

However altering the operating regime of tidal lagoons to generate power outside the optimum time window, or to curtail output to help balance the system, would reduce the overall energy yield during the cycle, potentially reducing the operator's revenues. The isolation of the generator from the fluctuations in sale price of power in the electricity market through the provision of a guaranteed CFD strike price would mean that there would be little economic benefit to the operator to generate during periods of high electricity demand based on the market price alone. Demand-based dispatch (where possible) will not be a feature of tidal lagoon operations unless operators are provided with an incentive to do so under an alternative regulatory framework.

There is an inevitable question about how the system could accommodate very significant volumes of power generation from tidal lagoons that may be predictable but not necessarily when demand is greatest. National Grid have been reassuring in their evidence to us that such power could be accommodated and managed, and as we move towards 'smarter' ways of managing energy demand, consumers will be more able to use power more cheaply when it is most plentiful.

While tidal lagoons cannot provide the same dispatchable power that some other sources of generation can, they do offer significantly more reliability than any other type of renewable generation in the UK, apart from biomass and energy from waste (for which there are clear limitations on the volume that can be developed) and large scale hydro.

So, **I am persuaded that power from tidal lagoons could make a strong contribution to UK energy security, as an indigenous and completely predictable form of supply. Even though it offers limited dispatchability, National Grid expressed no particular concern that this would pose problems they could not readily manage.**

It has been put to the Review that while tidal lagoons may not be able to provide dispatchable power, a number of tidal lagoons operated together as a portfolio could come close to providing a consistent level of generation throughout the day. The principle on which this claim rests is that high and low tides come at different times of the day at different points around the UK's coastline. If tidal lagoons were placed to take advantage of that phenomenon, with generation increasing at one tidal lagoon as it decreased at another in line with the different tidal cycles, the output from the tidal lagoons taken together would be less 'peaky', and therefore more consistent.

While I believe that such a smoother output profile could have advantages, advice from our technical consultants is that operating tidal lagoons in a portfolio like this would still leave periods of the day when there was no output, particularly at neap tides. This is, in part, a matter of geography: the areas of the coastline that offer suitable locations for tidal lagoons do not offer a perfectly smooth output profile as their tidal cycles do not align (for example, there is a significant gap of tidal lagoon potential in the coast of mid-Wales). Moreover, a programme of tidal lagoons that could deliver the goal of providing constant, or as near as possible to constant, power would be an absolutely huge undertaking, requiring tidal lagoons around much of the country. **It is my belief that this is too ambitious a goal to be set at this time, before even one has been built, and could only be considered properly when more progress has been made on building a number of tidal lagoons.**

It has also been suggested that the issue of dispatchability could be addressed by using the tidal lagoons themselves in a similar way to pumped-hydro facilities, where water can be stored during times of excess power supply over demand, and then almost instantaneously released to provide the power needed in times of high demand. As noted above, the evidence indicates that this would only make a small improvement to the dispatchability of tidal lagoons, as the tides only offer a small window in which to shift dispatch effectively. I am also not persuaded by the economic and commercial cases for operating a tidal lagoon in this way.

In their evidence to the Review, some have made the case that the future outlook is such that tidal lagoons will be 'white elephants' in a few years' time. They argue that other technologies are developing so fast and costs falling so rapidly, that it would be a mistake to lock ourselves into a technology which would be out of date in a few years' time. For example, they say that the future is low-cost solar linked to storage.

This may be the case but, as I learned as a Minister, many predictions of 'absolute certainty' often came to nothing. Government decisions cannot be made on the basis of predictions about a radically different future, and I firmly believe that Government needs to pursue a range of options that can collectively deliver energy security, rather than putting too many of its eggs in one (optimistic) basket.

Churchill said (speaking of the oil needed for the navy a century ago) that 'Security comes from diversity and diversity alone'. In energy policy, I would contend that that remains the case in the UK today and **I would strongly caution against ruling out tidal lagoons because of the hopes of other cheaper alternatives being available in the future. There may be technological innovations forthcoming which could eventually make tidal lagoons redundant, but policy has to be**

made with the information we have now on the benefits and drawbacks they have, not in hindsight.

Lord Stern, in his evidence, commented that solar and wind with battery back-up can 'probably' be a good outcome for the UK, but the pace and success of their progress cannot be guaranteed. There will be, he added, an upper limit for what can be achieved through solar and onshore and offshore wind, so there is a continuing need for large scale renewable sources of power.

Whilst the key large scale elements of the Government's energy policy have been relatively clear – nuclear, offshore wind, gas and interconnection – the investment needed to deliver it has not yet been fully committed. That means there is inevitably a risk attached to each element. Should any element not go ahead as envisaged, then having tidal lagoons as another source of large volume, low-carbon power in the mix would be of significant benefit. There is strength in diversity. There is a cost to guaranteeing security of supply, but it is very much smaller than the potential cost of not having security of supply.

3.3. Decarbonisation targets

The UK's targets for decarbonisation and the high-level framework for achieving these targets, are set out in legislation. As I indicated earlier, I assume the Government will remain committed to these targets.

These commitments are challenging. We know there will be a need for significant amounts of new generating capacity in the 2020s and 2030s. The long-awaited Hinkley Point C station is in train for the second half of the 2020s, and offshore wind offers much promise; but with the abandonment of the proposed £1 billion support package for carbon capture and storage, gas-fired generation looks set to play a significant role in the UK's energy mix as older operating plant ceases operation over the coming years.

Decarbonisation targets

The Climate Change Act established a target for the UK to reduce its emissions by at least 80% from 1990 levels by 2050. The UK Government has also set a target of 15% of energy consumption to be met by renewable sources by 2020 (in line with the EU Renewable Energy Directive).

To ensure that regular progress is made towards the 2050 target, the Act also established a system of five-yearly carbon budgets, to serve as stepping stones on the way.

The first four carbon budgets, leading to 2027, have been set in law. The UK is currently in the second carbon budget period (2013-17). Meeting the fourth carbon budget (2023-27) will require that emissions be reduced by 50% on 1990 levels in 2025.

The Government is committed, under the Fifth Carbon Budget covering the period 2028-32, to reduce carbon emissions by 57% from 1990 levels.

The UK Government has made significant progress in decarbonising the electricity sector to meet our 2050 obligations, although progress in other sectors has been slower than anticipated.

National Grid's work on future energy scenarios[13] provides a recent picture of what could happen between 2020 and 2030. Under all of the future energy scenarios described by National Grid, gas-fired power plants are predicted to play a significant role. Under one of the scenarios, described as the 'No Progression' scenario, it is predicted that up to 19 GW of new gas-fired generation would be required by 2030 in order to maintain the security of supply.

In this context, the search for low-carbon sources of electricity generation becomes more urgent.

Evidence TLP submitted as part of the Review, taken from the development consent process for Tidal Lagoon Swansea Bay[14], indicates that the lifetime carbon costs of the project would be 14gCO2e/kWh. This figure from 2014 needs to be updated to reflect changes in the project, notably the proposed construction of the seawall from

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[13] http://fes.nationalgrid.com/fes-document/

[14] https://infrastructure.planninginspectorate.gov.uk/wp-content/ipc/uploads/projects/EN010049/EN010049-000477-6.4.5.1%20ES%20Sustainability_Carbon%20Balance.pdf

rock and aggregate rather than lower-carbon geotubes, but also a higher estimated annual output. Nevertheless, even with rock and aggregate construction, our technical advisers indicate that larger tidal lagoons could achieve lifetime carbon costs in the region of 14gCO2e/kWh due to a higher ratio of output to seawall length.

This broadly aligns with a 2014 report[15] by the Intergovernmental Panel on Climate Change, and would compare well against estimated median emissions from other generation technologies (see table below).

The table shows that nuclear, wind and 'ocean' technologies are in a league of their own in terms of their lifetime carbon emissions.

Even if the carbon emissions of tidal lagoons were to be driven up by changes in construction techniques, or in the provenance of component parts, they would still represent low-carbon generation.

If tidal lagoons can be constructed and operated with such low levels of lifetime emissions, then it is clear that they would contribute positively to progress towards the UK's decarbonisation goals. I have already discussed the proposed operating lifetimes of tidal lagoons, and suggested that I see no reason in principle why they should not continue operating once renovated beyond their proposed lifetime of 120 years. Given that the largest proportion of the carbon emissions from the construction of a tidal lagoon would come from the initial construction of the seawall, extending the life of tidal lagoons beyond 120 years would have further decarbonisation benefits as well as providing low cost electricity.

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[15] Climate Change 2014: Mitigation of Climate Change. http://www.ipcc.ch/report/ar5/wg3/ -- excerpt from Table A.III.2, Emissions of selected electricity supply technologies (gCO2eq/kWh)

Technology	Median lifetime emissions (incl. albedo effect), gCO2eq/kWh
Currently commercially available technologies	
Coal – PC	820
Gas – combined cycle	490
Biomass – cofiring	740
Biomass – dedicated	230
Geothermal	38
Hydropower	24
Nuclear	12
Concentrated Solar Power	27
Solar PV (rooftop)	41
Solar PV (utility)	48
Wind onshore	11
Wind offshore	12
Pre-commercial technologies	
CCS – Coal – Oxyfuel	160
CCS – Coal – PC	220
CCS – Coal – IGCC	200
CCS – Gas – Combined Cycle	170
Ocean (including wave and tidal)	17

Table 4: Emissions of selected electricity supply technologies
Source: IPCC

3.4. Impacts on the environment and other uses of the waters

Although tidal barrages have been built on a few occasions elsewhere in the world, there have been no tidal lagoons built, so it is not possible to give an absolutely factual assessment of full life-cycle of environmental consequences. The Severn Tidal Power Feasibility Study highlighted a consensus that there are challenging environmental issues to be overcome if tidal power generation of any kind is to be deployed. The evidence I have received reiterates this point.

It will be necessary in many cases for developers of potential tidal lagoon sites to make good the loss of existing habitat for wildlife in order to comply with the Habitats and Birds Directives (see Annex G). Although this would not affect Tidal Lagoon

Swansea Bay, it is anticipated that Tidal Lagoon Cardiff alone would require a very significant amount of such 'compensatory habitat'.

Strong representations have also been made by individuals and organisations who are concerned about the impacts that tidal lagoons could have on fish species, particularly migratory fish, as well as other forms of marine life. The assessment of the environmental effects of major infrastructure projects already forms part of the established development consent process. Work continues to be done to improve the modelling of fish behaviour around tidal lagoons but, as with other types of impact on the environment, evidence on the actual effects on fish should be monitored carefully and mitigating action should be taken promptly when it is necessary.

As part of the process that has seen them receive development consent for TLSB, TLP have brought in expert and very credible advisers in order to assess the impact a tidal lagoon might have on habitats, fish movements, birdlife and the processes are already in place for these issues to be fully considered during the formal consenting process.

I have also been impressed by the work that has already been committed by TLP to considering locations where sufficient compensatory habitat[16] may be found to enable a programme of tidal lagoons to comply with environmental regulations. The company are pushing this work forward as part of what they refer to as an 'Ecosystems Enhancement Programme'.

While recognising the issues, it is not in my terms of reference to delve too deeply into the environmental challenges and their potential solutions. Comprehensive assessments already form an integral part of the development consent process, and regulators such as Natural Resources Wales and the Environment Agency already have statutory roles to play in that process. Others can register as interested parties and play a role too, and I would encourage them to do so to ensure that rigorous scrutiny is given to the environmental impacts of these large infrastructure projects. I have seen nothing that makes me think these existing procedures are not robust and comprehensive.

As the environmental impacts of tidal lagoons are uncertain, **I would therefore recommend that, should tidal lagoons be built, the Government should require a high level of on-going monitoring of environmental impacts** to ensure that mitigation can be put in place where impacts are judged to require it. This would have the additional benefit of being exactly the sort of skill set which the UK should

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[16] I.e. alternative habitats created to compensate, for example, for existing wildfowl habitat that may be adversely affected by a development. See Annex G for more detail on the Habitats and Birds Directives.

be looking to develop in order to play a leading role in the development of tidal lagoons internationally. Several of our Universities, such as Cardiff, are very well placed to do this.

Such a proposal for careful and on-going monitoring should fit well with the "adaptive environmental management" approach being taken for Tidal Lagoon Swansea Bay (a description of this approach can be found at Annex G).

In addition, I have given great attention to the uncertainty about the cumulative consequences of a series of tidal lagoons. In addition to a potential build-up of ecological impacts, I have received evidence that indicates tidal lagoons in proximity to each other could produce less electricity as a result of complex negative hydrodynamic interactions.

I have heard from academics at Cardiff University and elsewhere that the hydrodynamic effects of tidal lagoons could still be felt many tens of miles out to sea. The consenting process would need to be mindful of such impacts.

More immediately relevant is the cumulative impact of a number of tidal lagoons in the Severn Estuary itself. There is inevitably a point where the retention of such significant volumes of water will have a detrimental impact on the interests of other legitimate users of the estuary, in particular the ports, where their business requires them to be able to make full use of the tides (especially high tides) for shipping movements.

Bristol Port

Due to its location, the operation of Bristol Port is potentially very sensitive to the development of tidal lagoons in the Severn Estuary. The Port is itself a nationally significant piece of infrastructure.

- The Port supports around 19,000 jobs, providing an estimated £1.0 billion gross value added contribution to UK GDP;
- The Port is highly productive, with labour productivity of 2.5 times the national average; and
- Since privatisation in 1991, more than £450 million of private capital has been invested in the Port.

It is clear that tidal lagoons could have a range of effects on the operation of ports. These include simple physical facts about the presence of a large structure in the water presenting a potential hazard to shipping. Other factors might include the effect of turbine wakes on the stability of vessels passing a tidal lagoon, wave reflection from the seawalls, or a change in the ability of vessels to access the port if the tidal range outside the lagoon is altered. Importantly, changes in the flow of waters past the tidal lagoon may affect patterns of siltation, which in turn may require changes in existing maintenance dredging practice and disposal options.

Evidence submitted to me indicates that the design of tidal lagoons can seek to minimise potential navigation impacts by, for example, careful siting of turbine and sluice housings in a way that does not result in cross-flow conditions within navigation channels; the siting of the seawall in alignment with existing bathymetric contours to help minimise flow acceleration around the structures; and by ensuring that the seawall is designed so as to minimise the potential for wave reflection.

Of course, the biggest issue would be economic, in terms of loss of access to and from the port because water levels had been changed by the presence of tidal lagoons. I am advised that the impact of a tidal lagoon in Swansea Bay would be negligible in this regard, but sooner or later, a programme of tidal lagoons in the Severn Estuary would have a detrimental impact.

I do not consider it acceptable that the business interests of established commercial organisations should be unreasonably impacted by the creation of tidal lagoons in the Severn Estuary.

I am therefore encouraged by the discussions taking place between TLP and other commercial interests. Negative cumulative impacts need to be avoided and legitimate concerns addressed through a proactive strategic approach to a tidal lagoon programme.

It must be understood that, even though the tides themselves are robust and certain, the environmental balance in estuaries is something that has been developed over millennia and the impact of sudden interventions are not known. Similarly, the full impact of sand movements and the build-up of silt, needing constant dredging, is an issue with both environmental and economic consequences, if it is not managed properly. I have heard during the Review that dredging costs could be more significant than anticipated. The Port of Bristol, whose records of operation in the Severn give them much valuable data, advise us that they have to move 0.5 metres of silt each month to keep the entrance to the Port fully usable. **I recommend that developers should be required to demonstrate, as part of the planning and consenting process, that they have taken full account of potential deposition rates.**

Other factors such as health and safety will also need to be addressed. In particular, the sheer force of water coming through the turbines poses a significant danger to anyone and anything in its way, with possible implications for proposed water-based leisure activities in or around the lagoon, and there would need to be safety barriers both along the walk-way and around the turbines. There may also be issues with public access to the considerable seawalls in bad weather. These should be addressed in the development consent process, on a case-by-case basis, or in subsequent health and safety considerations.

3.5. Hybrid Infrastructure

In the submitted evidence I have had many representations about the potential value of tidal lagoons, apart from for power generation. This is a very strong part of the local appeal of a tidal lagoon, especially in Swansea, where it is seen as an immensely important driver of local economic regeneration and of new recreational opportunities.

3.5.1 Coastal and Flood Protection

Flood protection has been identified as a potential benefit by many respondents to the Review, especially with regard to the challenges of climate change, and how tidal lagoons could mitigate the impacts of sea level rises over the next 100 years. Evidence I have received suggests that losses for areas in England and Wales due to costal and river flooding average are at around £1.2 billion annually, with predictations that these costs will rise almost six fold by 2050.

The NWTE project on the coast of North Wales is a tidal lagoon project that has coastal protection as a key element of its development.

> "The benefits of schemes such as those proposed by NWTE go far beyond the low-carbon energy they generate. Our proposals, and a number of others, offer essential coastal protection and economic impact to often struggling communities. By integrating energy generation with coastal defence, we will not only deliver a greater return on investment but help to ensure the economic and environmental security that communities along the coast are seeking."
>
> *Evidence submitted to the Review by NWTE*

The realisation of flood risk protection will be dependent on both the location and on the generating mode. Two-way generation (potentially with added pumping) offers flood risk protection along the coastline impounded by the tidal lagoon. Even without pumping a two-way generating tidal lagoon will generally lead to lower peak water elevations and thereby reduced flood risk along the impounded coastline. The seawall also further improves the flood risk protection potential as it reduces the wave and wind action (or energy) impacting on the impounded coastline.

However, it needs to be noted that larger tidal lagoons operating two-way generation could lead to an increase in the flood risk some distance away from the lagoon itself. This is due to the displaced water volume created by the lower peak tidal elevations (even with pumping) and reduced wave activity having to go somewhere. Given the uniqueness of each proposed site for a tidal lagoon, the claimed benefits can only be assessed on a case-by-case basis.

A strong argument has been made by developers, local authorities and the Welsh Government alike that a tidal lagoon on the North Wales coast, at Colwyn Bay, could provide significant flood protection for that area. I do not doubt the credibility of these claims.

By contrast, I have received evidence that in low lying areas such as the Somerset Levels where widespread and long-lasting flooding occurred in 2014, there would have been only a limited fluvial flooding benefit if a tidal barrier or lagoon had been operational. This is because the flooding there was a result of water overtopping the raised embankments upstream of the tidally influenced area[17].

In any event, evidence from the Environment Agency indicates that the sums normally spent on protection against flooding and coastal erosion are very much smaller in scale than the sums involved in the development and construction of a tidal lagoon. So, whilst tidal lagoons might in some cases assist with flood defences, and whilst environmental regulators will wish to reassure themselves that a tidal lagoon development would in no way increase flooding risks, the assumption should be that there is unlikely to be a significant contribution to the capital costs of a tidal lagoon from existing funds set aside for flood protection.

While the main benefits from tidal lagoons for protection against flooding and coastal erosion would seem to stem from the size and position of the seawall, it has also been suggested that changes in the way lagoons are operated could make a difference. **Where a tidal lagoon is being used to help contain or prevent flooding, it would inevitably mean that it would not be deriving income from generating power at those times and the developers of the tidal lagoon would reasonably expect to be compensated for this loss of income. Government should carefully consider whether this compensation should come from energy bills.**

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[17] However, I have been advised that if a tidal lagoon or barrage had been in place, it could have reduced the duration and extent of the flooding slightly if it resulted in reduced maximum tide heights. This would have had the consequence that pumps used to evacuate water from the downstream moors would have been able to operate continuously, instead of having to shut down over the very highest tides.

Protection against flooding and coastal erosion

We have received evidence that suggests tidal lagoons could contribute to protection against flooding and coastal erosion. Potential benefits are likely to accrue mostly to land behind the seawall, and would result from:

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

Some potential risks have also been identified:

- Increased low tide water levels restricting drainage from outfalls from rivers, surface water and land drains
- Need for additional defences outside the lagoon if water levels have increased locally
- Changes to erosion patterns due to changes in the flows of water and sediment

Potential mitigation of the risks described might include altering the location, shape, or operation of the lagoon, or by improving defences, outfalls or by beach recharge.

Furthermore, it is likely that there will be a ‘development gain’ if tidal lagoons are built, as land which was previously susceptible to flood risk or costal erosion would then be protected and become suitable for development. It would not be possible in advance to make a complete assessment of where this gain would arise or how substantial it might be, but I believe it would be appropriate to recognise that some element of that ‘development gain’ should be provided for the public good. However, this falls outside the remit of the Review, so I leave it to Government to establish whether such a link is appropriate and if so, how it should be allocated.

3.5.2 Regeneration benefits

There has been some divergence of opinion about the extent to which economic regeneration benefits and additional recreational opportunities would significantly add to the cost of developing a tidal lagoon in Swansea Bay as an electricity generating asset.

The developers contend that these are by-products of the work that is needed to be done to construct the tidal lagoon. Others have suggested that the additional recreational uses, which I discuss in more detail in Section 4.5, have resulted in significant increases in costs, because they require a much wider lagoon 'seawall' than would otherwise have been necessary for a project which is purely there to generate power. We have sought clarification on this issue from Atkins, the developer's consultants, who advise us that the width of a tidal lagoon seawall is based on many factors. Key amongst these is the need to ensure suitable access to the seawall is allowed for maintenance purposes, meeting required standards for consents and as an insurable asset.

The weight of the expert evidence I have received supports the scale of seawall being proposed for TLSB, and I have not seen engineering-based evidence to persuade me it could be significantly reduced.

Others have highlighted that through flood protection areas of land could be unlocked for the development of homes and land. In the case of TLSB evidence from the Swansea Bay City Region suggests that a tidal lagoon development could act as a "catalyst for the wider regeneration of the Swansea Bay City Region". **I think it is beyond question that, in the case of Swansea Bay, local economic regeneration would follow a tidal lagoon.** The non-energy generating Cardiff Bay Barrage (opened in 2001) was built to regenerate the Cardiff waterfront and most people would agree that it has had a positive impact.

However, it is also reasonable to recognise that a programme of works intended solely for the economic regeneration of, for example, the greater Swansea area would be done in a very different way and also at lower cost than the building of a tidal lagoon.

Cardiff Bay Barrage

The barrage was the centrepiece of a programme of work carried out by the Cardiff Bay Development Corporation (created in the late 1980s) to regenerate the Cardiff Bay area.

- Work on the barrage began in May 1994, and was largely completed by the time the Corporation was wound up in March 2000, although works carried on until the barrage was opened to the public in 2001.
- Following the wind up of the Corporation, Cardiff County Council assumed responsibility for the operation, maintenance and management of the Barrage and the Bay and a new Harbour Authority, which is part of the County Council, was responsible for carrying out the necessary work.
- The overall costs were estimated at £191 million in March 1995. By March 2000 this estimate had risen to £220 million. Related to these cost increases, the Audit Committee recommended that if the public sector is to undertake similar investments in the future, it should look to transfer as much risk to the private sector as possible.
- Shortly before it wound up, the Corporation calculated that, as a minimum, £170 million a year was already being returned to the public purse as a result of direct and indirect tax revenues attributable to developments in Cardiff Bay.

My recommendation is therefore that the Tidal Lagoon Swansea Bay should be considered as an electricity project to all intents and purposes, but one which would incidentally bring very real and substantial economic and recreational benefits to the Swansea Bay area.

This distinction is important as it relates to how the project should be paid for. My recommendation is therefore that Tidal Lagoon Swansea Bay should be considered an electricity project rather than a hybrid project with multiple sources of funding support. This does not mean that any such contributions would not be welcome to help realise these wider social benefits, which could help offset the construction costs of tidal lagoons.

My conclusion therefore is that tidal lagoons would certainly bring wider benefits beyond those of power generation, but these are very site specific, are hard to quantify and are unlikely to make a significant contribution to capex. I consider in the Chapter on competition how some of these benefits might be taken into account.

4. Supply chain

Key findings

- TLSB is targeting 65% UK and 50% Welsh content
- TLSB could support 2,260 direct FTEs during its five year construction period and subsequent operation phase (1,197 manufacturing and assembly, 1035 construction, and 28 O&M per year for the useful life of the tidal lagoon).
- Cardiff could support five times more total direct FTEs than TLSB (11,482); Colwyn Bay could support six times more (13,918)
- 49% of the TLSB jobs would be in the manufacture of fabricated metal industry, 20% in steel casting and 11% in forging /stamping
- Tidal lagoons have the potential to provide high-skilled jobs (skill level 3 or above) in manufacturing (steel casting; manufacturing fabricated metal products; metal forging; and manufacturing lifting and handling equipment)
- More than 1,000 UK businesses registered to be part of the TLSB supply chain
- Tidal lagoons could enable supply chain companies to diversify product offerings and be more competitive, which could protect as well as create jobs.
- A caisson facility for larger scale projects could enhance UK civil engineering capability and up-skill industrial workforce.
- Public and Cross-Party political support

I have heard in detail and on many occasions about the commitment from TLP to source materials and components in the UK (and specifically in Wales) wherever possible. The ambitions of 50% Welsh content and 65% UK content are certainly very positive in comparison to other large scale energy projects and I have no doubt that it is a genuine and sincere ambition.

Indeed, it would be hard to find a project where there have been such detailed discussions with potential suppliers at this stage in the project's development, about the finer details of where each component would be produced and to emphasise the need for this to be done in Wales/the UK. TLP has already appointed preferred Tier 1 contractors and the supply chain companies themselves are equally in no doubt that TLP is serious in this intent[18].

The UK has been much more successful in attracting supply chain investment in offshore wind than in other renewables sectors, such as onshore wind and solar. In

[18] It should be noted that other potential developers may not necessarily make the same commitment.

part, this reflects that the UK has been an early mover into offshore wind and so has had the opportunity to be actively involved in developing ways of bringing costs down, whereas for onshore wind and solar, the UK has moved into these areas much later in the process, and so has had to be a price-taker rather than a price-setter.

In addition, it reflects the fact that there was a much clearer Government policy and strategy towards offshore wind. It is the inevitable challenge of whether to get involved earlier in the process, where costs of installation are almost certainly higher, in the hope of securing the wider industrial benefits or to wait until costs have fallen before getting involved, recognising that the supply chain patterns and intellectual property opportunities will almost certainly have gone elsewhere.

Holding back to see how events unfold, inevitably means slipping into the second of those categories. Avoiding the risks also means avoiding the opportunities. It would have been possible that few other countries would have followed the UK down the offshore wind route, but the UK's leadership has helped create a new global industry, where costs have fallen by approaching half in a few years, where huge investment is being made into new technological breakthroughs such as floating turbines, and where the UK is at the forefront of that new industry.

4.1. Jobs

The issue of jobs and UK content is an absolutely central element to my considerations in this Review. The support that projects have received from business, local authorities and communities is substantially based on the volume of new commercial opportunities it is understood that a tidal lagoon programme would bring. Various studies[19] have been carried out estimating the number of jobs that could be created. The most recent studies by Miller Research and Semta ('A study to forecast the manufacturing and labour requirements for the Swansea Bay Tidal Lagoon') and CITB and Whole Life Consultants Ltd ('A study to determine the construction labour and skills demand, supply and gaps associated with the creation

[19] (1) 'Turning Tide: the economic significance of the Tidal Lagoon Swansea Bay' by Prof Max Munday, Prof C Jones, Welsh Economy Research Unit, Cardiff Business School (2013) – http://tidallagoon.opendebate.co.uk/files/TidalLagoon/Cardiff_Business_School_Report.pdf; (2) 'The Economic Case for a Tidal Lagoon Industry in the UK' by Centre for Economics and Business Research (2014) – https://www.cebr.com/reports/tidal_lagoons-2/; (3) 'Assessing the economic potential of tidal lagoons in the UK' by ICF Consulting Services in association with Cambridge Econometrics for Department for Business, Innovation and Skills (2016) – this report is not publicly available.

of the Swansea Bay Tidal Lagoon'), commissioned by the Welsh Government[20], estimate TLSB could create over 2,200 direct FTE jobs which I talk about in more detail later. I have only focused on the number of direct jobs that could be created and do not take into consideration numbers resulting from indirect[21] or induced[22] effects. That is not to say I would not expect them to happen - on the contrary, I certainly would - but it is too hard to quantify with accuracy.

The range of employment opportunities will be far-reaching; not just in design, build and manufacturing, but also in the related services, such as tourism, recreation, recruitment, and legal and financial services. I have heard from many companies, not just those in Wales, expressing their interest in becoming part of the tidal lagoon supply chain, which the map below shows. In the TLP document 'Ours to Own' they state over 1,000 UK businesses 'have registered an interest in supplying parts and skills…'

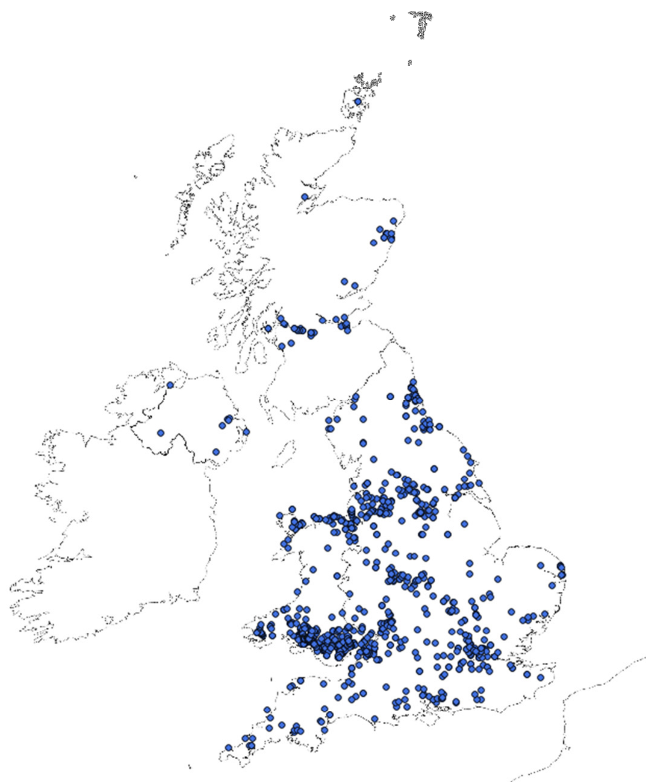

Figure 2: UK businesses TLP claim have registered an interest in supplying parts and skills
Source: TLP

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[20] The full reports can be accessed from http://www.learningobservatory.com/sbtl.

[21] Indirect effect is the effect of the initial output/employment supporting output/employment in the suppliers of the company where the original impact occurred.

[22] Induced effect is the effect of output/employment supported in the supply chain being recycled in the local economy.

In a survey[23] carried out by Swansea Bay Business Club, every single respondent agreed with the statement that: "…the lagoon would bring economic and regenerative benefits to the bay region." Swansea Business Improvement District[24] said in their evidence: "The Tidal Lagoon development will have far reaching multiplier effect economically and otherwise across Swansea and indeed the wider Swansea Bay City Region… Investments of this type can have a catalytic effect economically as they send a message which creates a business confidence thus stimulating further investment, regeneration and economic growth in an area."

It also brings new opportunities for established areas of excellence such as the FloWave Tank at the University of Edinburgh, which is already the largest and most sophisticated tank of its kind in the world. This gives the UK a very strong opportunity for being the location of choice for developing, testing and improving technological innovations. There could also be a positive impact on the work of other world leading areas of excellence such as the Offshore Renewable Energy and High Value Manufacturing Catapult centres.

The two recent reports commissioned by the Welsh Government, have looked at the construction and manufacturing labour requirements for the TLSB project. The proposed project in Swansea (the smallest of the proposed fleet of tidal lagoons from TLP), would require 16 bulb turbines and generators, 8 sluice gates, one turbine and sluice gate structure and a 9.5 km seawall, and is a good example for understanding the scale of jobs tidal lagoons could offer the UK.

Based on the two reports mentioned above, TLSB could support 2,260 direct full-time equivalent (FTE) jobs during a five year build period and operating phase, covering roles in manufacturing and assembly[25], power plant operation and maintenance[26], and construction[27]. A detailed breakdown of the manufacturing and assembly element can be found in the Annex.

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[23] The Swansea Bay Business Barometer is an anonymous survey sent to almost 200 Swansea Bay Business Club member businesses in the Swansea Bay area.

[24] Swansea Business Improvement District (BID) is a not for profit business-led and business funded body formed to improve a defined commercial area (http://www.swanseabid.co.uk/faq.asp).

[25] For the twelve distinct turbine components making up the manufacturing element of the turbine set work package

[26] Scheduled and unscheduled maintenance and repair, and replacement of parts of the power plant.

[27] For the seawall, turbine and sluice structure, ancillary civils works and buildings

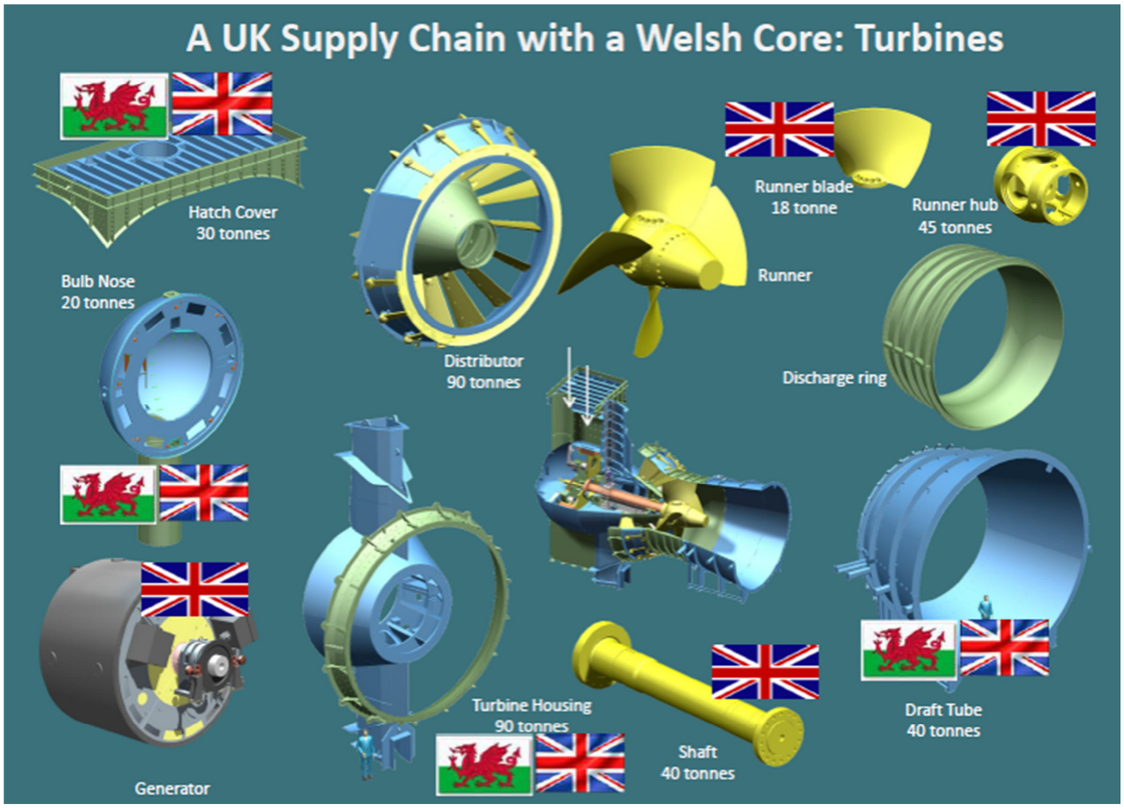

Figure 3: Proposed sources of core turbine parts for TLSB
Source: TLP

I am absolutely persuaded that the scale of tidal lagoons provides an opportunity for significant investment and employment, particularly in the manufacture of electromechanical equipment such as turbines and generators. Thousands of tonnes of steel would be required providing an important (some would say, vital) boost to the UK steel industry. Findings in the manufacturing report estimates that 49% of the jobs would be in the manufacture of fabricated metal industry, 20% in steel casting and 11% in forging /stamping metals. Many of the jobs required for tidal lagoons are regarded as high skilled jobs equivalent to level 3 skills (A level). It is estimated that for TLSB 76% of the manufacturing and assembly workforce could be jobs at level 3 or above, highlighting that tidal lagoons have the potential to provide high-skilled job opportunities.

	Manufacturing and Assembly Jobs (direct FTEs)	Construction Jobs (peak direct FTEs)	O&M Jobs (direct FTEs)	Jobs Total
Tidal Lagoon Swansea Bay	1,197	1,035	28	**2,260**
Tidal Lagoon Cardiff	8,143	3,150	189	**11,482**
Tidal Lagoon Colwyn Bay	9,924	3,770	224	**13,918**
Tidal Lagoon Newport	3,582	2,720	84	**6,386**

Table 5: Numbers of jobs that tidal lagoons could support
Source: TLP

Some have pointed out the potential number of jobs TLSB could create are relatively small when compared to other manufacturing plants. In response to this, we should recognise that TLSB is the smallest of all the proposed tidal lagoon projects, but when looking at the proposed larger scale tidal lagoon projects the potential jobs created increases immensely (as shown in the table above) with Cardiff potentially supporting five times more direct FTEs than TLSB and Colwyn Bay six time more direct FTEs. The manufacturing and assembly estimates are only for the main component parts (see Annex E).

Both reports warn of the challenges Wales faces in meeting the required labour demand for the TLSB project. The Welsh Government manufacturing report highlights the notable shortages in Wales' capability and capacity to meet the demands for certain labour areas (steel casting, forging and fabricated metal aspects). The Welsh Government construction report warns of a real risk in the medium to long term of occupational pinch points in terms of numbers and skills, due to around 18,000 workers who will be eligible for retirement over the next ten years (based on figures from Labour Force Survey), and trends in higher and further education qualification numbers pointing towards a reduction in the supply of qualified workers. Nevertheless, the Welsh Government states that, with the right investment and adequate training put in place, Welsh labour could be available to meet the demand.

I have heard from many people in communities adjacent to proposed sites of tidal lagoons that they would support a lagoon programme even if local jobs do not materialise, because of the benefits of long-term low-carbon generation. Nevertheless, I think there would be a significant sense of let-down, bordering on betrayal, if the jobs were to go elsewhere.

It is not just local communities and businesses that support a tidal lagoon programme. There is vocal support from across the Welsh Assembly for TLSB, and for a programme of tidal lagoons. This is not, however, limited to Wales. A survey[28] conducted by ComRes earlier this year on behalf of TLP indicated that 83% of Conservative MPs and 71% of Labour MPs support TLSB. This matches my experience of speaking to politicians of all parties, both in Parliament and in the Welsh Assembly, where support is overwhelming. Indeed, I have not been presented with any evidence of political opinion against a tidal lagoon in Swansea Bay or a tidal lagoon programme more generally. Some media commentators have been opposed but these tend to be those who oppose most types of renewable generation.

4.2. Skills and Education

Education, skills and training sectors will have a key role to play to address the skills deficit highlighted in the Welsh Government reports I discussed in Section 4.1. During the course of the Review many stakeholders have outlined the work they are undertaking to address some of the shortfalls highlighted. University Wales Trinity Saint David (UWTSD) detailed how it has “re-focussed its effort to ensure that in all its curriculum delivery, there is a focus on responding to and anticipating skills needs and opportunities identified in the region”. UWTSD highlight their vision for “a multi-million pound innovation quarter in the heart of Swansea” that will see a “range of innovation hubs” created including “priority sector areas” in Advanced Materials & Manufacturing; Construction and the Built Environment; Energy & Natural Environment and Financial & Professional Services (further details on these specialist centres can be found in Annex E). The magnificent new Bay Campus for Swansea University is a further example of local vision and ambition.

UWTSD also outlined how “all skills and training providers are working in partnership to anticipate the region’s needs in a coordinated way including the voluntary establishment two years ago of a Tidal Lagoon Skills Advisory Group which has worked with the Welsh Government to analyse skills needs and delivery.”

[28] http://www.comresglobal.com/polls/tidal-lagoon-power-tidal-energy-survey/.

In their evidence the Welsh Government said:

> "The Welsh Government believes there are significant economic benefits from this industry in terms of the skilled workforce. To realise this potential, the Welsh Government is working with others to ensure the relevant skills are available, including education institutions to ensure the development of a highly qualified, skilled workforce with transferrable skills to support the tidal lagoon industry.
>
> "As a current example, the Welsh Government has been working with TLP to understand the skill needs for the proposed Swansea Bay tidal lagoon development. This work is helping TLP to understand their skill needs, allow Wales' providers to understand the likely opportunity and assist Wales in positioning itself to take full advantage of this emerging industry."

Whilst these sectors are making preparations in anticipation of a tidal lagoon industry materialising, it has to be noted that there will be a real need for true collaboration and partnership working with strategic coordination, if tidal lagoons are to achieve the wider and long-term economic benefits. The education, skills and training sectors are working together to ensure there is the capability and capacity to build tidal lagoons. The supply chain, Government, industry and related sectors will all also have to work together if tidal lagoons are to be successful in delivering the new business, employment and training opportunities that are possible.

4.3. Collaboration

"Pembrokeshire has become an important hub for the marine energy sector. Acting as a development and delivery point, the region has brought together academia, developers, supply chain and regulators to explore how best to extract energy from the region's abundant energy resources… While some technologies are stand alone in their structure, there will always be component parts that have the shared commonality of needing to operate and survive in a marine environment. By working closer together, we can increase potential for standardisation which in turn contributes towards reduction of levelised cost of energy...The tidal lagoon industry has also focused attention on the need for greater collaboration within the supply chain."

Evidence submitted to the Review by the Port of Milford Haven

It is clear from speaking and listening to stakeholders that industry and the supply chain are taking active steps to make tidal lagoons a reality. The establishment by TLP of the Tidal Lagoon Industry Advisory Group to help facilitate a suitable tidal lagoon supply chain has resulted in valuable work being undertaken, such as the group feeding into the 'Study to forecast the manufacturing and labour requirements for the Swansea Bay Tidal Lagoon' report.

Tidal Lagoon Industry Advisory Group Terms of Reference <u>Primary Purpose</u> • To support the fostering of a world class cluster of manufacturing, assembly and construction businesses capable of supplying an initial 6 tidal lagoons in the United Kingdom, with the potential thereafter to supply further UK locations and up to 50 locations worldwide. This with particular emphasis on developing a supply chain to ensure Tidal Lagoon Power achieves: o 65% UK content rule o 50% Welsh content rule

The report[29] from the Energy Wales Marine Energy Task and Finish Group, making several recommendations to help support the belief and goal "…that Wales should be striving to be a world-leader in marine energy – as a significant generator, and just as importantly, as an exporter of marine energy knowledge, technologies and services" is also a welcome activity and has resulted in many of the recommendations being accepted[30] and valuable work being undertaken, such as development of the first Welsh National Marine Plan. It shows the extent of ambition that what happens in Swansea should be world leading.

Potential supply chain companies are already working together. For example, in the North the collaboration between Bonds, BEL Engineering and A&P Tyne; the collaboration of Davy Markham with Sheffield Forgemasters; and in Wales the 'Pembroke Alliance' of engineering companies in and around the Pembroke Dock, who are combining their capabilities to enhance their competitiveness when bidding for larger contracts.

[29] Marine Energy Task and Finish Group (2016) Marine energy Plan for Wales – Unlocking the Energy in Our Seas, Summary and Recommendations'.
[30] The Welsh Government response to the recommendations made in the report can be accessed at http://www.assembly.wales/laid%20documents/gen-ld10653/gen-ld10653-e.pdf.

4.4. Benefits to supply chain companies and other sectors

The manufacture of the turbines and generators holds the most potential for investment and creation of jobs. Turbine costs account for approximately 25% of the capex cost for small tidal lagoons and 35% for larger schemes[31]. Evidence received points towards significant opportunities being felt in other industries such as the steel sector, as over 11,200 tonnes of steel would be needed to manufacture major components for the 16 turbines; or oil and gas supply chain companies where there could be opportunities for companies to diversify their product offering, in light of the sector's recent down-turn.

Many companies have described the potential tidal lagoon programme as a 'lifeline'. Given the challenges facing the UK steel industry, this is probably no understatement, so this is not just about the 'jobs created' but about the 'jobs saved for the long-term' as well.

Preferred Tier 1 contractor for the turbines and generators for TLSB – the consortium of GE and Andritz Hydro (GEAH) – have committed to guarantee the annual energy production of the power plant and will provide full operation and maintenance support of the plant during the first five years, to demonstrate their belief in the success of tidal lagoon technology and 'a high level of investor confidence'.

They have already undertaken a very substantial amount of work to ensure that British industry is positioned to establish the manufacturing capability for this project, using a majority of UK suppliers, demonstrating the capability of UK industry and potentially establishing an industry capable of supplying future UK and overseas tidal lagoons.

In their evidence to the Review, Andritz Hydro, a world market leader in Kaplan Bulb Turbines and provider of turbines to the Sihwa, La Rance and Annapolis tidal range plants, outlined their procurement investigations to understand the UK supply chain capabilities[32] and detailed their future plans.

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[31] The capex cost for tidal lagoons is largely a function of the cost of turbines and the cost of the seawall. As tidal lagoons become larger, they are theoretically able to enclose a larger body of water for a diminishing additional size of seawall. This means that as the cost of the seawall goes down as a proportion of total cost, the relative cost of turbines goes up.

[32] A table of potential UK suppliers for hydro turbine mechanical components is found in Annex E.

“In addition to the technical effort, Andritz made a complete screening of the UK supply chain. It developed a tailor-made turbine design in order to maximise local UK based suppliers...

“For the project execution of Swansea Bay Andritz Hydro will establish the centre for tidal projects in the UK. This company will have the leading role for future projects… the future Andritz Hydro company in the UK will be the centre of tidal projects worldwide… It would be a catastrophic sign to the market, if the project was turned off at such an advanced stage… The highly developed know-how base would disappear and the projected market for a new British industry would be removed for years.”

Evidence submitted to the Review by Andritz Hydro

Andritz Hydro’s consortium partner GE, outlined in their evidence their belief in tidal lagoon technology and the benefits involvement with TLSB could mean for their company.

“We firmly believe that tidal lagoons have a part to play in developing a balanced UK energy mix. Lagoons are predictable, reliable and sustainable. Different types of lagoons are being proposed in a number of UK locations by a range of developers. If developed these would provide a complementary set of power stations and deliver time-displaced generation. The power generation solution within the different types of lagoons can be common, which would provide a replicable, scalable and cost effective solution…

“If the Swansea Bay project is given the green light, around 150 GE employees will work on the project. A typical rule of thumb is that four times this number will be involved from the wider supply chain… We are poised to invest, both directly in the lagoon projects and by capital investment in manufacturing plants. The UK would become our global centre of excellence for tidal lagoon power… The development of a tidal lagoon industry would be well-timed to help UK industry plug a gap that has been left by the slowdown in the oil and gas and steel sectors.”

Evidence submitted to the Review by GE

Companies like Sheffield Forgemasters, who have been earmarked to potentially provide the Kaplan blades, hub and forged shafts, are clear that involvement in a project such as TLSB would provide a huge boost to their business. In our meeting with them, Sheffield Forgemasters said the tidal lagoon programme was “an enormous opportunity for Sheffield Forgemasters, we don’t know of another project like it.” They also coordinated a follow-up supply chain stakeholder event, with a range of potential supply chain companies from across the North of England. The discussions also supported the points made that tidal lagoons could offer opportunities not just to Wales but to the UK as a whole.

Sheffield Forgemasters have told me that they have already made significant investment of around £1 million in new machinery to improve their capability and efficiency for work on a future tidal lagoons programme. The new machines would enable machining operation to take place much more quickly (8 hours compared to a previous 8 days), requiring less 'setting time' and reducing the required downtime. They suggest that there involvement would also create an additional 39 positions within the company, 14 of them apprenticeship roles, in addition to securing existing jobs. Other companies such as Bonds and BEL Engineering and Ledwood Engineering have also already made significant investment in improving their facilities and equipment on the basis of TLSB.

I am satisfied that, if TLSB goes ahead, companies in Wales and the Northern Powerhouse regions have a real commitment to invest seriously.

Evidence received from other stakeholders such as preferred Tier 1 contractor for the ancillary civils work Griffiths, Sheffield-based heavy engineering company DavyMarkham, local Welsh manufacturing company Ledwood Engineering, North Yorkshire based structural steel company Allerton Steel and leading steel producers Tata Steel all reiterate similar points raised by GEAH and Sheffield Forgemasters.

Potential benefits to supply chain from a programme of tidal lagoons

- Retention of current workforce, following down-turn in other sectors, such as oil and gas
- Continuing of apprenticeship schemes
- Provide much needed boost to economic growth
- Sustainability of skilled jobs
- Diversification into other areas of marine renewables
- Develop a cost effective and competitive manufacturing supply chain

Liberty House Group and Simec also outlined to me their "Green Steel" vision and the key role tidal lagoons might play. The link is important enough to them to have made a direct investment in TLP. They plan to create an indigenous clean steel industry by converting steel operations to use electric arc furnaces. Powered by local renewable energy they would use these to recycle scrap steel (which the UK has in the past often exported for recycling). The steel produced would be low-carbon, and therefore green.

Tidal lagoons would be well suited to this purpose, with proposed sites close to their Newport facility. The predictable nature of tidal energy would have particular value as a steel manufacturer would be able to schedule arc furnace use to maximise the value of the large amount of power available at otherwise inopportune times – such as at 3:00am.

This is a good illustration of how valuable predictable low carbon generation could be to industrial users faced with carbon charges on power from other sources and that this will help secure off-take agreements and a route to market. I am clear that other new industrial opportunities will be identified and developed by other sectors alongside a lagoon programme. The potential for private off-take agreements such as this would need to be taken account of by Government in any contract negotiation.

4.5. Other benefits

I have also received many representations about the additional benefits tidal lagoons could bring in terms of tourism, recreational and amenity facilities. This is inevitably hard to predict with accuracy, although without question it would be beneficial, as the visitor numbers to other "unique" installations demonstrates.

> "Mumbles Development Trust believes the project will bring great opportunities and benefits both to the local community and those visiting the area… wider project benefits such as the Boating Centre will provide opportunities for younger generations to try water sports such as Sailing, Rowing, Canoeing, Swimming, Kayaking and Triathlon – thus also promoting healthy living... This will certainly have a positive effect on business and tourism in Mumbles, and will ultimately lead to the creation of more much needed jobs in the area. Mumbles will become a top tourist attraction..."
>
> *Evidence submitted to the Review by the Mumbles Development Trust*

> "…Wales we believe is lacking on the international scene compared to the rest of the UK due to budget constraints for tourism. This is where the Tidal Lagoon development will make a big different to visitor numbers not just from the UK but the world as well. Tourism is already a significant contributor to economic activity in Swansea and the SA1 Waterfront area… As an innovative and sustainable energy solution, the Project will have the capacity to broaden the appeal of Swansea Bay and Wales to new, and potentially international, business visitors... TLSB provides an opportunity for the regeneration and further development of Swansea Bay thus having positive effects on business and tourism of the Swansea and the entire region."
>
> *Evidence submitted to the Review by Fly2Wales*

> “The Lagoon has the potential to create numerous opportunities for our sport… The Lagoon has attracted the interest of Canoe Wales and British Canoeing with the prospect of hosting International and National Sprint and Marathon competition… To Canoe Wales this project is ‘The Lagoon of Dreams’”
>
> *Evidence submitted to the Review by Canoe Wales*

The tourism figures for operating barrages show visitor numbers in the tens of thousands each year and there is every reason to think that tidal lagoons in the UK could match, or exceed, those numbers, given their easy accessibility to large numbers of visitors and their uniqueness, bringing real benefits to the local tourist industry. TLSB has estimated visitor numbers in the range of 70,000 – 100,000, which are similar figures to those achieved at the La Rance Power Station. I have heard that tourism numbers at the largest tidal range power station – Sihwa Lake Tidal Power Plant in Korea – are much higher (this may be in part due to the additional tourism activities and facilities that have been developed such as an Eco Park Area). Some believe that TLSB could be attractive for visitors in the same way Cornwall has been with the Eden Project. The Eden Project attracted 960,000 visitors in 2015 and was recognised by the British Travel Awards as the Best UK Leisure Attraction 5 years running (2011-2015).

Current additional benefits proposed for TLSB include the potential provision of a playground, beach, rock-pools, an offshore visitor centre, a lobster and oyster hatchery, and development of a marine aquaculture zone in partnership with local businesses; as well as hosting sporting events such as triathlons, rowing and cycling. However, none of these provisions have been confirmed or fully scoped out, with some stakeholders expressing concern about the real potential of additional benefits.

Others have questioned the benefits, and have suggested that the sporting activities would simply be relocated from elsewhere rather than genuinely new. For this reason, I have not included estimates of economic impacts.

I recommend that much more detailed work should be done to assess possible tourism impacts, in conjunction with local FE colleges, to plan ahead with the necessary skills training that significant visitor numbers could require, and to ensure that the design of the visitor attractions reflect the potential of this economic uplift.

The design of the proposed tidal lagoons is not of itself a matter for this Review, but I have long held the view that energy infrastructure should aspire to be aesthetically pleasing. That is the case for the magnificent Hellisheiði geothermal plant in Iceland, and even if they cannot be attractive, as least they can be designed to fit in with the environment rather than being a scar, in the way that the Langage gas plant in Devon has achieved.

TLP are to be commended with the designs they have proposed for the architecture of the Swansea Lagoon visitor centre, creating an iconic structure which will draw visitors from far afield, showing that utilities don't have to be utilitarian.

4.6. Innovation and Cost Reduction in Tidal Range technologies

It has often been stated that tidal lagoons use relatively established technology. It is certainly the case that the bulk of the construction costs are in the civil engineering work and the UK has companies which are capable of delivering this professionally, and turbine technology has been around for many decades.

However, this overlooks the technological improvements which are already being made to the turbines themselves. The GEAH proposal for the first UK tidal lagoon would be to use triple-regulated turbines which are highly innovatory. Triple regulated turbines have a variable pitch runner, adjustable wicket gates/guide vanes and variable speed, in addition to key design features such as a reduced number of blades (three rather than four) and a lower average rotational speed, allowing efficient bi-directional operation and minimising impact on fish.

The UK would be the first location where triple-regulated turbines would be used at scale and this would position the UK in a strong position to help develop international applications for the technology. Whilst technological innovation does bring with it some additional risk for investors, this appears to be more than counter-balanced by the extra efficiency and output it allows through the turbines.

I accept that there is probably less scope for innovation for tidal lagoons than we have seen, for example, in offshore wind, which has been such an important factor in bringing down costs, but the creation of an industry will always lead to innovation and improvements.

One possible example is the Tidetec rotating turret. A prototype of the solution was deployed in Svelvik, Norway in September 2016. Tidetec state: "The main intention of the turret is to turn the turbine, to enable optimal bi-directional functionality." I am advised this would enable optimal efficiency in both directions, as two-way generation turbines tend to have reduced efficiency on the incoming tide. They estimate that 5-10% savings could be made in turbine designs when incorporating their technology and provide 7-8% increase in power production.

I am in no doubt that there are promising innovations and technological advancements that could be made as part of a tidal lagoon programme, and that could help drive down costs. The new public body UK Research and Innovation and the Energy Innovation Board could play useful roles in this regard.

It should be recognised too that innovation is not just about ‘new ideas, devices or methods’, it can also simply mean improving the application of solutions to make a more effective product or investing upfront long term in efficient technology. The potential use of a modular construction or a design for manufacturing and assembly approach; alternative construction methods for the seawall; or using caissons all fall into these categories.

The use of a design for manufacturing and assembly (DfMA) approach is a more efficient way of using precast concrete components. Rather than constructing the facility in-situ offshore, DfMA enables the modular construction of Sections of the turbine house in an off-site environment, reducing time, risk and cost in the construction schedule. Each container, which can be mass produced off-site, would house mechanical and electrical balance of plant items, allowing the assembly, installation and pre-commissioning of the plant items to take place within their containers. The containers would then be delivered to site, before being placed directly on to the turbine house structure, providing faster and more cost effective construction and commissioning of the turbine house.

4.7. Caissons

Caissons offer significant scope for achieving cost reductions, as they can be used to construct the turbine house structure on land, reducing the construction programme as they remove the need for temporary ‘cofferdams’ and can be built in parallel with the remaining infrastructure/ civil works.

Concrete caissons can also be used in the formation of the tidal lagoon seawall opening up sites in deeper water.

Caissons are vast water-tight box like structures used in underwater construction for quay-wall and breakwater construction or as foundations for structures such as bridges and buildings. There are various types of caissons, with the most commonly used being a Box Caisson – a prefabricated concrete box with sides and bottom that is set down on prepared bases and filled with concrete making it part of a permanent structure, such as the foundation of a bridge pier; or an Open Caisson – similar to a box caisson, with the exception that it does not have a bottom.

Caissons used for tidal lagoons would be on a similar scale to those used for turbine facilities in hydro-power generation plants - mega-caissons. By contrast, a mega-caisson is much larger in dimension than a standard caisson and can weigh upwards of 20,000 tonnes, making their construction more challenging as their size and weight puts them beyond the capabilities of any land or marine based cranes and equipment.

A mega-caisson would typically be constructed in a purpose built dry dock basin, which is then flooded, allowing the caissons to be floated before being towed to site and sunk/installed to form the intended structure. The ideal location for the basin would be as near to the shoreline as possible, close to deep water and existing port or transport infrastructure.

The use of caissons would require upfront long term investment as there is currently no UK facility of a suitable size to manufacture caissons for the tidal lagoon sector, although a number of potential sites have been identified. This would make it possible to install and 'dry commission' the turbines and generators offsite, which significantly reduces the amount of weather dependent site-based activities.

Whilst there are challenges with using caissons (particualrly with regard to their floating draft, stability, construction and launching methods) in the construction of tidal lagoons, they do offer the opportunity to widen the tidal lagoon supply chain very significantly. In developing the ability to manufacture and use caissons, the UK civil engineering capability would be further enhanced and the industrial workforce upskilled, making the UK workforce exportable internationally.

Should a programme of tidal lagoons go ahead, I see very significant benefits in principle in the development of a caissons capability in the UK. This would give UK manufacturing a very significant advantage over foreign competition.

Potential locations would be in Wales, the North-West of England and the West Coast of Scotland, spreading the economic benefits to many different parts of the country.

4.8. Supply chain conclusions

The commitment which TLP has made to local sourcing and manufacture is very welcome and would be a very significant attraction of a tidal lagoon programme. Very substantial and highly credible companies such as GE are actively looking at how this can fit in with their existing UK capabilities and where new manufacturing facilities might be built.

When talking about jobs, some have suggested that green jobs are simply displaced from elsewhere in the economy. I do not accept this would be the case. As an emergent sector tidal lagoons have the potential to provide a lifeline to many companies and industries facing significant challenges. Their potential scale offers continuity of employment and more importantly the creation of new high-skilled jobs within the UK.

It is important however to recognise two cautionary aspects.

First, there can be no guarantee that the work would ultimately come to the UK. We have seen aspirations for other energy projects and sectors ultimately fall far short of their initial ambitions. When faced with tough financial targets, there will often be pressure to source from the most affordable suppliers, even if they are outside the UK. Where this happens, it is sometimes a false economy in the long term as risks to delivery and quality are sometimes higher. **I have been encouraged that the current financial backers strongly sign up to TLP's ambition of developing a supply chain in the UK. This should reduce those pressures to go for potentially cheaper products from abroad, but it does remain a risk.**

Second, and more significantly, the full opportunities for a UK supply chain will only be realised if there is long-term clarity about the number, scale and timing of tidal lagoons to be built in the UK. It is unrealistic to expect large international companies to invest in new manufacturing facilities if they cannot see a full order book for some years ahead. It has often been said to me that the turbines for Swansea Bay could be produced from existing facilities, but tidal lagoons at, say, Cardiff and Colwyn Bay would require a new facility to be established. However, this could not happen if there is not something approaching a continuous flow of work.

While the benefits and opportunities innovation could bring have been outlined, they inevitably also carry elements of risk and challenge that could impact on the cost reduction trajectory of tidal lagoons.

It should also be recognised that there is an inherent conflict between this need for the work on a second project to be undertaken before Tidal Lagoon Swansea Bay is complete, in order to secure the supply chain benefits, and the general view from many financiers, environmental organisations and others that they would prefer the first tidal lagoon to be fully operational before committing to subsequent and larger projects.

Educational and qualifying bodies, such as the Institution of Civil Engineers (ICE), the Royal Academy of Engineering (RAEng) and the Institution of Mechanical Engineers (IMechE) voiced their concerns about an overlapping scheme development approach in their submitted evidence:

> "The current proposals from TLP are for work on the Cardiff site to commence before the Swansea is completed. Under this approach there is a risk of unforeseen consequences arising from the first scheme – for example around changes in the flood risk, hydrodynamics of the estuary and silting in the lagoon – that might not be able to be corrected in later schemes."
>
> *Evidence submitted to the Review by ICE, RAEng & IMechE*

I address this issue directly in Chapter 10.

Nevertheless, overall, a tidal lagoon programme offers a significant economic opportunity for Wales and the UK more generally. There are few other energy sectors where the UK can realistically aspire to have such a significant supply chain, where the skills already exist for a 'pathfinder' project or where there is such commitment to large scale manufacturing in the UK from the world's largest firms in this sector.

The UK stands little chance of playing a meaningful role in the supply chain for either onshore wind or solar; and it may capture some important parts of the supply chain for new nuclear, but the main reactor technologies are now based overseas. The exception is offshore wind where the investments in offshore wind turbine and blade manufacturing facilities in Hull are an integral part of the UK's leadership in this technology.

Marine energy technologies offer an energy opportunity where the UK can reasonably aspire to be the global leader, with some substantial supply chain opportunities to match it.

If the UK is to commit to a new source of power generation, such as tidal lagoons, then 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.

To help achieve maximum UK advantage, the Government should make it clear that its support for tidal lagoons is, in part, based on the supply chain opportunities and the wider industrial and economic benefits such a programme would bring.

If the UK is to adopt tidal technologies, and tidal lagoons in particular, and to get the industrial benefits of such an approach, then I recommend that it needs a strategy similar to that for offshore wind, with a clear sense of purpose and mission. It needs to bring the industry together to address each challenge as it emerges and to set the industry itself the goal of making the step-changes which would determine whether this becomes a new industry or a small niche.

I would urge the Government to look at these opportunities not just in tidal lagoons but for marine renewable energy more generally. Whilst wave technologies are further behind tidal technologies, the UK should be promoted as a centre of global excellence and opportunity for the development of all marine energy technologies, where appropriate giving a central focus to the work of organisations like Marine Energy Wales and Wave Energy Scotland.

5. Export Opportunities

Key findings

- Opportunities for potential development of tidal lagoons outside of UK waters include Canada, France and India.
- Overseas supply chain potential for UK likely to be limited to professional services, rather than manufacturing and construction.

One of the arguments put to me for the UK leading the development of tidal lagoons in UK waters, has been that this would lead to the UK becoming a global leader in the development of the technology elsewhere.

Some work has been done to establish where such potential would exist. Critically, they would need very high tidal ranges and also to be in locations where they can be connected to grid infrastructure or local demand. Even where this is the case, harnessing their tidal ranges may still not be as attractive as other renewable opportunities, such as hydro, wind and solar in these countries.

The main opportunities are as follows.

5.1. Canada

The Bay of Fundy has the highest tidal range in the world and is considered a very attractive location as it has Nova Scotia on one side and New Brunswick on the other. While market opportunity in Nova Scotia and New Brunswick is somewhat limited due to the low population density, it is close to the US New England market offering good power export potential for renewable energy.

A study[33] by Seaforth Geosurveys and Atlantic Marine Geological Consulting Ltd for TLP identified five sites in both Nova Scotia and New Brunswick with a prospective capacity of 5-8GW.

[33] Tidal Lagoon Site Assessment Bay of Fundy, Canada

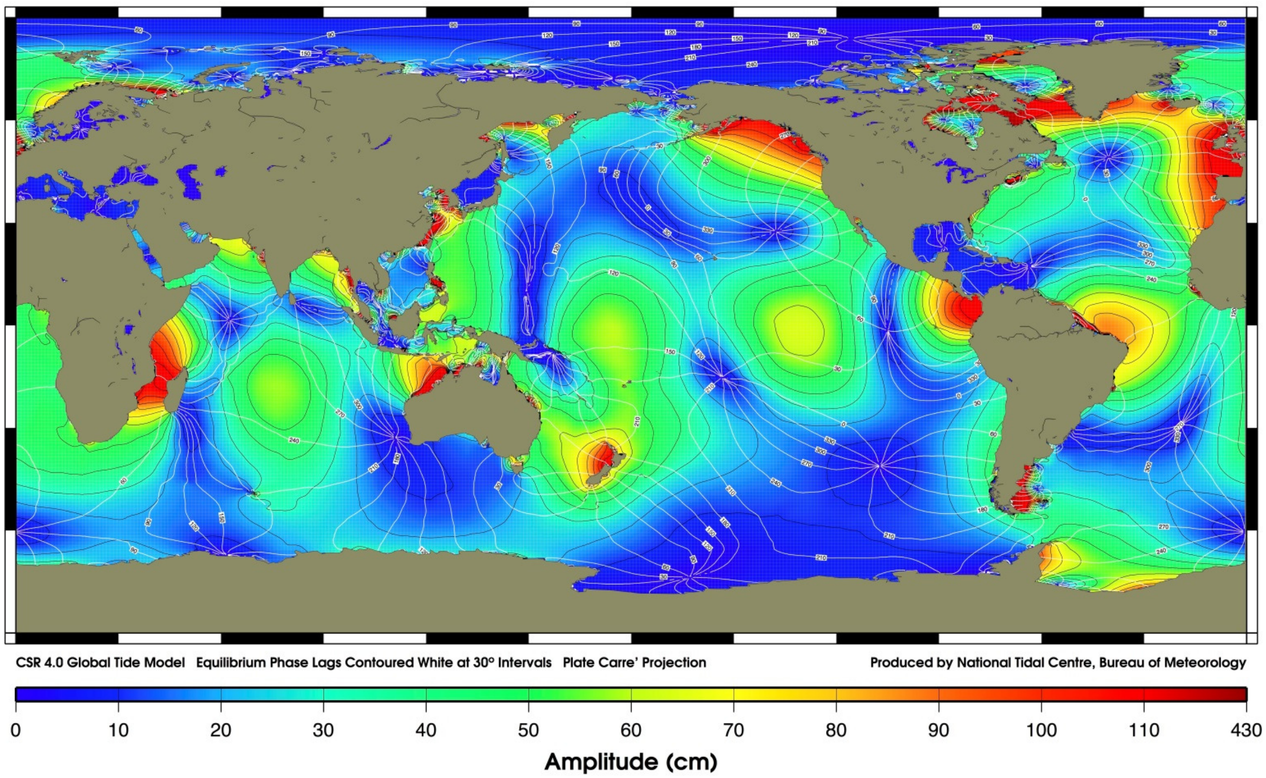

Figure 4: Global tidal ranges
Source: Tidal Model: Centre for Space Research, University of Texas. Visualisation: National Tidal Centre, Australian Bureau of Meteorology

5.2. France

Alongside the UK, France holds the most significant opportunity for the development of tidal lagoons in Europe. The tidal range in France is as high as that in the UK and is home to the La Rance Power Station, the longest operating tidal range plant in the world. Potential locations highlighted for development include the west coast of Cotentin Peninsula and Picardy Coast, with potential capacity of up to 15GW.

Tidal lagoons are not included in any strategy for marine renewable development. However, with the successful operating years of the La Rance Power plant and France's COP21 commitments, it is thought tidal lagoons could be an opportunity that would enable France to achieve its policy goals. Evidence received from French stakeholders indicates that there is an appetite in certain regions of France to progress tidal lagoons. However, the evidence also suggests that TLSB would need to be under construction in order for work to begin towards political and public acceptance of tidal lagoons in France.

> "…To fully evaluate and understand the interest in developing tidal lagoons in France, including the Baie d'Authie, in North of France, we believe it is necessary that the initial project in Swansea Bay enters its construction phase as soon as possible. Being able to follow the development of an actual project and see first-hand its interactions with the natural and human environment will be fundamental to building interest in France for initiating tidal lagoon projects."
>
> *Evidence submitted to the Review by the Mayor of Berck-sur-Mer*

5.3. Mexico

The Gulf of California has tidal ranges of 6-7m which makes it a viable location for tidal lagoons. While there are several areas within the Gulf of California close to or with protected designation, making potential sites available for development limited, there is still the opportunity to develop tidal lagoons with potential site capacities totalling up to 1GW. However, understanding sedimentation and wildlife conservation issues will be significant to enabling commercialisation of tidal lagoons in this area.

5.4. India

The Gulf of Kutch and Gulf of Khambhat, both in Gujurat have the highest tidal ranges in India. Of the two, The Gulf of Kutch is less commercially attractive for development due to the number of protected marine areas, lower average tides and likely energy yields when compared to a potential development in the Gulf of Khambat.

Tidal lagoons in the Gulf of Khambhat could have positive environmental impacts as the water quality and natural habitat have deteriorated in the last 20-30yrs. Identified sites could potentially provide an estimated total installed capacity in excess of 16GW. The State Government of Gujarat have shown an interest in exploring tidal lagoon potential, inviting TLP to enter into a Memorandum of Understanding to undertake feasibility work on the possibility of three tidal lagoons in the Gulf of Khambhat.

5.5. China

The East Coast of China has fairly high tidal ranges in certain regions. Several investigations into tidal range generation have been undertaken in China since 1958 with up to 76 experimental plants built, although these were very small, ranging in capacity from 5 to 300 kW.

It is estimated that China has a potential installed capacity of 20 GW.

5.6. Export Opportunities – Conclusions

An assessment by our technical advisors concluded that an established tidal lagoon industry in the UK could contribute to global developments. However, this is likely to be limited to design and consultancy, which is also suggested in submitted evidence by TLP.

"Naturally, each of these countries has aspirations to develop its domestic manufacturing and supply capability and they will naturally act to temper the UK's aspirations to maximise exports… there is evidence from the wind power industry that pressure is applied to source locally… but the capacity to source components locally is restricted by relatively under-developed supply chains… our belief is that the likely supply chain for the overseas markets will be for the provision of key consultancy and design services to be sourced from the UK but for most marine and civil works to be sourced locally… In the case of turbines, generators and electrical connections, we envisage that the supplier would need to establish assembly plants at the closest practicable point to the lagoon site, and componentry would need to be as local as possible. An opportunity exists for UK firms who become world leaders in tidal turbine componentry to establish operations in nearby markets such as France to be able to meet requirements for locally sourced content."

Evidence submitted to the Review by TLP

Given the very large and long term strategic nature of tidal lagoon projects, they would only happen if they received clear support from their Governments. Additionally the locations of highest tidal resource may be significant distances away from the areas with high demand for power. This makes it difficult to assess the global potential and I have limited the Review to a high level assessment of the feasibility of projects elsewhere. However, **I am satisfied, through the academic and commercial input I have received, and given the clear evidence of suitable locations, that there is some overseas potential for tidal lagoons.**

It does, however, require an additional leap of faith to believe that the UK would be the main industrial beneficiary of such a global programme. The civil engineering work, which is such a significant element of the overall cost, would most likely be done locally, using locally quarried stone. For projects further away from the UK, it has to be likely that the turbines would be produced in countries closer to the projects, especially with such strength in heavy engineering in countries such as Korea, who are also developing their own tidal potential. For projects closer to home, such as in France, there might be more prospects for such work coming to the UK (especially if there is a caissons facility in the UK), but we should also recognise that the French would be naturally inclined to use their own manufacturing capabilities to meet such demand.

The UK would stand a very real prospect of developing advisory engineering and modelling expertise which could be used around the world in other tidal lagoon projects, and certainly in environmental assessments. Our universities with particular relevant skills could also expect to benefit but on its own this does not add up to a global industry.

Nevertheless the UK could further benefit by capitalising on its extensive and world class marine test infrastructure and knowledge base, to develop 'centres of excellence' for tidal lagoons and build supply chain capabilities that address some of the challenges tidal lagoons and the marine sector domestically and internationally face such as turbine efficiency[34], resource characterisation and control systems. Facilities in the UK could also be used for hydro projects more generally around the world, even if the potential for international tidal lagoons is not huge.

It should also be recognised that facilities built in the UK to supply elements for a tidal lagoon programme would be well placed to capitalise on opportunities more generally in hydro and tidal projects.

So **I conclude that there are international opportunities for tidal lagoons which could provide supply chain opportunities for the UK, but these are far from certain. There is not currently firm evidence of a commitment to develop such resources in many of the identified countries and even if they would be developed, they would probably look more locally for many of the supply chain elements and skills they would need.**

Therefore, **I recommend that the UK tidal lagoon potential should be looked at for its own merits. The international opportunities would be 'good to have' but they are not sufficiently concrete that they can be relied upon.** However the existence of other supply chain opportunities more generally in tidal and hydro projects will provide additional investment evidence for supply chain companies.

To capitalise most effectively on the supply chain opportunities for the UK, I would recommend that the Department for International Trade hosts a summit in the UK bringing together countries from around the world with tidal lagoon opportunities to showcase the skills and expertise the UK has to offer.

[34] Tidal range turbines typically have a load factor of 25%.

6. Generation costs and the potential for cost reduction

Key findings

There are strong prospects for large scale tidal lagoons to decrease electricity generation costs relative to the costs of a pathfinder project. These include:

- High potential for cost reductions due to site location and design;
- Moderate potential due to reductions in capex and opex; and
- High potential due to reductions in costs of capital

Subsidy costs are very sensitive to generation costs and therefore to improvements in these areas. Competition is essential to drive cost reductions.

This Chapter is the first part of my assessment of whether tidal lagoons could play a cost effective role as part of the UK energy mix.

This Chapter examines the scope for large scale tidal lagoons to decrease the costs of generating electricity ("generation costs") relative to a pathfinder project and the ways in which this can be achieved. Chapter 7 looks at comparative levels of subsidy costs and what these would mean for consumers.

I consider there are three key drivers that have the greatest potential to reduce generation costs: site location and design, project costs (capex and opex) and financing costs (cost of capital).

6.1. Site location and design

Generation costs for a tidal lagoon are driven by the strength of the tidal range, the lagoon design and the bathymetry and topography of the site.

The strength of the tidal range is particularly important. Power generated by tidal lagoons is proportional to the area impounded, multiplied by the squared head of the tide. This means that a small increase in a tidal range has a much larger impact on power output.

In addition, the ratio of the enclosed area relative to the seawall length will also directly impact upon project economics. Taking Swansea Bay as an example, the ratio of the proposed enclosed area (11.5km^2) to seawall length (9.5km) is c.1.2x. Subject to site design, larger tidal lagoons have the potential to very significantly improve upon this ratio, decreasing the cost of marine works as a proportion of total capex[35] and lowering the cost of electricity per MWh.

The table below sets out illustrative assumptions produced by our expert advisors, ITP, for potential tidal lagoon sites in the UK. Sites with the highest tidal ranges are in the Severn Estuary, followed by North Wales / Liverpool Bay and the North West. Ratios of enclosed areas to seawall lengths are presented in the far right column. Tidal lagoons with larger installed capacities are expected to achieve higher ratios, illustrating the impact of economies of scale.

Potential tidal lagoon sites in the UK					
Site	**Tidal range**	**Installed capacity**	**Enclosed area**	**Seawall length**	**Ratio of enclosed area to seawall length**
	metres	**MW**	**km^2**	**km**	**km^2 per km**
Severn Estuary					
Swansea Bay	6.2	320	11.5	9.5	1.2x
Stepping Stones	7.7	790	18.0	10.6	1.7x
Cardiff	8.6	3,240	71.8	21.0	3.4x
Newport	8.6	1,440	40.2	17.5	2.3x
Bridgwater Bay	8.1	6,480	243.2	34.1	7.1x
North Wales and Liverpool Bay					
Conwy	5.2	740	40.0	16.5	2.4x
Colwyn Bay	5.5	3,200	119.8	22.8	5.3x
Sefton	6.1	2,600	101.9	27.7	3.7x
Wirral / Liverpool	6.3	1,600	67.1	21.9	3.1x
North West					
West Cumbria	5.6	2,200	92.1	22.4	4.1x
Blackpool	6.1	2,600	96.3	24.5	3.9x
Wyre	6.5	3,045	120.0	19.9	6.0x
Barrow in Furness	6.5	1,600	56.8	23.2	2.5x

[35] Marine works may comprise c.25% of the construction cost of a pathfinder project.

East Coast					
The Wash	4.5	695	50.0	18.8	2.7x
East Lincs Coast	4.7	1,940	120.0	29.9	4.0x
South East					
Sheerness	4.2	1,310	100.0	28.6	3.5x
Thames Estuary	4.3	515	50.0	19.0	2.6x
Sussex Coast	4.6	2,415	160.0	34.8	4.6x

Table 6
Source: ITP Technical Report and Hendry Review analysis. Key assumptions set out in Annex I

It is clear that not all of these sites could produce low generation costs in the near future. As I discussed in Section 2.2, it is considered by some that a minimum head of five metres is required. On this basis, sites around the East Coast and the South East would be discounted as suitable options for development. I recognise, of course, that technological improvements creating greater operational efficiencies could well change this in the future and note that some turbine manufacturers have submitted evidence that current bulb technology could be economically viable for heads as low as four metres, but for the time being it would be wise to consider 5 metres as the minimum range.

One way in which those sites with the potential for the greatest cost reductions can be identified is to consider the ratio of estimated capex to annual energy production (AEP). This ratio does not consider operating costs or financing costs, but it is helpful for assessing the potential impact of site location and design on generation costs.

The table below compares ITP's capex to AEP ratio for Swansea Bay to the top six large scale sites ITP has identified with the lowest ratios of capex to AEP. The total installed capacity of these large scale tidal lagoons is 17.6 GW. Capex to AEP ratios for these projects (1.6x-2.0x) are a significant improvement upon the ratio for a pathfinder project (2.3x).

Ratios of capex to AEP					
	Tidal range	Installed capacity	Capex	AEP	Capex / AEP
	metres	MW	£m	GWh	Ratio
Pathfinder scale (<500MW)					
Swansea Bay	6.2	320	1,300	570	2.3x
Large scale (>500MW)					
Stepping Stones	7.7	790	2,880	1,410	2.0x
Blackpool	6.1	2,600	8,110	4,100	2.0x
Wyre	6.5	3,045	9,070	4,700	1.9x
Cardiff	8.6	3,240	9,660	5,530	1.7x
Newport	8.6	1,440	4,480	2,600	1.7x
Bridgwater	8.1	6,480	19,180	11,730	1.6x
Total		**17,595**	**53,380**	**30,070**	**1.8x**

Table 7
Source: ITP Technical Report. Key assumptions set out in Annex I

I have received evidence that cumulative impacts on energy yields may be significant, whereby the consequence of having a number of tidal lagoons is to reduce their operating efficiency. For example, Professor Falconer has identified that the impact of a tidal lagoon at Newport may be to reduce the energy yield of a tidal lagoon in Cardiff by around 2.5% on two-way generation. This level of impact would not affect a trend for Cardiff to significantly improve upon the capex to AEP ratio of Swansea Bay.

However, the addition of a Bridgwater tidal lagoon (proposed to be a very large project – 6.5GW) to a programme of lagoons would be likely to have a high impact on other sites in the Severn, perhaps giving rise to an additional 15% reduction in energy yields at Cardiff.

Assuming a total reduction for Cardiff of 17.5% due to Newport and Bridgwater, the ratio of capex to AEP for this project would increase from 1.7x in the table above to 2.1x, a level that is still below that estimated for Swansea Bay as a standalone project (2.3x).

So **I conclude that high-level modelling indicates that large scale tidal lagoons would decrease generation costs relative to a pathfinder project due to high tidal ranges and favourable designs. Moreover, this reduction would still apply even in a scenario where cumulative impacts on energy yields are**

significant. This trend would be further accentuated when reductions in project costs and financing costs are taken into account.

6.2. Project costs

TLP is developing a number of initiatives, including the use of modular design techniques, which could significantly decrease project costs and construction timelines. TLP anticipates that the establishment of a supply chain with a firm order book will further decrease costs.

Other stakeholders have also commented on the impact of a tidal lagoon programme on economies of scale. GE's conclusions are summarised below.

> "Further savings can be made on economies of scale, and having a common design, so that for future lagoons after Cardiff, given a steady flow, the costs could be reduced by an additional 5-10% per MW. This further discount is made up of volume discount on materials, increased standardisation and automation of the manufacturing process."
>
> *Evidence submitted to the Review by GE*

The Review's technical adviser, ITP, offer a more cautious assessment than TLP and GE, estimating that large scale tidal lagoons may be able to achieve moderate cost reductions, including perhaps 8-10% of capex relative to a pathfinder. ITP's rationale is summarised below.

ITP – An assessment of potential costs for future tidal lagoons

Overview

The majority of elements that comprise a tidal lagoon are based on established technologies and construction methods. While this may be attractive in terms of risk, the potential for cost reductions from learning on construction techniques and technology development is limited. Supply chain development and operational techniques may offer some opportunities for decreased costs and increased revenues. Potential capex cost reductions in the order of 8-10% are expected as a result of learning by doing.

Turbine costs

Turbine costs account for approximately 25% of the capex for smaller tidal lagoons and 35% for larger schemes. Although low head turbines are well established, the proposed two-way generating turbines are a new development and are largely untested. It is conceivable that learning and cost reduction here could be significant. In addition, improvements in the operation of tidal lagoons and the supply of electricity to the grid, through operational experience, present opportunities to increase revenue.

Marine works

A tidal lagoon's seawall, representing a cost of as little as 15% of the capex for largest schemes, has limited opportunities for cost reductions. However, a small percentage saving in the seawall from developments in design and construction (e.g. geo-tubes) would have a significant absolute value.

Benchmarks

As a benchmark, SI Ocean[36] estimates that the overall learning rate for the tidal stream industry is 12%. Tidal lagoons would be a novel combination of relatively established technologies, so the learning rate is likely to be lower than that for tidal stream.

I have concluded that there is scope for project costs to reduce following a pathfinder project, probably at least by 8-10% of capex and potentially by significantly more. The extent of these reductions will in part depend on Government's willingness to create the right framework for securing the greatest cost reductions, as proposed in Part Two of the Review.

In particular, effective competition between developers to progress projects will put downwards pressure on project costs and help to ensure that consumers will benefit from cost reductions as a result of a pathfinder, innovation, a strong supply chain and efficient financing.

Competition for Government CFDs allocated as part of Electricity Market Reform has been a notable success in this respect. I set out how competition might be delivered efficiently in Section 11.1.

[36] Ocean Energy: Cost of Energy and Cost Reduction Opportunities May, SI Ocean, 2013

Role of competition in reducing costs

The intention at the outset of the introduction of Government's Contract for Difference scheme was to move at pace toward competitive allocation as the most efficient means of delivering efficient low carbon energy investment. The final report of the Competition and Market Authority's Energy Market Investigation this year underlines the value of this approach.

"The competitive allocation of CFDs is likely to be a more efficient means of providing support in most cases. The competitive mechanism should put pressure on suppliers to reduce costs in order to be successful in the auction, and avoids the need for DECC to second guess the efficient level of support, and incentivises suppliers accurately to reveal their costs."

I also note their findings that the first competitive auction for CFDs resulted in prices approximately 25% lower than administratively set prices would have achieved.

6.3. Financing costs and the cost of capital

Of course, the cost of capital for investors and financiers inevitably has a very significant impact upon the overall costs of projects and it should be the aim of a tidal lagoon programme to drive down such costs as much as possible (as they provide no greater power output or efficiency but simply result in additional deadweight costs to consumers).

The table below provides an indication of the sensitivity of generation costs to costs of capital. In this example, a five percent decrease in the cost of capital for a £1 billion funding requirement equates to a saving of £100 per MWh (assuming annual generation of 500 GWh).

Costs of capital illustration		
Project assumptions		
Construction cost	£m	1,000
Electricity generation	GWh pa	500
Cost of capital		
15.0%	£ per MWh	300
10.0%	£ per MWh	200
5.0%	£ per MWh	100
2.0%	£ per MWh	40

Table 8
Source: Welsh Water evidence submission

I consider that there are three key drivers that are the primary elements in determining the costs of capital for tidal lagoons:

1) Role of a pathfinder project;
2) Financing structure implemented; and
3) Long term clarity of policy

On the role of a pathfinder, there is a consensus amongst the investors and financiers who have engaged with the Review during "roundtable" events and via evidence submissions that a pathfinder project would materially decrease costs of capital to develop and construct large scale tidal lagoons.

This is because the construction of a pathfinder would demonstrate that complex interfaces between construction parties can be managed and would also establish credibility in the supply chain. An operating track record would decrease perceived risks relating to project performance.

Whilst there is some debate amongst investors and financiers as to the exact point in the life cycle of a pathfinder project that the lowest cost of capital could be secured for large scale tidal lagoons, there is general agreement that moving forward with a single pathfinder project at the scale of Swansea Bay would facilitate material reductions in costs of capital for large scale projects that follow.

Costs of capital will also be very significantly affected by the particular financing structure that is implemented to support projects. As I discuss in Chapter 12, there are many benefits to a CFD model and I consider this model is the most appropriate form of support for a pathfinder project.

For large scale tidal lagoons, the introduction of a Regulated model, for example, could facilitate lower costs of capital that improve the value for money case of projects (although, as I highlight, there would be many challenges relating to the design and implementation of this type of model and its interaction with the electricity market).

I have also received evidence that suggests a very low cost of capital for large scale tidal lagoons could be achieved by introducing an alternative ownership model. This model is illustrated by an example of the approach taken to finance Welsh Water, summarised below. I recognise that there is potential to develop this type of model for large scale tidal lagoons, but I note that successful development would require many of the risks currently associated with projects, in particular revenue risk, to be mitigated and may also require a backdrop of strong regulation.

Consequently, I have not based my conclusions on financing costs on an assumption that this model could be introduced, rather I note that it is an interesting example of how the industry may develop.

Welsh Water – financing example

Welsh Water is owned and financed by Glas Cymru, a not-for-profit company that acquired the utility in 2001. The transaction was financed by a £1.9bn bond issue in the capital markets, reported to be the largest ever sterling bond issue not backed by Government, attracting a very low cost of capital to support the company.

Glas Cymru has no shareholders and reinvests financial surpluses in improving its services. It benefits from a high credit rating, strong governance and regulation. Collectively, these characteristics enable the company to raise low cost, long term finance in the capital markets. Furthermore, bond investors take comfort that it is in the interests of Glas Cymru to maintain / improve its credit rating – as this creates lower funding costs in the future.

The Glas Cymru ownership model illustrates how a capital intensive industry with low risk characteristics can be funded at a low cost. For tidal lagoons to access such a model, risks associated with projects, in particular revenue risk, would require mitigation. A strong form of industry regulation may also be required to facilitate access to the lowest cost of capital.

Critically, the extent of Government's long-term commitment to a tidal lagoon programme, and the creation of an appropriate framework to deliver on such a commitment, would reduce political risk for such investments and thereby also reduce financing costs.

I therefore devote a significant part of my Review to assessing how Government can best provide such long term clarity and direction.

6.4. Conclusions on generation costs and the potential for cost reduction

There is potential for large scale tidal lagoons to significantly decrease generation costs relative to a pathfinder project, due to site location and design, including in a scenario where cumulative impacts on energy yields are significant.

There is a moderate potential for project cost reductions as the industry establishes itself following a pathfinder. And there is a high potential for cost of capital reductions (due to the role of a pathfinder).

Whilst it is inevitably very difficult to quantify this potential precisely at this stage, it should be noted that generation costs (and therefore subsidy costs) are very sensitive to improvements in these areas. However, all the methods used show the same trends of reducing costs for projects built at scale.

Effective competition is essential to efficiently drive cost reductions. In Chapter 11, I recommend how to deliver a strategy that will secure the greatest value of cost reductions in a programme of tidal lagoons.

7. Subsidy costs and other considerations

Summary of subsidy costs

Review approach

Large scale tidal lagoons in the Severn Estuary appear to have high potential for low generation costs (and therefore the lowest subsidy costs) due to site location and design. The Review has focused on potential sites at Cardiff, Newport and Bridgwater and based estimates of subsidy costs upon:

- TLP's current project assumptions; and
- TLP's proposed financing structure for Swansea Bay

Estimates of subsidy costs are illustrative and should be considered in the round with other social and economic benefits of projects and in light of the risks that may be transferred to consumers as part of CFD agreements.

TLP estimates the Strike Price required for the First Operating Year for Cardiff, Newport and Bridgwater tidal lagoons to be in a range of:

- £105-120 per MWh due to site location and design
- £90-115 per MWh after cost reductions attributed to a pathfinder
- Partial indexation decreases the "real" value of strike prices during CFD terms

To help compare partially indexed CFDs (proposed for tidal lagoons) to fully indexed CFDs (for renewables and nuclear), TLP proposes a "CFD Equivalent" measure. TLP estimates CFD Equivalent values for Cardiff, Newport and Bridgwater to be in a range of:

- £75-90 per MWh due to site location and design
- £65-85 per MWh after cost reductions attributed to a pathfinder
- By this measure, illustrative subsidy requirements for large scale tidal lagoons are competitive with targets for new offshore wind and nuclear projects that may commission in the mid-2020s

I have calculated illustrative annual costs for households for tidal lagoon, offshore wind and nuclear projects commissioning around the mid-2020s on the basis of equivalent amounts of annual electricity generation (assumed to be 550 GWh at pathfinder scale and 5,500 GWh at large scale).

For a pathfinder tidal lagoon, the Review estimates the average additional cost on a household's annual electricity bill to be:

- c.35-45p in earlier periods (first 15 years)
- c.20-30p in later periods (Year 30 to Year 60)

For a large scale tidal lagoon, the Review estimates the average additional cost for households to be:

- c.£1.85 to £2.10 in earlier periods
- c.50p to £1.40 in later periods

In this analysis, tidal lagoons are more expensive than offshore wind and nuclear during earlier periods. During a 60-year period, a large scale tidal lagoon is less expensive than offshore wind and significantly less expensive than nuclear.

This measure does not take into account the potential for periods of low bills costs for tidal lagoons after Year 60 and "subsidy free" generation thereafter, which is one of the most substantial benefits in favour of tidal lagoons.

The Review's illustrative assessment of CFD cost per MWh over project lifetime

This measure is very helpful because it takes into account the forecast operating lives of projects, upon which periodic estimates of subsidy costs are based.

For tidal lagoons before cost reductions (attributable to a pathfinder):

- Cardiff and Bridgwater are less expensive than nuclear

For tidal lagoons after cost reductions:

- Cardiff and Bridgwater are less expensive than the currently anticipated cost of offshore wind
- Newport is in line with nuclear (with potential to be significantly less expensive than both nuclear and offshore wind subject to the design of its financing structure)

Summary of other considerations

Energy system modelling

There is a shortfall between capex targets for tidal lagoons to form part of a "least-cost" pathway to the UK's 2050 greenhouse gas emissions target in ETI's Energy System Modelling Environment (ESME) and estimates of capex levels for illustrative large scale projects. This variance helps to demonstrate the importance of financing structures in driving down subsidy costs.

My assessment of potential subsidy costs for tidal lagoons has been undertaken at a time of ongoing negotiations between Government and TLP in respect of a financing structure and project assumptions for Swansea Bay and very early stage work by developers for large scale tidal lagoons. There is no other such detailed work available for other proposed lagoons.

In light of this, I have identified that the most appropriate course of action for the Review is to focus on estimates of subsidy costs for large scale tidal lagoons based upon TLP's current project assumptions and their proposed financing structure for Swansea Bay.

Whilst TLP has an interest in making the most positive case for its projects, the developer's figures are inevitably also the most considered and robust available, given the expertise and rigour applied in developing data for the purposes of the Swansea Bay negotiation and to secure investment.

It has not been in the scope of the Review to undertake due diligence on all of the project and financing assumptions and calculations that support TLP's figures, including those relating to the proposed financing structure for Swansea Bay, which is being examined by Government.

I have, however, reviewed, discussed and challenged key assumptions and performed calculations to derive estimates of subsidy costs based on the Strike Price requirements reported by TLP.

Subsidy cost estimates for key comparators – offshore wind and nuclear – are based on Government's Strike Price targets and agreements for these technologies. Outputs of all calculations differ moderately to TLP's own conclusions.

The financing structure proposed by TLP for Swansea Bay may materially change as part of future negotiations with Government (including as a consequence of other Sections of my Review). I would certainly expect aspects to change to ensure that large scale tidal lagoons are delivered as efficiently as possible. However, with so many inter-related elements to any viable financing structure, I determined that it would not be appropriate to add a layer of hypothetical alternative structures to my analysis of subsidy costs.

Nevertheless, it is important to note that recommendations that I make elsewhere in the Review could materially increase Strike Price requirements (and therefore subsidy costs) from the figures set out in the analysis that follows. However, I consider that this is the right approach, as it makes the process more transparent and less anti-competitive.

For example, as I explain in Chapter 12, I have concluded that there are significant risks for Government relating to a very long contract term. The analysis that follows in this Chapter is based on a 90 year CFD (as proposed for Swansea Bay). A shorter CFD term would give rise to higher Strike Price requirements, which should then be considered when comparing tidal lagoons to other renewable energy and low carbon projects. My understanding is that a shorter term of around 60 years would only require a moderate increase in a Strike Price.

Furthermore, assuming a 120 year operating life for tidal lagoons, it must be recognised that following the end of the CFD period there would then be a period of many decades of "subsidy free" power, at a time when other technologies would have reached the end of their operating lives. This is a very significant 'gain' for future consumers.

Subsidy costs can be measured in many ways, and certainly, when comparing very different technologies, as in this case, no single measure should be considered in isolation. This Chapter examines:

- TLP's illustrative Strike Price requirements for large scale tidal lagoons
- TLP's "CFD Equivalent" measure of subsidy costs
- The Review's illustrative assessment of impacts on bills
- The Review's illustrative assessment of a "CFD costs per MWh" measure of subsidy costs

For the purpose of this analysis, I have assumed that a pathfinder tidal lagoon would have less than 500 MW of installed capacity. The large scale sites that I have considered are Cardiff, Newport and Bridgwater, as these sites are amongst those that our expert advisor, ITP, has identified to have a high potential for low generation costs due to site location and prospective design (as discussed in Chapter 6).

I compare estimates of subsidy costs for these sites to those for new offshore wind and nuclear projects commissioning in the mid-2020s. It is very challenging to make a 'like-for-like' comparison due to variances between projects – including different operating lives and CFD tenors and varying levels of indexation of Strike Prices.

As TLP's proposal for Swansea Bay is confidential, I have not been able to focus on any particular points on risk transfer that may relate to this proposal, but Government should fully consider the implications of any risks that would be transferred to consumers under CFD arrangements.

Whilst the figures show that tidal lagoons do stack up economically when compared to other sources of large scale, low-carbon generation, the full value of tidal lagoons is only properly assessed by taking into account broader economic benefits and other benefits in terms of security of supply and decarbonisation.

7.1. CFD costs for tidal lagoons

The CFD element of TLP's proposal for Swansea Bay is for a 90 year contract term with partial indexation of a Strike Price. These features are designed to facilitate an efficient capital structure for the project that reduces total CFD costs by certain measures, such as the Net Present Value of CFD payments.

Partial rather full indexation of a Strike Price to a measure of inflation (such as the Consumer Price Index) reduces the "real" value of the Strike Price during the contract term – so the level of subsidy paid will rise more slowly than the level of the rise in inflation.

TLP's proposal is structured to provide a "Starting Strike Price" that is subject to partial indexation from 2016. The purpose of this notional value is to provide a lower "real" Strike Price when the facility actually starts operating and thereafter.

The table below sets out TLP's calculations of Strike Price requirements for Cardiff, Newport and Bridgwater on the basis of two measures:

- *Strike Price before cost reductions* – this measure applies the exact CFD structure proposed for Swansea Bay to TLP's current project assumptions (all subject to design iterations that will impact upon Strike Price requirements)
- *Strike Price after cost reductions* – this measure applies further cost reductions that TLP believes would be brought about from the lessons learned of using a tidal lagoon in Swansea Bay as a pathfinder project. The Review's expert advisor agrees with TLP's estimates for these projects.

TLP illustrative analysis of Strike Price requirements				
2012 prices		**Cardiff**	**Newport**	**Bridgwater**
Installed capacity	MW	3,240	1,440	6,480
CFD contract term	Years	90	90	90
First Operating Year	Date	2027	2030	2030
Starting Strike Price				
Strike Price before cost reductions	£ per MWh	140.1	148.0	129.9
Strike Price after cost reductions	£ per MWh	113.0	141.7	110.1
First Operating Year Strike Price				
Strike Price before cost reductions	£ per MWh	115.6	120.4	105.7
Strike Price after cost reductions	£ per MWh	96.1	115.3	89.6

Table 9
Source: TLP data. Key assumptions set out in Annex I

Taking Cardiff as an example, TLP estimates that this project would require a Starting Strike Price after cost reductions (facilitated by a pathfinder) of £113 per MWh. In "real" terms, the value of this Strike Price would decrease year-on year – falling to £96.1 per MWh by the project's First Operating Year (2027) and continuing to decrease thereafter.

Based on TLP's Starting Strike Price, I estimate that the "real" Strike Price for Cardiff may fall below illustrative targets for nuclear (£92.5 per MWh) in Year 4 of operations and for offshore wind (£85 per MWh) in Year 10.

TLP anticipates that the CFD proposal for Swansea Bay could be optimised for Newport to significantly reduce Strike Price requirements from the figures presented here, which are on the basis of applying the exact proposal for Swansea Bay.

7.2. CFD Equivalent measure of subsidy costs

It is challenging to gain a clear sense from these figures of how a partially indexed CFD for tidal lagoons compares to a fully indexed CFD for other renewable energy and low carbon projects as allocated by Government to date as part of Electricity Market Reform.

To address this, TLP has proposed a "CFD Equivalent" value to facilitate comparisons, which calculates the value that a fully indexed Strike Price would need to be in order to generate the same Net Present Value (NPV) of CFD payments as a partially indexed Strike Price.

For example, if a partially indexed Starting Strike Price of £120 per MWh is forecast to result in a NPV of £500 million for CFD payments, a CFD Equivalent is the value of a fully indexed Strike Price (eg £80 per MWh) that gives rise to the same NPV of £500 million of payments.

This measure provides a helpful reference point for a high level comparison of total discounted costs of tidal lagoons to other projects. However, it should be borne in mind that a CFD Equivalent is a notional value and does not reflect levies on household bills. An inevitable result of partial indexation is that CFD payments would be higher in earlier periods than in later periods.

The table below sets out TLP's calculation of CFD Equivalents for the projects under consideration. The Review's internal analysis supports these calculations.

TLP illustrative analysis of CFD Equivalent values				
2012 prices		**Cardiff**	**Newport**	**Bridgwater**
CFD Equivalent before cost reductions	£ per MWh	85.0	89.4	77.8
CFD Equivalent after cost reductions	£ per MWh	70.4	85.4	66.0

Table 10
Source: TLP data. Key assumptions set out in Annex I

Taking Cardiff as an example, TLP calculates a CFD Equivalent after cost reductions of £70.4 per MWh based on a Starting Strike Price of £113.0 per MWh.

CFD Equivalent values for Cardiff, Newport and Bridgwater are broadly in line with a "Strike Price challenge" for tidal lagoons seeking to enter the UK's energy mix in the mid to late 2020s. This challenge, which determines the level at which lagoons are competitive with other technologies is outlined below.

"Strike Price challenge" for tidal lagoons

For large scale tidal lagoons seeking to enter the UK's energy mix in the mid to late 2020s, the most natural "competitors" for CFD support are new offshore wind and nuclear projects.

At Budget 2016, Government set a cap for future CFD support at £105 per MWh for 2021, falling to £85 per MWh for projects commissioning by 2026 (2011-12 prices)[37]. The Review has heard from stakeholders who anticipate that successful bids for CFDs are likely to be significantly lower than these caps.

Government has agreed a Strike Price of £92.5 per MWh for Hinkley Point C, which could reduce to £89.5 per MWh (2012 prices), subject to a decision by EDF in relation to its proposed Sizewell C project[38].

These headline figures broadly quantify a "Strike Price challenge" for tidal lagoons seeking to enter the UK energy mix on a low cost basis.

[37] CFD Equivalents are stated as 2012 prices. Converting Offshore Wind Strike Prices from 2011-12 prices to 2012 prices results in a small uplift in values.
https://www.gov.uk/government/publications/budget-2016-documents
[38] https://www.gov.uk/government/collections/hinkley-point-c

CFD Equivalent values should be considered alongside the practical impact of partial indexation of Strike Prices on bill costs for energy consumers.

The table below illustrates my analysis of this impact, presenting average CFD costs on household bills over a range of different timescales. Tidal lagoons are compared to offshore wind and nuclear projects on the basis of equivalent amounts of annual electricity generation (assumed to be 550 GWh for a tidal lagoon at pathfinder scale and 5,500 GWh for a tidal lagoon at large scale).

Offshore wind projects are assumed to operate for 22 years supported by a CFD for 15 years. A fully indexed Strike Price is assumed to start at £85 per MWh and decrease by 20% for subsequent projects. Potential trends for offshore wind cost reductions are discussed below.

Offshore wind cost reductions

Recent results from tenders in European markets indicate that offshore wind projects are continuing to achieve dramatic cost reductions.

For example, the 700 MW Borssele I and II projects in the Netherlands will receive support at €72.7 per MWh[39] (around £62 per MWh on current exchange rates). The projects, built by Dong and set to commission in 2020, will be delivered under a build and operate model that mitigates many development risks and costs. This model varies significantly to the model for UK offshore wind projects to receive CFD support. Nevertheless, the very low pricing achieved from competitive tenders (in this case site specific) illustrates the potential for offshore wind projects to be built at a very low cost.

Looking ahead to the long term, a study of wind experts' views published in September 2016 reported that reductions in Levelised Cost of Energy (LCOE) for offshore wind are expected to be 20% from 2020 to 2030 and a further 11% from 2030 to 2050, driven by reductions in capex and financing costs[40]. LCOE estimates may provide an indication of subsidy requirements.

For illustrative purposes, the Review has assumed a 20% reduction in CFD values for sequential offshore wind projects with operating lives of 22 years: CFD1 £85,

[39] https://www.government.nl/latest/news/2016/07/05/netherlands-offshore-wind-farm-borssele-cheapest-world-wide.

[40] Median estimates for "fixed-bottom" offshore wind projects in a survey of 163 wind energy experts conducted by the US Energy Department's National Renewable Energy Laboratory in collaboration with the International Energy Agency and other partners http://www.nature.com/articles/nenergy2016135.epdf?author_access_token=xOjt15xAsgbwf-DTbC9umtRgN0jAjWel9jnR3ZoTv0Pm0tcEncNIRUyqt3vi2Zdm55gFQx3FMImKG0Gh8VsP0wqN8AeZekJAOtf6AfxskkGU8raC7OZ5Y_20S7qTMDRvAjSHfuoi9oAte8h3yQ3nDw%3D%3D

CFD2 £68, CFD3 £54.

Projects may be able to achieve significantly lower Strike Price requirements and operating lives may extend considerably.

A nuclear project is assumed to operate for 60 years supported by a CFD for 35 years. A fully indexed Strike Price of £92.5 per MWh is assumed.

Tidal lagoon Starting Strike Prices are based on TLP's figures for Swansea Bay as a proxy for a pathfinder scale project and for Cardiff, after cost reductions, as a proxy for a large scale project. Indexation levels are based on TLP's proposal for Swansea Bay.

Hendry Review – illustrative impact on bills					
2016 prices	**Annual Electricity Generation GWh**	**Annual cost per household**			
		Years 1-5 average £2016	**Years 1-15 average £2016**	**Years 1-30 average £2016**	**Years 1-60 average £2016**
Pathfinder scale					
Tidal Lagoon	550	0.43	0.37	0.31	0.18
Offshore Wind	550	0.17	0.17	0.10	0.05
Nuclear	550	0.23	0.22	0.24	0.14
Large scale					
Tidal Lagoon	5,500	2.10	1.86	1.41	0.49
Offshore Wind	5,500	1.55	1.75	1.06	0.54
Nuclear	5,500	2.10	2.29	2.39	1.40

Table 11
Source: Hendry Review analysis. Key assumptions set out in Annex I

This analysis suggests that a large scale tidal lagoon generating 5,500 GWh of electricity per annum could have an average cost on annual household bills of around £1.85-£2.10 in earlier years falling to 50p-£1.40 in later periods.

On this basis, tidal lagoons are more expensive than offshore wind and nuclear during earlier periods. During a 60-year period, a large scale tidal lagoon is less expensive than offshore wind and significantly less expensive than nuclear (with an average annual cost of c.£0.50 as compared to c.£1.40).

Whilst this analysis provides a snapshot of forecast bill costs at particular points in time, it does not take into account the full CFD term (90 years) and operating life (120 years) that the costs of tidal lagoons have been predicated upon and therefore does not capture the potential long life benefits of tidal lagoons. In contrast, considering a period of up to 60 years enables "subsidy free" periods for both offshore wind and nuclear to be considered (and also cost reductions for sequential offshore wind projects).

The scope of this calculation therefore has a built-in bias towards offshore wind and nuclear – it is not a level playing field, but even in such circumstances, tidal lagoons compare favourably. Offshore wind does emerge more cheaply in earlier periods, but it does not have the absolute predictability of tidal lagoons, which brings consumer benefits of a different nature.

7.3. CFD cost per MWh over project lifetime

An option to assess projects on a more 'like-for-like' basis than estimates of bill costs in particular periods is to consider the effective cost of CFD payments for each MWh of electricity delivered during the lifetime of projects (a "CFD cost per MWh").

This approach calculates NPVs of two forecasts:

1. CFD payments during the terms of contracts; and
2. Electricity generation during the operating lives of projects

A "CFD cost per MWh" is calculated by dividing the NPV of CFD payments by the NPV of electricity generation[41]. Discount rates used to calculate NPVs are based on guidance in HMT's Green Book[42].

For example, if a project has a NPV of forecast CFD payments of £500 million and a NPV of forecast electricity generation of 10,000 GWh (based on all periods of electricity generation, including those that follow the end of the CFD term), the effective cost for the project of delivering all electricity during its lifetime is £50 per MWh (£500 million divided by 10,000 GWh).The chart below presents the Review's analysis of this measure for the projects under consideration.

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[41] The mechanics of this approach are outlined by TLP in its "Power Cost League Table": http://www.tidallagoonpower.com/wp-content/uploads/2016/09/New_Power_Cost_League_Table_2016.pdf.

[42] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/220541/green_book_complete.pdf

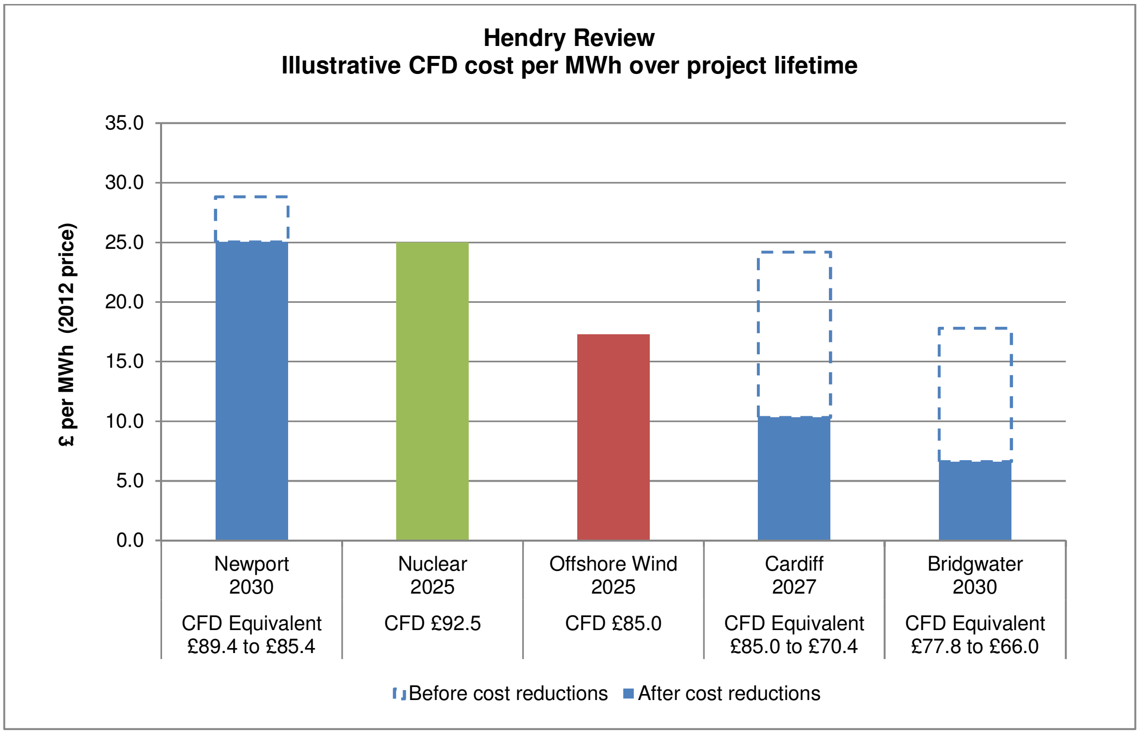

Figure 5
Source: Hendry Review analysis. Key assumptions set out in Annex I

Based on this analysis, Cardiff and Bridgwater are less expensive than nuclear before cost reductions for these tidal lagoons are considered. After cost reductions, these projects are significantly less expensive than the currently anticipated cost of offshore wind.

Newport is in line with the cost of Nuclear after cost reductions are considered. This project has the potential to be significantly less expensive than both nuclear and offshore wind subject to the design of its financing structure, which has scope for optimisation.

As I discuss in Chapter 12, measure of impacts on bills and “CFD cost per MWh” are contingent upon power price assumptions, which are uncertain, particularly so in the very long term. I recommend that Government undertakes sensitivity analysis of different power price scenarios when considering these measures.

7.4. Conclusions

It is challenging to make a direct and comprehensive comparison between tidal lagoons and other renewable energy and low carbon projects because the projects have very different characteristics.

Based on current project assumptions and the financing structure proposed for Swansea Bay, **I have concluded that a "CFD Equivalent" measure of subsidy costs indicates that large scale tidal lagoons have potential to be competitive with low carbon projects commissioning in the mid to late 2020s.**

Costs for energy consumers would be higher in earlier periods than in later periods due to partial indexation of a Strike Price under this approach. In their later years, tidal lagoons would be producing very reasonably priced electricity indeed.

A measure of CFD costs per MWh over project lifetimes is particularly helpful because it is able to take into account forecasts of operating lives of projects, upon which estimates of costs in individual periods are based.

Potential subsidy costs should be considered by Government in the round with estimates of other direct and indirect public costs and the wider social and economic benefits of projects.

I conclude that the potential impact on consumer bills of large scale tidal lagoons appears attractive, particularly when compared to nuclear projects over a long time period; and that a measure of CFD cost per MWh over project lifetimes indicates that a tidal lagoon programme has potential to be very valuable and competitive.

Large scale tidal lagoons, delivered with the advantages created by a pathfinder, are likely to be able to play a valuable and cost competitive role in the electricity system of the future.

7.5. Other considerations

Energy system modelling

An alternative approach to consider the circumstances in which tidal lagoons could play a cost effective role in the UK's energy mix is to assess what would be required in cost and performance terms for tidal lagoons to be a part of a "least-cost" energy system transition to delivering the UK's energy targets.

Energy system models can be used for this purpose. The Energy Technologies Institute (ETI) has undertaken analysis for the Review using its Energy System

Modelling Environment (ESME)[43] to identify the capex levels at which tidal lagoons would need to be built for them to be part of a least-cost pathway to deliver the UK's statutory target to reduce greenhouse gas emissions in 2050 by 80% from 1990 levels[44].

Please refer to Annex H for details of ETI's approach and key findings. ETI's targets for tidal lagoon capex levels range from £1,200 per KW in a "baseline" case to £1,800 per KW in a 'low nuclear and no CCS case'. These targets are significantly lower than capex estimates for large scale tidal lagoons based on ITP's analysis. For example, capex estimates for Cardiff, Newport and Bridgwater, net of a 10% reduction to reflect the role of a pathfinder project, are in a range of £2,700 - £2,800 per KW.

I do not consider that the shortfall between estimated capex levels for large scale tidal lagoons and ETI's targets illustrate that tidal lagoons cannot be cost effective. Rather, the variance indicates the importance of the role of a financing structure in driving down subsidy requirements, which are the key criteria for projects to be cost effective.

The analysis also draws attention to challenges in comparing tidal lagoons to other low carbon projects on a 'like-for-like' basis. ETI's ESME model focuses on a pathway to 2050, whilst, as I have discussed, tidal lagoons have the potential to operate for a very significantly longer period of time. The "CFD cost per MWh" approach is more appropriate for appraising this potential (although I note that other technologies with forecasts for long operating lives, including nuclear and heat networks, are deployed within ESME because they are deemed to be a cost effective way to meet targets).

System impacts

ETI's ESME model makes broad assumptions of the ability of tidal lagoons to provide flexibility to the energy system and to contribute at times of peak demand.

I have received evidence in relation to these impacts. Aurora Energy Research, for example, has concluded that a very large portfolio of distributed tidal lagoons could decrease system costs in terms of wholesale power prices and the capacity market, whilst increasing consumer bills and reducing carbon emissions during a period from

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[43] More information can be found here: http://www.eti.co.uk/programmes/strategy/esme.
[44] Climate Change Act 2008 Chapter 27: http://www.legislation.gov.uk/ukpga/2008/27/contents.

2030 to 2040[45]. Aurora estimates intermittency costs for tidal lagoons to be lower than those for wind projects.

Aurora's analysis is based on a theoretical portfolio of 25 GW of tidal lagoons. This estimate appears very high. For example, ITP identified a theoretical portfolio of 17.6 GW for the top six sites with the highest potential for low generation costs.

I encourage Government to engage with stakeholders on these issues to further its understanding of potential system impacts for tidal lagoons in a range of deployment scenarios and time periods.

Other analytical assessments

I have examined estimates of Levelised Costs for tidal lagoons. This type of analysis estimates the cost for a project of generating each MWh of electricity based on total costs during its lifetime. Whilst this cost may indicate the level of subsidy required, it does not take into account particular financing structures that may be proposed. Given this, and that estimates reviewed are based on historic assumptions, I have not considered Levelised Cost calculations further. I consider the key drivers of Levelised Costs in Chapter 6.

Funding requirements for large scale tidal lagoons

I have considered how the very large funding requirements for large scale tidal lagoons may be met. The capex requirement for Cardiff, for example, is estimated by TLP to be in the region of £8bn[46].

The European Investment Bank (EIB) would have been a natural place to look for investment in projects. However, following Brexit it appears relatively certain that EIB will scale back its support for UK investments from around 6bn Euros this year to a few hundred million Euros when the UK has left the EU.

I have examined the potential for the UK Guarantees scheme to facilitate the financing of this scale of requirement. As set out below, this scheme would not be expected to reduce financing costs (costs of capital) but could assist with liquidity.

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[45] Based on Aurora's power market model, which considers investor decisions (how investors would act given a set of assumptions about the power market) rather than solving for decarbonisation targets (the approach taken in ETI's ESME model).
[46] ITP's own estimate, noted in Chapter 6, is considerably higher (£9.7bn).

UK Guarantees scheme – potential role for tidal lagoons

Background

The UK Guarantees scheme helps projects to raise debt finance in cases where market conditions, unrelated to projects, have constrained typical lenders (such as commercial banks) and also aims to attract new sources of finance (such as pension funds and other institutional investors).

Under the scheme, HMT guarantees that lenders are paid all interest and principal payments. The risk taken by lenders is the risk of lending to HMT rather than the risk of lending to the project. In return, HMT receives a guarantee fee from the project, which is priced at the estimated market rate of providing debt finance.

As at 31 March 2016, HMT had approved guarantees to nine projects covering a total of c.£1.8bn of debt, including three projects in the energy sector – a biomass conversion for Drax, an ethane facility at Grangemouth and an energy efficiency deal[47].

These commitments are recognised as contingent liabilities, which are not on Government's balance sheet and therefore do not affect public sector net debt.

HMT has also agreed a guarantee with nuclear plant Hinkley Point C, which was reported in September 2015 to cover £2bn of debt.

The duration of the scheme was extended to at least 2026 in Autumn Statement 2016. The notional funding cap for the scheme is £40bn.

Role for tidal lagoons

It appears that in principle the scheme could play a role in helping large scale tidal lagoons to meet funding requirements.

However, I understand that the interaction of a guarantee with other forms of Government support, such as a CFD, could raise issues as to whether projects are treated as public or private, with the possibility of a project being placed on Government's balance sheet.

[47] https://www.gov.uk/government/publications/infrastructure-financial-assistance-act-2012-annual-report-for-year-ending-31-march-2016.

8. Conclusion: The Strategic Case for a Tidal Lagoon Programme

My conclusion is that tidal lagoons would help deliver security of supply; they would assist in delivering our decarbonisation commitments; and they would bring real and substantial opportunities for the UK supply chain.

I have also concluded that they could play a competitive role as part of the UK's energy mix alongside low carbon energy from nuclear and offshore wind. Nevertheless it must be recognised that an analysis purely on economic aspects inevitably overlooks wider benefits of a lagoon programme and that it is why it is ultimately a strategic decision, every bit as much as an economic decision.

Around the world, all Governments look to harness their most abundant renewable resources. For the UK, those are offshore wind and the marine resources which surround us. Offshore wind has shown that where a country shows real leadership, then it reaps the long-term economic gains and can deliver quite staggering cost reductions. If we don't take steps to develop marine technologies, then either other countries will steal that lead from us, or they will remain forever unharnessed.

To put this in context, the cost of a pathfinder project (such as Swansea Bay) financed through the Contract for Difference approach is expected to average around 30 pence per household per annum during the first thirty years. This seems to me an extremely modest amount to pay for a new technology which delivers those benefits and which has clear potential to start a significant new industry.

Moving ahead with a pathfinder lagoon is, I believe, a no-regrets policy. The Secretary of State for Business, Energy and Industrial Strategy, Greg Clark, has rightly spoken about the obligation on policy makers to plan for the longer-term.

I don't believe there would be any debate in decades to come about whether this was the right thing to do, even if it ended up as the only lagoon constructed – but I would expect it is much more likely to be seen as the decision which started a new industry, and all done at the cost of a small number of pence to consumers each year.

This is not therefore just about how we decarbonise the power sector in the most cost effective way <u>now</u>; it is also about very long-term, cheap indigenous power, the creation of an industry and the economic regeneration that it can bring in its wake.

If this is the conclusion, it also follows that we should start that process as swiftly as we can. After years of debating, the evidence is I believe clear that tidal lagoons can play a cost-effective part of the UK's energy mix.

Part Two of this report therefore focuses on the circumstances that will deliver this with the maximum benefit to the UK and at the most affordable cost to consumers, while minimising possible negative consequences.

PART TWO

9. First of a Kind Project

Key findings

- There is a very strong case for a small scale pathfinder project (less than 500MW) as soon as is reasonably practicable.

There has been significant amount of discussion and evidence regarding the importance of delivering a relatively small 'first of a kind project' in the form of Tidal Lagoon Swansea Bay, as a precursor to larger projects, showing that tidal lagoons can work and be effective. This reflects the huge amount of work has already been committed to advancing the Swansea Bay project.

The terms of reference for this Review require me to consider different sizes of projects as a 'first of a kind'. However, before we reach the question of size, it is necessary to establish what attributes an ideal first of a kind project would have.

It should be a standalone development that would be unlikely to impact upon other potential sites for tidal lagoons, thereby keeping options open for a future programme. It should be of sufficient scale to test the ability of the supply chain to deliver, and to test the complex interface between construction approaches. It should be large enough to demonstrate that a large funding requirement is a viable investment proposition. It should facilitate the monitoring of environmental impacts and the testing of mitigation strategies. Finally, it should be able to come forward quickly, capitalising on the momentum built to date.

The evidence in support of a pathfinder of a relatively small size (i.e. less than 500 MW) can be summarised as follows:

- Investors need to see that a smaller lagoon can be brought forward before they will commit to a larger lagoon project
- Developers need to 'learn by doing'
- It would open up clearer opportunities for achieving economies of scale
- It allows the UK supply chain to gear up for much larger projects
- It allows environmental impacts to be assessed

On the other side of the argument, it has been suggested:

- That larger lagoons may provide better value for money

- A small pathfinder may not prove the contractual risk-sharing and financing arrangements for a large scale lagoon
- That there are limited opportunities for achieving economies of scale in the construction costs, which are significantly determined by the costs of the civil engineering work (but larger lagoons would produce much more power relative to the investment costs than smaller lagoons).

The challenges of securing investment for a very large project as the first tidal lagoon would be very considerable, if not insurmountable. A smaller project would help develop the supply chain and allow the skills base in the UK to grow to support a larger industry. In most respects as much can be learned from the experience of building a small project, as could be learned from a very large lagoon. I therefore have concluded that a first lagoon should be relatively small in scale (i.e. less than 500 MW), as I consider this to be much more deliverable and would not significantly reduce the learning opportunities.

I consider that the term "pathfinder project," rather than a "first of a kind" better reflects the value that a smaller first lagoon could bring: it will establish the technology and prepare the supply chain to reap later benefits; yet follow-on projects will be different – in particular bigger – and therefore will face challenges of a different nature.

Whilst I have not been asked to identify a specific pathfinder project, it must be noted that there is currently no project other than Swansea Bay in the advanced state of development necessary to become a pathfinder in the near future. Lord Stern was particularly emphatic in his evidence that Swansea Bay should be pursued as a prototype, because it combines diversification and urgency. He believed that what is involved in its construction and the existing knowledge of what this would require means both that its construction is likely to be successful and that much would be learned that would be of benefit to future projects. He therefore believed it should be given every chance of going forward.

I have carefully considered whether this pathfinder project should be selected through a competitive process. It is not realistic to expect an organisation such as TLP to survive several years of delay in order to create a competition for the first project: the opportunity would be lost; it would set the programme back significantly; and would create an unnecessary risk that the programme will not happen at all, and would damage the UK's reputation as a dynamic place to invest in innovation.

During the Review I saw material relating to TLP's position as part of the 'first-stage negotiation' underway with Government for a CFD for Swansea Bay. I have not seen a formal response from Government, nor received an assessment of final terms that might be acceptable to Government negotiators. **It is therefore not possible for a full Value for Money case to be made for this particular project; and**

regardless such a case would clearly be beyond the scope of my independent Review.

I do conclude that there is a very strong case for a smaller pathfinder project as soon as is reasonably practicable and I urge the Government to capitalise on work already done rather than starting afresh. This clear commitment would deliver earlier benefits and accelerate a future programme.

I recommend that the Government now move to a timely 'final-stage negotiation' to explore robust and satisfactory terms that might be acceptable to both the developer and the Government.

TLP has created a very professional project development organisation, but the construction of a billion-pound national infrastructure project is a different and formidable challenge, and projects of this magnitude have almost always been undertaken with a delivery partner with a proven track record. **To assure the taxpayer, the electricity consumer and the Government, it would be very beneficial for TLP to secure such a delivery partner with a corporate track record in major energy or infrastructure projects. Such a partner should be in-place for the conclusion of a final phase negotiation with the Government.**

Any case to conclude a negotiation should reflect my assessment of the strategic value of a pathfinder project, the considerable value of a subsequent tidal lagoon programme, and the economic value created in the UK supply chain.

10. The relationship between the pathfinder project and a programme

Key findings

- The pathfinder project should be commissioned and be operational for a reasonable period before financial close is reached on the first larger-scale project.
- This pause would allow in-depth monitoring to be carried out and research to be conducted to address issues as they arise. To maximise the learning from this period of monitoring and research, I recommend that smaller scale lagoons continue to be developed and constructed during this pause.

This has been one of the most challenging questions for the Review. A rapid follow-up project at scale delivers the programme benefits sooner and secures a strong supply chain; while a delay allows lessons to be fully learned and provides time to foster real competition. This is a genuinely binary choice.

TLP have proposed a lagoon at scale at Cardiff, with an installed capacity of c.3 GW, an output of c.5.5 TWh, representing an investment of c.£8 billion of private capital. It has been suggested this could reach financial close before construction of the lagoon at Swansea is complete. This raises two key issues: how quickly should a project at scale follow the pathfinder; and how quickly should competition – especially in terms of competitive allocation of Government support – be introduced into the delivery of the lagoon programme?

A key argument for a large project following on quickly from a pathfinder is that this will provide the longer term clarity and certainty that the supply chain needs for planning their future investments.

On the other hand, leading environmental groups, local authorities representing communities in the Severn Estuary and other business users of the Estuary, have said that it is essential to move forward in a more considered way, to ensure that impacts – and especially cumulative impacts – are understood before building new projects. Many financiers have also suggested that it would be much more difficult to finance follow-on projects on the most competitive terms until a track-record for a pathfinder had been established. Whilst this does not mean it would not be possible to secure the finance, it does mean that the risks involved would be higher, and so therefore the costs of capital and the overall costs would be higher as well.

I understand the views of those wanting to move swiftly to the large scale tidal lagoon, that the necessary environmental protections would be assessed through the construction process and much would be learnt as the work continues. I also understand that some financiers believe it is possible to reach financial close on a vast lagoon before the pathfinder is fully operational. However, I am persuaded by the evidence in favour of taking a more cautious approach. I recognise this will be disappointing to those who have put forward proposals, and because of the critical importance of this issue, I have included a number of the points made on this subject in the written evidence to the Review in Annex F, to show the wide range of views urging that there should be a pause.

> "Overarching these issues is a high degree of uncertainty. Neither developers nor regulators have experience of development of the type and scale proposed. There is a limited evidence base. We currently have little knowledge of, and low confidence in, the modelling proposals for some of the schemes being promoted. While we are confident further improvements will be forthcoming, it is likely that regulatory decisions may have to be made with a limited understanding of the impacts on estuaries, coasts and rivers."
>
> *Evidence submitted to the Review by the Environment Agency*

We need to be sure that we learn as many lessons as we can before progressing to the largest lagoons. We need to heed the warnings of the environmental groups about the threats of incorrectly estimating the consequences. We need to recognise that many financiers and their advisers have suggested that it would be hard, if not impossible, to finance a large lagoon on the most competitive terms before the first one is fully operational. And we need to exercise caution in knowing exactly what the cumulative effects of a programme of lagoons in the Severn Estuary will be, as urged by many of the local authorities and commercial interests along the Severn.

Even in a policy area where so much vision is required to move forward, I have concluded that we have to exercise sensible caution in moving to a programme of lagoons too quickly, in order to understand their full impact and learn the full lessons of how the programme can be improved going forward.

I have concluded that it is therefore inevitable that the pathfinder project should be separated from the wider lagoon programme, and that the pathfinder should be commissioned and be operational for a reasonable period before financial close is reached on the first larger-scale project.

The pause would allow in-depth monitoring to be carried out and research to be conducted to address issues as they arise. To maximise the learning from this period of monitoring and research, **I recommend that smaller scale lagoons (and potentially small scale barrages) continue to be developed and constructed during this pause**. Such a strategic approach will also allow the supply chain for lagoons to continue to develop in preparation for larger lagoons; and I recommend that the Government should be clear that its eventual aim is the construction of large scale lagoons such as Cardiff, Newport or Colwyn Bay.

Other opportunities for maximising the opportunities for ‘learning’ from a pathfinder have been put to me in the course of the Review. It has been suggested that one turbine bay in the pathfinder lagoon could be kept as a test bed for a range of developers to trial new turbine designs at full scale. It has also been proposed that data and learning from the pathfinder project should be open-sourced, to allow a whole industry to grow to the benefit of the UK.

I see considerable attractions in such an approach, especially given the public funding involved, and whilst I recognise that there may be difficulties in doing this in a way the respects the intellectual property interests of the operator of the pathfinder project, I recommend that the Government investigates whether these difficulties can be overcome.

11. Future Programme

Key findings

- Competition by competitive tender should be introduced for tidal lagoons as soon as possible after the pathfinder project.
- There should be a National Policy Statement for tidal lagoons.
- A body should be set up to deliver a programme of tidal lagoons.

TLP have demonstrated that it is possible for an entrepreneurial business to develop a project in the absence of a Government policy on tidal lagoons. They have sought and received development consent for Tidal Lagoon Swansea Bay, and they are in advanced negotiations with Government on the terms of a support package.

However, if we wish to maximise the potential of tidal lagoon generation with a programme of lagoons, I believe steps need to be taken to clarify policy and establish the right environment to deliver that potential. Government's strategy should be to deliver a lagoon programme in the most competitive way possible. The recommendations that follow are about achieving that strategic goal, and touch upon the competitive allocation of support for a programme of lagoons, a National Policy Statement to describe what the programme should look like, and a delivery body to realise this industry's potential for the UK.

It is legitimate to ask why tidal lagoons should benefit from such an approach. Why not do the same for other technologies? I believe there are a number of reasons why this approach is needed.

This would be a new industry. While much of the technology is based on current applications elsewhere, there is no track record of building tidal lagoons in the UK or elsewhere. And this new industry faces a challenge that offshore wind, for example, did not face at a similar stage in its development. When the offshore wind industry was in its early stages, it was eligible for Government support under the Renewables Obligation. Under the Renewables Obligation all eligible schemes received support, precisely to offer the certainty of income that would enable developers to finance immature technologies and eventually bring down their costs. By contrast tidal lagoons are emerging in a more challenging context, where developers must compete against each other for a limited amount of support.

This is particularly risky for tidal lagoons. They are very large pieces of infrastructure, with significant development costs. To help ensure that these projects can be brought forward, I believe a substantial degree of policy certainty and central support is needed.

Furthermore, a level of central coordination for a programme of lagoons will help achieve the best overall result for the UK. A limited number of sites are suitable for tidal lagoons, and the evidence I have received indicates clearly that not all of those sites can be exploited collectively – the development of some will exclude, or at least interact negatively, with the development of others. **In a situation such as this, I believe it is best for Government to take a view on which configuration of lagoons offers the best outcome for the UK.**

But whichever configuration is selected, it is my opinion that the most will be achieved for the country if the Government allocates a specialist resource to foster the whole industry, increasing competitiveness through innovation, efficiency, and organisational stability.

11.1. Competition

I have identified nothing unique about tidal lagoons that precludes them from competitive CFD allocation and I recommend that there must be a move to competition as soon as this can be effective to deliver the most substantial cost reductions.

There are however challenges to competition both by the particular attributes of the technology and by the fact that it is an entirely new industry to the UK. The key questions are therefore: when would competition be possible; what methodologies should be applied; and who should deliver it?

11.1.1. When to move to a competitive structure

The key challenge to driving competition in a UK tidal lagoon programme is nurturing a nascent industry to a point where dynamic competition can occur. When the Swansea Bay proposition emerged the Government took the view, following a call for evidence process, that a competition was not possible at that time and that Swansea should progress on the basis of a bilateral negotiation.

I heard from Ecotricity that a delay of two years, if coupled with a clear Government framework, could deliver a real competition for the first of a kind project. This approach would have attraction in delivering robust price discovery. However I consider that two years would certainly be a best-case scenario; that there would be a damaging hiatus while the Government developed a robust competition framework, followed by a huge challenge of trying to re-energise industry to invest.

I also consider that a hiatus followed by a competition on price risks the genuine UK supply chain opportunities already created by the Swansea project which, if realised, would create a more dynamic competition between future projects and ensure that more of the economic benefit from these projects is captured as part of the UK economy.

On balance I have concluded that the risks involved in a competition to select the pathfinder are too significant: the Government has a realistic option of a pathfinder project and this option should be taken.

I heard views about whether competition is possible for a larger subsequent tidal lagoon project. Those who believe that competition should be introduced later on, say that both a pathfinder and a project at scale are required to establish a competitive market. This, it is suggested, would allow the UK supply chain to build upon the initial experience from the pathfinder and invest with a view to becoming competitive in supplying to a number of developers for future projects. It has also been suggested that a project at scale is required to prove the contractual arrangements for lagoons larger than a pathfinder.

I recognised the supply chain challenge of a competition within this time horizon, and believe this is best addressed by the proactive Government approach to the supply chain as set out in Chapter 4.

I do not consider that these issues sufficiently outweigh the benefits to the UK consumer of delivering a real competition for the first large project. It is a genuine challenge but the issues are fixable with a clear policy and competition framework and the prize is worthwhile.

In an early first round of competition, there would be merit in having smaller schemes (either lagoons or small barrages), from which there can be early learning advantages, and which will provide demand for the supply chain, whilst giving time for a full competition for larger schemes thereafter. It would be for Government to decide, within the constraints of the Levy Control Framework, how many rounds of competition there should be, but there should be sufficient for a programme to be developed through the 2020s to deliver the optimum benefits for the supply chain, for costs to be brought down substantially (as has happened with offshore wind) and to explore opportunities internationally.

11.1.2. Approach to delivering competition

To deliver an efficient competition for the first large project the Government needs to set out clear policy and commitment to a pipeline of tidal lagoons in ample time for the sector to respond.

I have considered the question of the stage of project development at which a competition could sensibly be run: it would be desirable to be able to award a Government support package to projects which have already received their consents, with resulting high cost certainty and high deliverability. However with development capital requirements at likely more than £50 million per project, a competition between two or more projects at this stage of development seems unrealistic.

There is also the possibility of a competition with more than one contract awarded at the same time. With a larger ratio of successful to unsuccessful projects, allocation risk might be more acceptable to developers. However it would require a very unusual level of commitment from Government; it would need an even greater minimum number of credible developers; it would multiply the challenge to the supply chain and potentially create bottlenecks; and would lose the incremental benefits of learning. **I recommend that competition should be therefore phased with one contract agreed per competition.**

To minimise costs I also recommend that a competition is run earlier in the development process, at a time when seabed and environmental surveys are complete and any key obstacles understood, but before the consents have been secured.

I recognise there is a real risk that by providing a Government support package at an earlier point in project development, that the winning project won't progress and will damage the developing industry and block the levy control framework funding for other projects.

To prevent such an approach being abused, I would also recommend that a 'use-it or lose-it' approach is adopted, so that prospective developers could not simply lock out other developments by winning a competition and not progressing the project. If they cannot show real progress to develop a facility within an established timescale, then the offer of support should be withdrawn.

Indeed I recommend that the Government should go further, and consider securing a bid-bond from a winning developer to be paid if the project is not pursued efficiently and in good faith.

I also considered the question of what is being competed for. **Competition should be a driver for efficient project design, engineering, procurement, risk allocation and financing package. All of this feeds into the price required for electricity produced. I therefore conclude that competition should be for the Government package of support (CFD and associated contracts).**

There are two strong models that would allow competition on price:

1. Allocation by auction: whereby a Government support package with fixed terms is competed between eligible developers, with the winner determined by price.

Auctions for renewable technologies have been shown to work well in securing projects and bringing down costs and allow competition purely on price. If Swansea goes ahead as a pathfinder it might provide a template for a generic tidal lagoon support package, against which an auction for price could be delivered. Other desirable attributes of projects – such as location, deliverability, and local economics might be managed through eligibility criteria.

2. Allocation by competitive tender: whereby a clear competition framework is used to compare the merits of iterative tender documents and identify the recipient of the Government support package.

   There is a clear risk that the financing arrangements for a large project will necessarily be different to the first small one and that therefore a contract put in place for Swansea might need to be changed.

On balance, I recommend allocation by competitive tender. These are such large and complex projects to develop and finance that the greater flexibility offered by tenders is highly desirable. An element of bespoke risk arrangements and contract terms could deliver material advantages to the consumer. A 'tender' model will also allow greater flexibility to reflect other desirable aspects of a project such as flood protection, regeneration and tourism.

I also considered whether competition should be between different developers at different sites, or between developers competing for the same pre-selected sites. On the one hand a competition that is as open as possible might be dynamic and help to develop a strong pipeline of projects; on the other hand, the prime sites are largely determined by the tidal range and different sites are difficult to compare because of very different local issues and auxiliary benefits.

Unless clear signals are created by Government to incentivise other considerations (e.g. accommodating less competitive price for a more useful location with flood defence benefits) developers are likely to cluster around a few sites anyway. **When delivering a competition by tenders, competing the same site allows for a clearer comparison of proposals.**

Moreover a site specific tender process would avoid investors becoming frustrated by preparing costly bids which make no progress and would enable a more structured approach to be taken, with a balance between projects in different parts of the country.

The approach should balance the capacity of the industry, project size, tidal range, location and other auxiliary benefits. The Dutch Government took a similar approach to certain offshore wind developments and recently announced impressive results of their tender for the Borssele I and Borssele II offshore wind projects.

I recognise that a tender process could interfere with the Crown Estate's commercial leasing processes. However I believe that tendering and leasing could be made to work well together, simplifying the overall process for all parties. Careful work must be done by the Government to ensure that the Crown Estate's commercial remit is not compromised.

11.2. National Policy Statement

Many organisations have suggested that there should be a National Policy Statement (NPS) for tidal lagoons. Natural Resources Wales wrote that such an NPS: “informed by the appropriate level of assessment of its environmental implications - would be a major benefit to the development of the sector, and would allow for opportunity to be maximised whilst at the same time minimising significant environmental risk.”

The development consent process

The planning process for dealing with proposals for nationally significant infrastructure projects, or ‘NSIPs’, was established by the Planning Act 2008 (‘the 2008 Act’). The Planning Act 2008 procedure was introduced to streamline the decision-making process for nationally significant infrastructure projects, making it fairer and faster for communities and developers alike.

The 2008 Act process, as amended by the Localism Act 2011, involves an examination of major proposals relating to energy, transport, water, waste and waste water, and includes opportunities for people to have their say before a decision is made by the relevant Secretary of State.

Any developer wishing to construct a NSIP must first apply for development consent. For such projects, the relevant Secretary of State will appoint an ‘Examining Authority’ to examine the application. The Examining Authority will be from the Planning Inspectorate, and will be either a single Inspector or a panel of three or more Inspectors.

Once the examination has been concluded, the Examining Authority will make a recommendation to the Secretary of State, who will make the decision on whether to grant or to refuse consent.

Certain bodies, such as Natural Resources Wales, the Environment Agency, and Natural England (to name three which submitted evidence to the Review) have a statutory role in various stages of the process.

It strikes me as unarguable that a fledgling industry would benefit from the clarity and stability represented by an explicit statement of Government policy that welcomes the development of tidal lagoons within defined parameters.

Moreover, given that there are only a limited number of sites around the country which would be suitable for tidal lagoons (as they need both a significant build-up of a head of water and also to be of a sufficiently shallow

depth where the wall can physically be constructed), there is a limit to how many installations would be possible.

Consents and licences required by lagoons

Tidal lagoon projects are subject to several licences and permissions. These include:

- Development Consent Order (DCO) under the Planning Act 2008
- Marine Licence (ML) under the Marine and Coastal Access Act 2009
- Various Planning Permissions under the Town and Country Planning Act 1990
- Potentially a Harbour Revision Order under the Harbours Act 1964
- Environmental Permits under the Environmental Permitting (England and Wales) Regulations 2010
- Seabed lease from the Crown Estate Commissioners under the Crown Estates Act 1961

Therefore, rather than being unclear, or allowing an ad hoc approach to the development of lagoons, I have received advice that a strategic approach should be taken by Government. Such a strategic approach would both look at the appropriate volume of tidal lagoons by region and in total, and would also give confidence to industry that the Government is serious in its intent to see lagoons being developed.

I therefore recommend that the consenting process should be informed by a National Policy Statement similar to nuclear new-build, where specific sites are designated by the Government as being suitable for development. Such an approach would also facilitate competitive allocation though a site-specific tendering process.

Further work is required to identify the order in which large scale lagoons should be developed, taking into account a range of issues, in particular environmental and navigational risks. Detailed specialist work would be required to explore the potential of individual sites, including assessments of bathymetry, ground conditions and exposure to wave activity. The viability of potential grid connections would need to be considered in selecting suitable sites for lagoons.

The potential cumulative impact of lagoons upon electricity generation of individual sites would be a major consideration. Professor Falconer of Cardiff University calculated in his evidence to the Review that the hydrodynamic impact of a Newport lagoon may reduce the energy yield of a Cardiff lagoon by c.2.5%. Bridgwater Bay, potentially an enormous project (6.5GW), may also have significant impacts upon other sites in the Severn Estuary.

A National Policy Statement for Tidal Lagoons

A national policy statement for tidal lagoons might usefully include:

- A statement of the public interest in tidal range technology, the benefits and opportunities it represents, and an evaluation of alternatives
- Suitable locations for tidal lagoons
- Relationships to other plans and policies, for example:
    - the Offshore Energy Plan and SEA;
    - marine plans
    - planning policy
- Devolution and regional policy context
- Principles of good design
- Key consenting and assessment requirements
- Advice to decision makers, for example, on:
    - Key impacts and risks of development and known conflicts with other developments
    - How to deal with cumulative effects
    - Generic mitigation options that (i) must be employed or (ii) are encouraged;
    - Synergies with other developments and activities and multiple benefits;
    - Associated development, and;
    - Decommissioning
- And miscellaneous positions on, for example:
    - Dealing with uncertainty and precaution through adaptive management techniques;
    - Reuse of information.
    - Sustainability of the main construction elements.

A series of lagoons in a particular area is likely to have an impact on the energy yield of individual sites and therefore careful consideration of the hydrodynamic interactions between sites will need to inform the NPS. In the same way, the NPS needs to ensure that the activities of other users of the waters are not affected unreasonably by the development of multiple lagoons.

I do not believe it would be useful at this stage to set a target or limit to the installed capacity the Government would wish to see consented. The work necessary to develop an affordable programme of lagoons, and to mitigate potential impacts, will improve our understanding of what is possible and desirable and will provide evidence on which to make judgements in due course.

Moreover, Government has not historically set out a target for how much power it wants to see delivered from a given technology, as that reduces the scope of a market to operate, and I imagine that will continue to be the preferred approach going forward. The time it would take to build a national network of lagoons to take advantage of different tide times around the country is so substantial (20 or 30 years) that any target would lack credibility as a formal Government target.

I do however recognise that such an NPS inevitably takes time to draft, consult on, finalise and authorise. Such delays would be especially damaging for Swansea Bay, which has already received its development consent from the former Secretary of State for Energy and Climate Change.

I would not want the work on Tidal Lagoon Swansea Bay to be lost because of an administrative exercise primarily intended to manage the development of very large tidal lagoons. There seems broad agreement that the scale and location envisaged for the tidal lagoon proposed for Swansea Bay would have negligible impact further up the Severn, so I recommend that the current Swansea Bay project should be excluded from this NPS approach.

There has also been a question of whether tidal lagoons can co-exist with a Severn Barrage. I have received evidence on both sides of this issue, but consider it to be outside the scope of the Review, as I have received no indication that the Government is reconsidering its earlier decision not to proceed with a Severn Barrage.

The consenting process also needs to give due weight to the local community interests. **I recommend that the process should encourage local authorities to have a significant role in deciding what is the right cumulative capacity of tidal lagoons in their vicinity.**

It has been made plain to me in the course of the Review that there are inefficiencies in the way the complex consenting arrangements for tidal lagoons operate in Wales. For example, in England a marine licence may be deemed through the Development Consent Order; whereas in Wales a marine licence must be sought separately from Natural Resources Wales.

Whilst I tread carefully in making any recommendations to the Welsh Government as a devolved authority, I do see evident benefits in streamlining the consenting process for tidal lagoons in Wales.

While a National Policy Statement may help, other things should be considered. For example, while it may not be possible to align responsibility for granting consent for ‘associated development’ (and other consents) for energy projects in Wales with the responsibility for granting development consent for the main project, greater information-sharing and collaboratively aligning timescales for processes may be helpful.

A number of respondents to the Call for Evidence have raised concerns about the links between the Chief Executive of TLP and Dean Quarry, from which stone for the bund wall might be extracted.

There is nothing inherently wrong in a developer wishing to secure the supplies of essential commodities. Just as a company might own gas generation plant and some of the fields to provide gas for those plants, it is not unreasonable that a developer of a tidal lagoon would wish to secure the supplies of quarry rock which is so central to the lagoon's construction. That must of course be done in a way that is transparent and sustainable and **I recommend that the National Policy Statement process should also include an assessment of the sustainability of the main construction elements for a longer-term tidal lagoon programme.**

11.3. Tidal Power Authority

For the reasons set out above, it is I believe the right decision to separate the pathfinder project from the subsequent tidal lagoons, but that means that **significant Government action is required if the benefits of a programme are not to be lost, especially for the supply chain. I consider this can be done, and actually be done in a way that will give greater long-term clarity and confidence to investors and industry.**

I propose that, at the same time as the pathfinder project is moving forward, the Government should set out a programme to bring forward additional tidal projects, so that the supply chain in particular has a clear understanding of the opportunities and contracts.

To deliver this vision, **I recommend that the Government should establish a Tidal Power Authority, with a remit to include the elements set out in the following box.**

The Authority would be established at arms-length from Government with a clear purpose and the resources necessary to deliver results. I recommend that the goal of the Authority should be to maximise UK advantage from this programme.

The Tidal Power Authority

The objective of the Tidal Power Authority is to make tidal power a success for the UK by delivering a programme of tidal lagoons.

In working towards its objective, the Authority should be accountable for:

- Ensuring value for money in the context of the UK's energy mix and industrial strategy.
- Maximising UK advantage from a tidal lagoon programme.

To deliver its objective the Authority should:

- Undertake early project development work, identifying appropriate sites for tidal power development, conducting environmental assessments which developers can use to inform planning applications, entering into negotiation with the Crown Estate and land owners and initiating engagement with local authorities and communities.
- Design an optimal tidal lagoon programme, reflecting other energy development and taking account of cumulative impacts (for example on the environment and navigation), to avoid negative consequences for other users and for environmental reasons. The programme shall be reviewed on an ongoing basis and revised if necessary in light of new evidence. The programme and any significant revisions shall be agreed with the Government.
- Deliver sequential competitions by tender. Before a decision is taken to proceed with each tender round, the Authority should submit a report to Government on supply chain developments. **If projects in previous tender rounds have not delivered a level of UK content that is acceptable to Ministers, the Government may wish to postpone or cancel the next tender round.**

In addition it will:

- Develop and support expertise
  - Foster the new industry, for example by helping to develop a caissons industry, and by exploring with the Welsh Government and local authorities how they might support the industry.
  - Drive cost reductions through a centre of excellence on tidal power and through collaborative work across the private and public sectors, potentially specifying industry standards (for example on a common turbine design).
- Give advice to Government
  - Advise Government on the design of efficient contractual structures for support to tidal lagoons within policy constraints set by Ministers.

- Advise Government on the development of a National Policy Statement covering tidal range technology.
    - Advise on decommissioning plans.
    - Work with the National Infrastructure Commission to ensure tidal power plays a full part of national infrastructure planning.
- Once the Authority is established and has made progress against its objective, it will also:
    - Promote the UK's tidal power industry
    - Promote UK capabilities abroad, collaborating with the FCO, the Department for International Trade, and other public bodies as well as with developers.

The Authority must:

- Report annually to its sponsoring Department on progress towards its objective.
- Provide evidence and recommendations in support of quinquennial Government reviews of the benefits of the lagoon programme.
- The Authority must submit 5-yearly strategic plans to the Department for approval.

I am not aware of a direct comparator for such an organisation, although it bears some similarities to the Olympic Delivery Authority, and to other organisations.

Unlike the ODA, **I am not proposing that the new Authority should have planning or consenting powers, nor should it take powers away from local authorities. A positive, symbiotic relationship with local authorities is essential.** It should however be given the necessary powers to bring together a range of skills and expertise to give a tidal lagoon programme impetus and direction.

The Authority should be responsible for deciding (after appropriate consultation) which locations should be offered for tender at which time, ensuring that this tendering process is managed so that any negative cumulative impacts (either environmental or commercial) from a series of lagoons can be avoided. This would need to tie in closely with the NPS process.

One of the current barriers to a competitive approach is that so much work has to be done in advance on environmental issues, construction costs and challenges, in order to be in a position to bid in a Government tender process, that few companies can afford to put at risk the millions of pounds this can involve. In offshore wind projects, where globally significant companies are present, such costs have been accommodated to date, but even such large companies are understandably very nervous about committing tens of millions of pounds if the process is competitive. It has therefore been argued that, if the Government wishes to see tidal lagoons developed and it wants to do this in a competitive way to bring down costs, then Government should itself undertake some of this essential work. I see substantial merit in this.

I recommend that the Authority should undertake some of the environmental assessment work for potential sites, or incentivise the Crown Estate to do this on a commercial basis, and seek to recover these costs at financial close within the strike price. The results of these environmental assessments should be made available to those bidding in the tender process, rather than requiring each developer to do this work themselves and individually. As well as benefiting developers, this could support robust and timely decision-making in the planning process. For example, if the Authority made a preliminary assessment of whether derogations from the Water Framework Directive would be justified for tidal lagoons at each of the potential sites it identifies, it could ensure a consistent high standard of assessment and streamline the process.

The Tidal Power Authority should also drive the process for securing cost reductions from tidal technology. This should follow the example of the Offshore Wind Cost Reduction Taskforce, led by industry, and providing the forum which brings together developers and policy makers.

In recent years, these fora (for nuclear, offshore wind and CCS) have been Minister-led and run by Government departments, but I consider that the Authority could achieve more progress, more quickly if run at arms-length from Government, albeit with the closest ties. This is not to say that it could not be done within Government, but I see merits in a dedicated body to perform these tasks.

The Authority should set up a Centre of Excellence to give tangible support for innovation in tidal lagoon technology, perhaps in partnership with the Offshore Renewable Energy Catapult[48], with the aim of developing skills in this sector that can be used in other tidal lagoon developments overseas.

The Authority should be responsible for deciding where common criteria are necessary, for example in considering whether it should specify a common turbine design for tidal lagoons, bringing together the expertise and experience of major turbine manufacturers such as Andritz Hydro, GE Renewable Energy, Voith and Toshiba.

The limited nature of the supply chain in this field means that it could be an area where industry cooperation is every bit as important as industry competition, as being the best way to move technology forward and achieve

[48] https://ore.catapult.org.uk/our-knowledge-areas/wave-tidal/

cost reductions. The larger projects would in any case need more than one of the turbine manufacturers to produce turbines for it, so there is sense in having cooperation from the outset. A consortium approach to the supply of turbines is used for some large hydroelectric projects and has involved the above manufacturers. Using more than one turbine manufacturer may cause site logistic and project build schedule issues. However, I do not believe these are insurmountable as the experiences from large hydroelectric projects have demonstrated.

The Authority should also work to foster the UK supply chain. I would urge Government to publicly set out its ambition for the level of UK content that the TPA will seek to deliver. I would recommend that, as with offshore wind, this should certainly be more than 50%.

I recommend that the Authority reports to Government regularly on progress towards its goals. **If projects in early rounds of the programme do not deliver sufficient UK content, the Government may wish not to continue with further rounds.**

The Government may, following consultation, take steps to wind up the Authority if it has reason to believe the objective has been achieved, as far as possible, or if it cannot be achieved.

I believe it is important that the Authority should be freed from some of the constraints imposed by the Civil Service, particularly around remuneration, so that it can compete for and retain specialist skills in what, to begin with, may be a small and dynamic sector. This will be necessary to make tidal power a true success for the UK. This will also enable the organisation to attract the type of leading business figure whom I recommend should be its head. A successful business figure as the head of the Authority will give reassurance that the body would be fully delivery-focused.

The choice of location for such an organisation would send a significant signal. Whilst many of the tidal lagoon opportunities are in Wales, this recommendation is intended to develop a UK-wide programme

As I have explained elsewhere this Review has focused on power from tidal lagoons. **However I invite Government to consider including tidal stream and small scale tidal barrage projects within the Authority's remit.**

11.4. Government Structures

The Government will require a period of time to assess these recommendations and to reflect them in their view of the proposals from TLP and their value for money. This work should take account of my conclusion on the very strong case for a pathfinder project and conclusion that cost-

competitive larger-lagoons will follow. A Negotiating Strategy will be necessary alongside this, and will form the foundation of any counter-proposal Government might make. This work will need to be undertaken by a lead official with an explicit mandate to deliver on a cross-departmental basis, supported by an enhanced transaction team.

Such is the significance and complexity of the strategic and fiscal considerations in implementing this policy beyond the pathfinder project that I recommend the appointment of a single senior official with sole responsibility for developing the financing structures that will form the basis of the Authority's first competition exercise.

From this basis the Authority should develop the CFD terms for each round of competition, amending them as necessary in each case to ensure the best value for consumers. Government should be consulted at all stages of the development of the detailed contract terms by the Authority, and the Secretary of State should be required to sign them off before the award of a contract.

The individual should have a strong commercial and Government policy background with reporting lines into both HMT and BEIS ministers. Proper time should be taken to bring departmental perspectives together.

The creation of the Authority, the day-to-day Government interface with the Authority and the development of the supporting policy framework might also fall to this individual.

In order to ensure that the Authority fully understands these contracts for the purposes of running competitions, **I recommend that the Authority seconds staff into the team led by the single senior official. I further recommend that the Government seconds policy staff into the Authority for the duration of the competition.**

12. Financing Structures

Summary

Review approach

Financing structures are forms of financial support and risk transfer that may be provided by Government to facilitate the construction and operation of projects.

I have assessed a range of potential financing structures for tidal lagoons. An optimal financing structure will:

- achieve an appropriate allocation of risks between the private sector and Government;
- minimise subsidy support costs whilst offering a viable investment opportunity; and
- incentivise efficient construction and operation

Pathfinder project

A CFD model is the most appropriate form of support for a pathfinder project. A term of no more than 60 years for a CFD appears to strike the right balance between risks and affordability. Risks of a longer term CFD include:

- Design lives of turbines and seawalls (c.60 years based on TLP data) may not be extended, resulting in termination of a project before the end of a CFD; and
- Estimates of subsidy costs are based upon inflation and power price assumptions, which are uncertain, particularly so in the very long term.

There is a general agreement that a decrease in a CFD term from 90 to 60 years would only modestly increase Strike Price requirements.

Large scale projects

A CFD model proposed for a pathfinder project appears to be replicable and scalable.

A Regulatory model may facilitate a lower cost of financing for projects that improves the value proposition for Government. However, there are many challenges in relation to its design, implementation and interaction with the electricity market.

My proposal to provide a period of separation between a pathfinder and subsequent projects provides time for Government to assess this option in greater depth.

12.1. A range of possible structures for financing tidal lagoons

The task for the Review is to assess a range of possible financing structures for tidal lagoons. In this context, "financing structures" refer to models of financial support and risk transfer that may be provided by Government to facilitate the construction and operation of projects.

The assessment that follows describes an illustrative range of financing structures and outlines potential benefits and issues, based on evidence provided to the Review by stakeholders. It is not in the scope of the Review to provide a view on the exact financial provisions that may be appropriate for particular models, but rather to comment and make recommendations in more general terms.

A complicating factor is that financing structures may require significant, additional forms of risk sharing by Government to be able to deliver projects with lower subsidy costs. Large scale lagoons may require different and possibly more extensive risk protections than a pathfinder project.

Considerations for tidal lagoon projects

An optimal financing structure for tidal lagoons will be attuned to the characteristics of projects, including the potential for very long operating lives, and will:

- achieve an appropriate allocation of risks between the private sector and Government[49];
- minimise subsidy support costs whilst offering a viable investment opportunity; and
- incentivise efficient construction and operation

12.2. Illustrative options for financing structures

The table below sets out a range of financing structures for tidal lagoons.

[49] Ensuring that risks are priced efficiently.

Option	Financing structure (A)	Illustrative description	Illustrative Government support (A)	Precedents
1	CFD model	Private sector finances and delivers project, supported by a Contract for Difference (CFD) allocated by Government. The term of a CFD would be for a part of the project's forecast operating life. Assuming a potential operating life of 120 years, a "Short CFD" may be around 35 years and a "Long CFD" may be around 90 years.	Government allocates a CFD to the project, established as a private law contract between the project and a government-owned company. CFD fixes the price received by the project for electricity generated during the contract term. CFD payments to the project may be funded via levies on electricity bills.	Government CFDs allocated to low carbon projects as part of Electricity Market Reform. (B)
2	Regulatory model	Private sector finances and delivers project, supported by a regulatory framework that determines revenues for the project. Framework may draw upon principles established for Regulatory Asset Base (RAB) models (C) and lessons learned from these projects.	Government appoints an independent Regulator. Regulator grants a licence to a private company to finance, construct and operate the project. Regulator has a duty to set revenues for the project at a level it assesses to provide a fair return on invested capital and to cover efficient operating costs (periodically reviewing this assessment). Revenues funded by levies on electricity bills or some other mechanism. Interface between regulated project and the electricity market (including electricity sales) to be considered.	RAB models in place for regulated UK utilities including electricity and gas distribution, water, rail and airports. Bespoke regulatory framework and additional Government protection agreed for Thames Tideway Tunnel.

(A) Each model can be designed in a variety of manners and combinations of models could be used for construction and operating stages of projects. Each model may require additional forms of Government support for risk sharing. These additional forms of support are not considered in this analysis.
(B) Government's publications on CFDs can be accessed at https://www.gov.uk/government/collections/electricity-market-reform-contracts-for-difference#the-CFD-contract.
(C) The term "RAB" refers to the Regulator's calculation of a "Regulated Asset Base" – the depreciated capital cost of the project – which is a key building block in its calculation of the revenues that a project is permitted to receive.

Option	Financing structure (A)	Illustrative description	Illustrative Government support (A)	Precedents
3	Concession model	Government owns project. Private sector finances and delivers via a concession agreement with Government. Concession may provide for private sector to operate the project for an initial period of time, perhaps supported by a CFD for this period. At the end of the concession, control of the project returns to Government. Government may explore options for the private sector to manage operations for the remainder of the project's operating life.	Government acquires project (D). Government allocates a CFD to a private company to finance, construct and operate. Duration of CFD matches term of concession. Following concession, Government may transition the project to another type of financing structure.	High Speed 1 concession agreement
4	Procurement model	Government owns project and provides all finance required to construct. Once project is operational, Government may sell the project to the private sector or transition the project to another type of financing structure.	Government acquires project (D). Government finances construction and operation whilst project is in its ownership. Private sector manages construction and operation via services agreements with Government.	Crossrail 1 procurement

(D) Government may own the project by acquiring it from a developer.

Table 12: A range of possible financing structures for tidal lagoons
Source: Hendry Review analysis

12.3. CFD model

The CFD model is a well-established support mechanism that has successfully facilitated the deployment of low carbon projects in the UK. In respect of tidal lagoons, Government has entered into a bilateral negotiation with a developer, Tidal Lagoon Plc, for potential CFD support for its Swansea Bay project.

A key benefit of a CFD model as compared to other financing structures is that it can be established quickly, offering the opportunity to build upon momentum gained to date in development of tidal lagoons.

A significant challenge for developers and Government is to ensure that forecast costs of projects are appropriate. There is an inevitable tension between driving down costs to reduce Strike Price requirements and in ensuring that projects are deliverable.

The appropriate term for a CFD is an important consideration. The term of the contract drives both the Strike Price requirement and the extent of some of the risks that Government may undertake.

Historically, Government has allocated CFDs with terms that comprise significant portions of the forecast operating lives of projects, typically around two-thirds for renewable energy projects[50].

A tidal lagoon has the potential for a very long operating life, perhaps 120 years if the design lives of turbines and structures are extended. On this basis, CFD terms for a tidal lagoon may range from a “Short CFD” of around 35 years to a “Long CFD” of around 90 years.

In CFD contracts that have been allocated by Government to date, Strike Prices are fully linked to the Consumer Price Index, a measure of inflation. The impact of full indexation is that Strike Prices remain constant in “real”[51] terms during the term of CFDs.

For tidal lagoons, a Strike Price in a Long CFD may be partially indexed. The impact of partial indexation is to reduce the “real” value of a Strike Price over time by having only partial protection to future levels of rising inflation.

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[50] For example, 15 year CFD terms for Offshore Wind and other renewable energy projects that may have operating lives of 20-30 years and a 35 year term for nuclear project Hinkley Point C on the basis of a 60 year operating life.

[51] Real values are adjusted for the effect of inflation.

The chart below illustrates this impact. In this example, the "real" value of a Starting Strike Price of £120 per MWh at 31 December 2015 reduces to c.£100 per MWh at the end of 2025 and c.£85 per MWh at the end of 2035, on the basis of annual inflation of 2.5% and partial indexation (a link to inflation) of 25%.

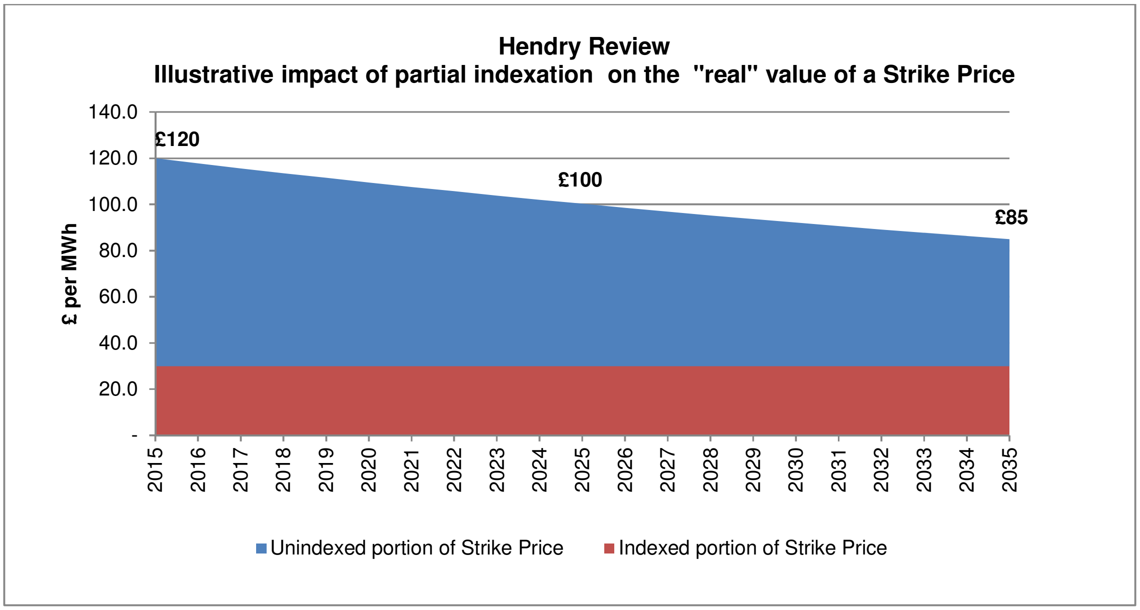

Figure 6
Source: Hendry Review analysis

A consequence of this trajectory is that the value of the Strike Price may fall below the value of electricity market prices in "real" terms. For example, on the basis set out above and assuming an electricity price of £50 per MWh, the "real" value of the Strike Price would fall below the electricity price in 2077 (63 years from the date of the Starting Strike Price).

For tidal lagoons, the purpose of a Long CFD with partial indexation of a Strike Price would be to facilitate an efficient capital structure for projects that reduces overall subsidy costs by certain measures, for example the Net Present Value of CFD payments. The structure could provide an adequate return to equity investors in earlier periods and over-time costs to consumers would fall.

In considering these terms, Government would need to strike a balance between the potential "affordability" of a Long CFD with partial indexation and the risks that may relate to this approach. These risks include:

- **Operating life risk:** The "value for money" case of a Long CFD with partial indexation is predicated upon a decrease in the "real" value of the Strike Price during the contract term. If a project were to stop operating before the end of the contract term, Government would effectively have paid more than it had anticipated for each MWh of electricity generated. For tidal lagoons to operate in excess of around 60 years[52], projects require the design lives of key components to be extended, including turbines and seawalls. Whilst there are clear drivers for project sponsors to extend design lives, there is a risk that sponsors may not do so.

- **Indexation risk:** The impact of partial indexation on the "real" value of a Strike Price depends upon the level of inflation that is assumed, with subsidy payments decreasing in "real" terms if inflation is higher than forecast and increasing in "real" terms if inflation is lower than forecast. I recommend that Government undertakes sensitivity analysis of different levels of inflation as a part of its value for money assessment of projects. In my view, a proposal for partial indexation of a Strike Price should be structured such that a fixed Strike Price is considered for the First Operating Year (and subject to partial indexation thereafter). A proposal based on a Strike Price with a base date for indexation prior to the First Operating Year of the project introduces unnecessary risks for Government relating to forecasts of CFD payments[53].
- **Power price risk:** Measures of subsidy costs, including the Net Present Value of CFD payments, utilise power price assumptions. Long term power prices are very uncertain and I recommend that Government undertakes sensitivity analysis of different power price scenarios when considering these measures. Tidal lagoons are particularly sensitive to long term power price assumptions due to the potential for projects to have very long operating lives.

12.4. Regulatory model

A Regulatory model may be able to be designed to create a low risk environment for tidal lagoons that facilitates low cost financing of projects. Such projects are very sensitive to financing costs and the very high funding requirements of large scale lagoons amplify the importance of this issue.

As with other financing structures, financing costs would depend in part on Government's appetite to offer risk protections. For example, the very low cost of financing secured for Thames Tideway Tunnel is contingent on a Government

[52] This assumption is based on evidence provided by TLP. Other stakeholders have indicated that the initial design life of tidal lagoons could be shorter, perhaps 50 years.

[53] For example, in the chart presented above, if the First Operating Year for the project were to be 2025, the value of the Strike Price in this period (£100 per MWh) would be the key reference point for stakeholders because it relates to the first period of CFD payments. A proposal for this value to be contingent upon a Starting Strike Price in 2015 and actual inflation from this date to the First Operating Year introduces unnecessary value risks for Government.

Support Package that provides support for exceptional events and for unforeseen issues relating to debt finance.

During the Review, stakeholders have noted that a Regulatory model appears well suited for tidal lagoons due to their potential for very long operating lives. Periodic reviews of remuneration could help to ensure that projects are not over subsidised.

A Regulatory model would also mitigate the risk inherent in a CFD model of overpaying for construction contingencies that are not subsequently required (as in a Regulatory model revenues would be based on actual rather than forecast capital expenditure).

Furthermore, a Regulatory model could offer a return on investments during construction, potentially “crowding in” low cost sources of finance that may not otherwise participate at this stage. The regulatory framework for Thames Tideway Tunnel, for example, provides for a return for investors during a lengthy construction period in order to facilitate a more efficient financing of the project.

Applying this type of approach (which may not necessarily require regulation) could enable earlier access to low cost, long-dated capital from pension funds and other institutional investors, improving the value proposition of projects for Government.

A Regulatory model could also be conducive to the introduction of new ownership models, such as the model that is in place for Welsh Water, whereby financial surpluses are reinvested in the company rather than distributed to shareholders (please refer to the my assessment of the role for tidal lagoons in the energy mix in Chapter 7 for details of this approach).

However, there are many difficult challenges for the introduction of a Regulatory model for tidal lagoons.

Design challenges

A Regulatory model would need to provide transparent and predictable regulation. Investors may struggle to gain comfort on how a Regulator would calculate future revenues for tidal lagoons in a RAB model.

For Thames Tideway Tunnel, the project’s Regulator, Ofwat, has not set out calculation methodologies for revenues during operations. Investors were able to gain comfort by looking at precedents for similar companies that are regulated.

Tidal lagoons appear to lack clear precedents that could provide comfort to investors.

Implementation challenges

Regulation would require an independent Regulator. It is unclear which public body may be most appropriate to act in this role. Establishing regulation would incur significant costs and require a significant period of time and new legislation.

Market challenges

Regulatory models are best suited to natural monopolies where this is no competition. Introducing a Regulatory model to the electricity sector could distort the market. This was a key reason for Government's decision not to pursue a RAB approach for Electricity Market Reform[54].

A further complication is how a Regulatory model could interact with electricity sales. For example, where would offtake risk sit and how to ensure that electricity is sold efficiently into the market (or otherwise).

12.5. Concession model

A Concession model could offer the opportunity for Government to retain long term control of projects whilst using the private sector to finance initial delivery.

A key challenge for this type of model is the affordability of the initial concession. If the concession was facilitated by a CFD, it appears likely, all things equal, that the private sector would require a significantly higher Strike Price to support their returns during the concession if control of the project (and available cashflow) returns to Government thereafter.

Government may need to take on liabilities of the project at the end of the concession, such as outstanding repayments on debt finance.

12.6. Procurement model

A Procurement model could take advantage of Government's ability to raise funds at significantly lower costs than the private sector.

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[54] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/42636/1041-electricity-market-reform-condoc.pdf

With Government as sole financier, a procurement model could allow for completion delays that may arise in a pathfinder project, which could then be refinanced or sold post completion.

Alternatively, this model could perhaps be particularly helpful to bring forward large scale projects in the absence of a pathfinder project.

However, I have discounted a Procurement model as an option for tidal lagoons because, whilst I see opportunities for Government to contribute to financing, I believe the delivery process is best led by the private sector. Furthermore, I note that a procurement model would represent a very significant departure from Government's current energy policy for low carbon projects.

12.7. Various pathways for tidal lagoons

The Review has identified various pathways to facilitate the deployment of tidal lagoons. These pathways are based on the above characterisations of financing structure models and on the following assumptions:

- Timeline
  - Pathfinder project operational from early / mid 2020s
  - Large scale project operational from mid / late 2020s

- Financing structure
  - Economic regulation would take a significant period of time to establish
  - Procurement has been discounted as an option

Based on these assumptions, the table below illustrates potential pathways for tidal lagoons:

Pathways	Pathfinder project (mid 2020s)		Large scale projects (mid to late 2020s)	
	Financing structure	**Potential reason for Government support**	**Financing structure**	**Potential reason for Government support**
A	Short CFD or Concession	Short CFD or Concession is affordable Long CFD risks are too great	Short CFD or Concession or Regulatory	Short CFD or Concession is affordable for large scale projects Regulation could be introduced Long CFD risks are too great (as for pathfinder)
B	Long CFD	Short CFD is unaffordable Concession requires development Long CFD risks are acceptable	Long CFD or Regulatory or Concession	Long CFD risks are acceptable for large scale projects Regulation could be introduced Concession could be introduced Short CFD is unaffordable (as for pathfinder)
C	"Light Regulation"	Light regulation could perhaps be effected by a contractual model (eg a modified CFD) This model may involve an independent arbiter that undertakes some of the roles of a Regulator	"Full Regulation"	Economic regulation could be introduced

Table 13: Potential pathways for tidal lagoons
Source: Hendry Review analysis

12.8. Conclusions

Pathfinder project

Whilst I have seen attractions in a regulatory model, I am persuaded that a CFD model is the most appropriate form of support for a pathfinder project.

Transitioning to an alternative financing structure at this stage would have the added disadvantage of introducing delays and uncertainty, at a time when I believe we should move forward quickly. I have not seen sufficient advantages of an alternative funding approach which would justify such delays and uncertainty.

A term of no more than 60 years for a CFD appears to strike the right balance between the risks I have discussed (in particular operating life risk) and affordability for investors and for Government. I consider that a longer term would increase Government's exposure to these risks whilst offering relatively small savings in subsidy costs.

90 years ago in 1926, no-one could have seen the Wall Street Crash, a second world war, the rise and fall of communism as a global force, or the pace of technological change. There is no reason to believe that the next 90 years will be more predictable.

The balance of risks and subsidy costs should be considered by Government in its value for money assessment of the appropriate terms of CFD support for a pathfinder project.

Large scale projects

I have received evidence during the course of the Review to support both a CFD model and a Regulatory model for large scale lagoons. A particular complication is to assess the full range of risks that any model may allocate between Government and the private sector.

Inevitably, in the short time available to the Review, I have collected a snapshot of opinions.

I have received evidence that a form of CFD proposed for a pathfinder project is replicable and scalable for large scale lagoons. I recognise that there are very significant challenges for the introduction of a Regulatory model, in spite of the attractions it could otherwise offer.

My proposal to provide a period of separation between a pathfinder and subsequent projects and to then approve future lagoons through a competitive tendering process, provides time and opportunity for Government to assess this option in more depth.

Such a change of approach would in any case require Government to undertake a formal consultation process and I recommend that time is taken to consider these very important issues in greater detail.

However, as stated above for the financing of a pathfinder project, **there would need to be a more compelling rationale than I have so far seen to justify moving from the CFD approach to a regulatory model for the wider programme.**

12.9. Sources of finance

It has been suggested that the Government might make a grant payment to bring down the costs of a pathfinder project. Whilst there may be merit in such a grant to help facilitate more efficient financing of a pathfinder and kick-start an industry, I consider that public funding can be better used instead to support the supply chain, if taken together with my wider recommendations to create supply chain confidence.

To ensure that UK companies/UK-based manufacturing is best placed to compete for the contracts for the lagoons, significant investment will be needed in new plant. This includes steel rolling to provide steel at the prices it could otherwise be imported from Eastern Europe; turbine manufacture; and indeed the development of a caisson facility which would give the UK a very strong lead in such technologies.

I would therefore recommend that the Government should use any grant funding available to this sector to support investment in these new and improved manufacturing facilities, for example in steel and turbine manufacturing technologies and facilities. This would not only help ensure that the jobs would indeed come to the UK, but would also help to reduce the costs of a lagoon programme. Initiatives such as the Growth Deal or City Deals could be viable avenues to achieve this. The Growth Deal supports industries across the countries which could benefit from the opportunities which a lagoon programme could present, making it an ideal vehicle for channelling the grant money to projects that support the manufacturing supply chain for lagoons.

It has been suggested to the Review that the UK Government could consider making a direct investment in the pathfinder project alongside private sector partners. This source of finance could potentially enable funding costs to be brought down, improve the attractiveness of the proposal to UK consumers and help to secure valuable benefits for the Welsh and UK economy. It would provide a huge confidence boost to the new sector. This would be an unusual step for the government to take but given the nature of a pathfinder project it might be viewed as an exception that did not create a precedent. This would be a departure from past practice, and would be a matter for wider consideration within Government. It could certainly assist with the development of a pathfinder and were this to be considered a detailed piece of work would be required to consider the full issues and to identify the optimal way forward. I note that there would be direct implications for the government's balance sheet until the pathfinder was operational, whereupon the government could sell its stake.

13. Decommissioning

Key findings

- Tidal lagoon seawalls should be treated as permanent structures for the purposes of decommissioning plans, and their maintenance should be paid for in perpetuity by funds established by their operators.

All significant infrastructure projects must be developed with consideration of what should happen at the end of their operational lives.

Following consultation, the Government decided in 2015[55] to extend the regime for the decommissioning of offshore renewable energy installations [56] to include nationally significant tidal lagoons.

Some central elements of this decommissioning regime are:

- The legislation gives the Secretary of State the power to impose an obligation on a person to submit a costed decommissioning programme before a renewable energy installation (or part of it) or a related electric line has been installed.
- If the programme is judged to be inadequate and is rejected, the Secretary of State has the power to prepare a suitable decommissioning programme and recover the costs from the responsible person.
- The Secretary of State has a duty to review approved decommissioning programmes from time to time.

A particular issue for tidal lagoons, which will be massive structures, is how much work must be done at the end of their operational life to render them acceptably decommissioned. On this issue, Government guidance[57] states that:

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[55] https://www.gov.uk/government/consultations/tidal-lagoons-attached-to-land.

[56] As set out in the Energy Act 2004, amended by sections 69-71 of the Energy Act 2008.

[57] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/47997/file35754.pdf. The guidance takes account of the UK's commitments under the United Nations Convention on the Laws of the Sea, the International Maritime Organization standards, and takes note of the OSPAR Convention for the Protection of the Marine Environment of the North-East Atlantic.

> “[W]e believe it is generally accepted that the ‘ideal’ decommissioning programme involves removing the whole of all disused installations and structures.”

On this basis, the Government’s approach has been that there should be a presumption in favour of the complete removal of disused installations in the decommissioning of offshore renewables installations. Nevertheless, it is recognised that there is room for exceptions in a number of cases, such as where the structure will serve a new use, where entire removal would involve extreme cost, or where entire removal would involve unacceptable risks.

If developers are required to fully decommission the tidal lagoon and remove the seawall, the costs would be so prohibitive as to render the projects uninvestable and therefore undeliverable. While I note that there are uncertainties about the environmental impacts of tidal lagoons, a number of respondents to the Review were of the opinion that requiring the full removal of the seawall in 120 years could also be more damaging to the marine environment than leaving it in place, as marine ecosystems would have developed around the seawall over its years of operation. I therefore believe it is better to leave the wall in place, but to remove the turbines and other operating parts, and possibly remove some Sections of the wall if necessary for environmental, navigational or other purposes. Operators will need to make provision to pay for this work as part of their decommissioning programme. **I recommend that the Government should accept that once built, the seawall of a tidal lagoon should be considered to be permanent for the purposes of decommissioning plans.**

However, even in doing this, there remains the question of who should have the legal liability for ensuring that the wall does not become a hazard as it subsequently decays over time when no longer in use. Government guidance makes clear that the persons who own an offshore renewables installation at the time of its decommissioning will normally remain the owners of any residues; and, as the tidal lagoons would be private sector initiatives, I do not consider that it is reasonable for the Government (or the Crown Estate) to be expected to take on this liability in the next century.

Nevertheless, the operators cannot be expected in all cases to do so, as there is no guarantee that they will still be in existence in 120 years’ time. The relevant local authority could do so – and would perhaps be best placed to do so, given its responsibility for the interests of the local community – but there is no guarantee that they would be willing to take on these liabilities in perpetuity, and I do not believe it would be appropriate to impose such a responsibility upon them.

The TPA should have a role in advising Government on decommissioning plans. But I recommend that, towards the end of the operating lives of the first tidal lagoons, a decommissioning body should be established to ensure there

is ongoing maintenance and repair for tidal lagoons after the end of their operational lives. This should include local authority representation from each area affected by the ongoing impact of a decommissioned tidal lagoon. Should the relevant local authorities all wish to take on the responsibility for maintaining the tidal lagoon after its operational life, then the Government should be willing to consider this, perhaps under the auspices of a community interest company.

Whichever body takes on a decommissioned tidal lagoon structure, it is clear that they would require funding to be available for such responsibilities. **I therefore recommend that the operators of tidal lagoons should be required by law to contribute to a fund over the operating life of the tidal lagoon, starting modestly at an appropriate time after it begins operating. This fund will provide the necessary resources for long-term maintenance once the operational life of the tidal lagoon is over** (similar to that required for nuclear facilities). It has been suggested to us that operators should begin to contribute from 30 years after tidal lagoons start operating. I believe this strikes the right balance, not taking too much from the revenues of the projects too early, and ensuring that, in the remote circumstances that early decommissioning is required, some financial contribution should be made by the operator.

Once the fund has reached a level agreed by Government (national and local), there should be no need to contribute to it further, although there should be periodic reviews (every five years) to ensure that the fund is adequate for future needs. The fund would not need to be sufficient to undertake the full removal of the tidal lagoon structure, but to ensure that it can be kept in a safe manner, to protect the on-going interests of the sea ecology and other legitimate users of the waters.

14. Summary of conclusions and recommendations

Report heading	Conclusions and recommendations	Section	Page No
Introduction	*Recommendation* I recommend that the Department for Business, Energy and Industrial Strategy considers publishing as much of the material received as possible, as a valuable resource for a range of interested parties.	1	Page 5
Security of supply	*Conclusion* I am persuaded that power from tidal lagoons could make a strong contribution to UK energy security, as an indigenous and completely predictable form of supply. Even though it offers limited dispatchability, National Grid expressed no particular concern that this would pose problems they could not readily manage.	3.2	Page 24
	Conclusion A programme of tidal lagoons that could deliver the goal of providing constant, or as near as possible to constant, power would be an absolutely huge undertaking, requiring tidal lagoons around much of the country. It is my belief that this is too ambitious a goal to be set at this time, before even one has been built, and could only be considered properly when more progress has been made on building a number of tidal lagoons.	3.2	Page 25
	Recommendation I would strongly caution against ruling out tidal lagoons because of the hopes of other cheaper alternatives being available in the future. There may be technological innovations forthcoming which could eventually make tidal lagoons redundant, but policy has to be made with the information we have now on the benefits and drawbacks they have, not in hindsight.	3.2	Pages 25-26

Report heading	Conclusions and recommendations	Section	Page No
Decarbonisation targets	*Conclusion* If lagoons can be constructed and operated with such low levels of lifetime emissions [i.e. c.14gCO2e/kWh], then it is clear that they would contribute positively to progress towards the UK's decarbonisation goals.	3.3	Page 28
Impacts on the environment and other uses of the waters	*Recommendation* Should lagoons be built, the Government should require a high level of on-going monitoring of environmental impacts to ensure that mitigation can be put in place where impacts are judged to require it.	3.4	Page 30
	Conclusion I do not consider it acceptable that the business interests of established commercial organisations should be unreasonably impacted by the creation of lagoons in the Severn Estuary.	3.4	Page 32
	Recommendation I recommend that developers should be required to demonstrate, as part of the planning and consenting process, that they have taken full account of potential deposition rates.	3.4	Page 32
Hybrid Infrastructure	*Recommendation* Where a tidal lagoon is being used to help contain or prevent flooding, it would inevitably mean that it would not be deriving income from generating power at those times and the developers of the tidal lagoon would reasonably expect to be compensated for this loss of income. Government should carefully consider whether this compensation should come from energy bills.	3.5.1	Page 35
	Conclusion The weight of the expert evidence I have received supports the scale of seawall being proposed for TLSB, and I have not seen engineering-based evidence to persuade me it could be significantly reduced.	3.5.2	Page 36

Report heading	Conclusions and recommendations	Section	Page No
	Conclusion I think it is beyond question that, in the case of Swansea Bay, local economic regeneration would follow a tidal lagoon.	3.5.2	Page 36
	Recommendation My recommendation is therefore that the Tidal Lagoon Swansea Bay should be considered as an electricity project to all intents and purposes, but one which would incidentally bring very real and substantial economic and recreational benefits to the Swansea Bay area. This distinction is important as it relates to how the project should be paid for. My recommendation is therefore that Tidal Lagoon Swansea Bay should be considered an electricity project rather than a hybrid project with multiple sources of funding support.	3.5.2	Page 37
	Conclusion My conclusion therefore is that lagoons would certainly bring wider benefits beyond those of power generation, but these are very site specific, are hard to quantify and are unlikely to make a significant contribution to capex. I consider in the Chapter on competition how some of these benefits might be taken into account.	3.5.2	Page 37
Benefits to supply chain companies and other sectors	*Conclusion* Many companies have described the potential tidal lagoon programme as a 'lifeline'. Given the challenges facing the UK steel industry, this is probably no understatement, so this is not just about the 'jobs created' but about the 'jobs saved for the long-term' as well.	4.4	Page 47
Other benefits	*Recommendation* I recommend that much more detailed work should be done to assess possible tourism impacts, in conjunction with local FE colleges, to plan ahead with the necessary skills training that significant visitor numbers could require, and to ensure that the design of the visitor attractions reflect the potential of this economic uplift.	4.5	Page 52

Report heading	Conclusions and recommendations	Section	Page No
Innovation and Cost Reduction in Tidal Range technologies	*Conclusion* I am in no doubt that there are promising innovations and technological advancements that could be made as part of a tidal lagoon programme, and that could help drive down costs. The new public body UK Research and Innovation and the Energy Innovation Board could play useful roles in this regard.	4.6	Page 53
Caissons	*Conclusion* Should a programme of tidal lagoons go ahead, I see very significant benefits in principle in the development of a caissons capability in the UK. This would give UK manufacturing a very significant advantage over foreign competition. Potential locations would be in Wales, the North-West of England and the West Coast of Scotland, spreading the economic benefits to many different parts of the country.	4.7	Page 54
Supply chain conclusions	*Conclusion* I have been encouraged that the current financial backers strongly sign up to TLP's ambition of developing a supply chain in the UK. This should reduce those pressures to go for potentially cheaper products from abroad, but it does remain a risk. More significantly, the full opportunities for a UK supply chain will only be realised if there is long-term clarity about the number, scale and timing of lagoons to be built in the UK.	4.8	Page 55
	Conclusion Overall, a tidal lagoon programme offers a significant economic opportunity for Wales and the UK more generally. There are few other energy sectors where the UK can realistically aspire to have such a significant supply chain, where the skills already exist for a 'pathfinder' project or where there is such commitment to large scale manufacturing in the UK from the world's largest firms in this sector.	4.8	Page 56

Report heading	Conclusions and recommendations	Section	Page No
	Conclusion Marine energy technologies offer an energy opportunity where the UK can reasonably aspire to be the global leader, with some substantial supply chain opportunities to match it. If the UK is to commit to a new source of power generation, then 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. To help achieve maximum UK advantage, the Government should make it clear that its support for tidal lagoons is, in part, based on the supply chain opportunities and the wider industrial and economic benefits such a programme would bring. If the UK is to adopt tidal technologies, and tidal lagoons in particular, and to get the industrial benefits of such an approach, then I recommend that it needs a strategy similar to that for offshore wind, with a clear sense of purpose and mission. It needs to bring the industry together to address each challenge as it emerges and to set the industry itself the goal of making the step-changes which would determine whether this becomes a new industry or a small niche. I would urge the Government to look at these opportunities not just in tidal lagoons but for marine renewable energy more generally. Whilst wave technologies are further behind tidal technologies, the UK should be promoted as a centre of global excellence and opportunity for the development of all marine energy technologies, where appropriate giving a central focus to the work of organisations like Marine Energy Wales and Wave Energy Scotland.	4.8	Pages 56-57
Export Opportunities	*Conclusion* I am satisfied, through the academic and commercial input I have received, and given the clear evidence of suitable locations, that there is some overseas potential for tidal lagoons. It does, however, require an additional leap of faith to believe that the UK would be the main industrial beneficiary of such a global programme.	5.6	Page 62

Report heading	Conclusions and recommendations	Section	Page No
	Conclusion I conclude that there are international opportunities for tidal lagoons which could provide supply chain opportunities for the UK, but these are far from certain. There is not currently firm evidence of a commitment to develop such resources in many of the identified countries and even if they would be developed, they would probably look more locally for the supply chain elements and skills they would need.	5.6	Page 63
	Recommendation The UK tidal lagoon potential should be looked at for its own merits. The international opportunities would be 'good to have' but they are not sufficiently concrete that they can be relied upon.	5.6	Page 63
	Recommendation To capitalise most effectively on the supply chain opportunities for the UK, I would recommend that the Department for International Trade hosts a summit in the UK bringing together countries from around the world with tidal lagoon opportunities to showcase the skills and expertise the UK has to offer.	5.6	Page 63
Generation Costs and the potential for cost reduction	*Conclusion* I conclude that high-level modelling indicates that large scale tidal lagoons would decrease generation costs relative to a pathfinder project due to high tidal ranges and favourable designs. Moreover, this reduction would still apply even in a scenario where cumulative impacts on energy yields are significant. This trend would be further accentuated when reductions in project costs and financing costs are taken into account.	6.1	Pages 68-68

Report heading	Conclusions and recommendations	Section	Page No
	Conclusion I have concluded that there is scope for project costs to reduce following a pathfinder project, probably at least by 8-10% of capex and potentially by significantly more. The extent of these reductions will in part depend on Government's willingness to create the right framework for securing the greatest cost reductions, as proposed in Part Two of the Review. In particular, effective competition between developers to progress projects will put downwards pressure on project costs and help to ensure that consumers will benefit from cost reductions as a result of a pathfinder, innovation, a strong supply chain and efficient financing.	6.2	Pages 69
	Conclusion There is potential for large scale tidal lagoons to <u>significantly</u> decrease generation costs relative to a pathfinder project, due to <u>site location and design</u>, including in a scenario where cumulative impacts on energy yields are significant. There is a moderate potential for <u>project cost</u> reductions as the industry establishes itself following a pathfinder. And there is a high potential for <u>cost of capital</u> reductions (due to the role of a pathfinder). Whilst it is inevitably very difficult to quantify this potential precisely at this stage, it should be noted that generation costs (and therefore subsidy costs) are very sensitive to improvements in these areas. However, all the methods used show the same trends of reducing costs for projects built at scale. Effective competition is essential to efficiently drive cost reductions.	6.4	Page 73

Report heading	Conclusions and recommendations	Section	Page No
Subsidy costs and other considerations	*Conclusion* Based on current project assumptions and the financing structure proposed for Swansea Bay, I have concluded that a "CFD Equivalent" measure of subsidy costs indicates that large scale tidal lagoons have potential to be competitive with low carbon projects commissioning in the mid to late 2020s. Potential subsidy costs should be considered by Government in the round with estimates of other direct and indirect public costs and the wider social and economic benefits of projects. I conclude that the potential impact on consumer bills of large scale tidal lagoons appears attractive, particularly when compared to nuclear projects over a long time period; and that a measure of CFD cost per MWh over project lifetimes indicates that a tidal lagoon programme has potential to be very valuable and competitive. Large scale tidal lagoons, delivered with the advantages created by a pathfinder, are likely to be able to play a valuable and cost competitive role in the electricity system of the future.	7.4	Page 85
	Conclusion I do not consider that the shortfall between estimated capex levels for large scale tidal lagoons and ETI's targets illustrate that tidal lagoons cannot be cost effective. Rather, the variance indicates the importance of the role of a financing structure in driving down subsidy requirements, which are the key criteria for projects to be cost effective.	7.5	Page 86
	Recommendation I encourage Government to engage with stakeholders to further its understanding of potential system impacts for tidal lagoons in a range of deployment scenarios and time periods.	7.5	Page 87

Report heading	Conclusions and recommendations	Section	Page No
Conclusion: The Strategic Case for a Tidal Lagoon Programme	*Conclusion* My conclusion is that tidal lagoons would help deliver security of supply; they would assist in delivering our decarbonisation commitments; and they would bring real and substantial opportunities for the UK supply chain. I have also concluded that they could play a competitive role as part of the UK's energy mix alongside low carbon energy from nuclear and offshore wind. Nevertheless it must be recognised that an analysis purely on economic aspects inevitably overlooks wider benefits of a lagoon programme and that it is why it is ultimately a strategic decision, every bit as much as an economic decision.	8	Page 89
	Conclusion Moving ahead with a pathfinder lagoon is, I believe, a no-regrets policy. The Secretary of State for Business, Energy and Industrial Strategy, Greg Clark, has rightly spoken about the obligation on policy makers to plan for the longer-term. I don't believe there would be any debate in decades to come about whether this was the right thing to do, even if it ended up as the only lagoon constructed – but I would expect it is much more likely to be seen as the decision which started a new industry, and all done at the cost of a small number of pence to consumers each year. This is not therefore just about how we decarbonise the power sector in the most cost effective way now; it is also about very long-term, cheap indigenous power, the creation of an industry and the economic regeneration that it can bring in its wake. If this is the conclusion, it also follows that we should start that process as swiftly as we can. After years of debating, the evidence is I believe clear that tidal lagoons can play a cost-effective part of the UK's energy mix.	8	Page 89

Report heading	Conclusions and recommendations	Section	Page No
First of a Kind Project	*Conclusion* The challenges of securing investment for a very large project as the first tidal lagoon would be very considerable, if not insurmountable. A smaller project would help develop the supply chain and allow the skills base in the UK to grow to support a larger industry. In most respects as much can be learned from the experience of building a small project as could be learned from a very large lagoon. I therefore have concluded that a first lagoon should be relatively small in scale (i.e. less than 500 MW), as I consider this to be much more deliverable and would not significantly reduce the learning opportunities. I consider that the term "pathfinder project," rather than a "first of a kind" better reflects the value that a smaller first lagoon could bring: it will establish the technology and prepare the supply chain to reap later benefits; yet follow-on projects will be different – in particular bigger – and therefore will face challenges of a different nature.	9	Page 92
	Conclusions and recommendations During the Review I saw material relating to TLP's position as part of the 'first-stage negotiation' underway with Government for a CFD for Swansea Bay. I have not seen a formal response from Government, nor received an assessment of final terms that might be acceptable to Government negotiators. It is therefore not possible for a full Value for Money case to be made for this particular project; and regardless such a case would clearly be beyond the scope of my independent Review. I do conclude that there is a very strong case for a smaller pathfinder project as soon as is reasonably practicable and I urge the Government to capitalise on work already done rather than starting afresh. This clear commitment would deliver earlier benefits and accelerate a future programme. I recommend that the Government now move to a timely 'final-stage negotiation' to explore robust and satisfactory terms that might be acceptable to both the developer and the Government.	9	Pages 92-93

Report heading	Conclusions and recommendations	Section	Page No
	Recommendation To assure the taxpayer, the electricity consumer and the Government, it would be very beneficial for TLP to secure such a delivery partner with a corporate track record in major energy or infrastructure projects. Such a partner should be in-place for the conclusion of a final phase negotiation with the Government. Any case to conclude a negotiation should reflect my assessment of the strategic value of a pathfinder project, the considerable value of a subsequent tidal lagoon programme, and the economic value created in the UK supply chain.	9	Page 93
The relationship between the pathfinder project and a programme	*Conclusion* Even in a policy area where so much vision is required to move forward, I have concluded that we have to exercise sensible caution in moving to a programme of lagoons too quickly, in order to understand their full impact and learn the full lessons of how the programme can be improved going forward. I have concluded that it is therefore inevitable that the pathfinder project should be separated from the wider lagoon programme, and that the pathfinder should be commissioned and be operational for a reasonable period before financial close is reached on the first larger-scale project.	10	Page 95
	Recommendation To maximise the learning from this period of monitoring and research, I recommend that smaller scale lagoons (and potentially small scale barrages) continue to be developed and constructed during this pause.	10	Page 95

Report heading	Conclusions and recommendations	Section	Page No
	Recommendation It has also been proposed that data and learning from the pathfinder project should be open-sourced, to allow a whole industry to grow to the benefit of the UK. I see considerable attractions in such an approach, especially given the public funding involved, and whilst I recognise that there may be difficulties in doing this in a way the respects the intellectual property interests of the operator of the pathfinder project, I recommend that the Government investigates whether these difficulties can be overcome.	10	Page 96
Future Programme	*Conclusion* I believe it is best for Government to take a view on which configuration of lagoons offers the best outcome for the UK. But whichever configuration is selected, it is my opinion that the most will be achieved for the country if the Government allocates a specialist resource to foster the whole industry, increasing competitiveness through innovation, efficiency, and organisational stability.	11	Page 98
Competition	*Conclusion* I have identified nothing unique about tidal lagoons that precludes them from competitive CFD allocation and I recommend that there must be a move to competition as soon as this can be effective to deliver the most substantial cost reductions.	11.1	Page 98
When to move to a competitive structure	*Conclusion* On balance I have concluded that the risks involved in a competition to select the pathfinder are too significant: the Government has a realistic option of a pathfinder project and this option should be taken.	11.1.1	Page 99
	Conclusion I do not consider that these issues sufficiently outweigh the benefits to the UK consumer of delivering a real competition for the first large project. It is a genuine challenge but the issues are fixable with a clear policy and competition framework and the prize is worthwhile.	11.1.1	Page 99

Report heading	Conclusions and recommendations	Section	Page No
Approach to delivering competition	*Conclusion* I recommend that competition should … be phased with one contract agreed per competition.	11.1.2	Page 100
	Recommendation I … recommend that a 'use-it or lose-it' approach is adopted, so that prospective developers could not simply lock out other developments by winning a competition and not progressing the project. If they cannot show real progress to develop a facility within an established timescale, then the offer of support should be withdrawn. Indeed I recommend that the Government should go further, and consider securing a bid-bond from a winning developer to be paid if the project is not pursued efficiently and in good faith.	11.1.2	Page 100
	Conclusion Competition should be a driver for efficient project design, engineering, procurement, risk allocation and financing package. All of this feeds into the price required for electricity produced. I therefore conclude that competition should be for the government package of support (CFD and associated contracts).	11.1.2	Page 100
	Recommendation On balance, I recommend allocation by competitive tender. These are such large and complex projects to develop and finance that the greater flexibility offered by tenders is highly desirable. An element of bespoke risk arrangements and contract terms could deliver material advantages to the consumer. A 'tender' model will also allow greater flexibility to reflect other desirable aspects of a project such as flood protection, regeneration and tourism.	11.1.2	Page 101
	Conclusion When delivering a competition by tenders, competing the same site allows for a clearer comparison of proposals. Moreover a site specific tender process would avoid investors becoming frustrated by preparing costly bids which make no progress and would enable a more structured approach to be taken, with a balance between projects in different parts of the country.	11.1.2	Page 101

Report heading	Conclusions and recommendations	Section	Page No
National Policy Statement	*Conclusion* It strikes me as unarguable that a fledgling industry would benefit from the clarity and stability represented by an explicit statement of Government policy that welcomes the development of tidal lagoons within defined parameters. Moreover, given that there are only a limited number of sites around the country which would be suitable for tidal lagoons (as they need both a significant build-up of a head of water and also to be of a sufficiently shallow depth where the wall can physically be constructed), there is a limit to how many installations would be possible.	11.2	Pages 103-104
	Recommendation I therefore recommend that the consenting process should be informed by a National Policy Statement similar to nuclear new-build, where specific sites are designated by the Government as being suitable for development.	11.2	Page 104
	Conclusion A series of lagoons in a particular area is likely to have an impact on the energy yield of individual sites and therefore careful consideration of the hydrodynamic interactions between sites will need to inform the NPS. In the same way, the NPS needs to ensure that the activities of other users of the waters are not affected unreasonably by the development of multiple lagoons.	11.2	Page 105
	Recommendation I would not want the work on Tidal Lagoon Swansea Bay to be lost because of an administrative exercise primarily intended to manage the development of very large lagoons. There seems broad agreement that the scale and location envisaged for the tidal lagoon proposed for Swansea Bay would have negligible impact further up the Severn, so I recommend that the current Swansea Bay project should be excluded from this NPS approach.	11.2	Page 106

Report heading	Conclusions and recommendations	Section	Page No
	Recommendation The consenting process also needs to give due weight to the local community interests. I recommend that the process should encourage local authorities to have a significant role in deciding what is the right cumulative capacity of tidal lagoons in their vicinity.	11.2	Page 106
	Recommendation I recommend that the National Policy Statement process should also include an assessment of the sustainability of the main construction elements for a longer term lagoon programme.	11.2	Page 107
Tidal Power Authority	*Conclusion* Significant Government action is required if the benefits of a programme are not to be lost, especially for the supply chain. I consider this can be done; and actually be done in a way that will give greater long-term clarity and confidence to investors and industry. *Recommendation* I propose that, at the same time as the pathfinder project is moving forward, the Government should set out a programme to bring forward additional tidal projects, so that the supply chain in particular has a clear understanding of the opportunities and contracts.	11.3	Page 107
	Recommendation I recommend that the Government should establish a Tidal Power Authority.	11.3	Page 107
	Recommendation The Authority would be established at arms-length from Government with a clear purpose and the resources necessary to deliver results. I recommend that the goal of the Authority should be to maximise UK advantage from this programme.	11.3	Pages 107

Report heading	**Conclusions and recommendations**	**Section**	**Page No**
	Conclusion I am not proposing that the new Authority should have planning or consenting powers, nor should it take powers away from local authorities. A positive, symbiotic relationship with local authorities is essential.	11.3	Page 109
	Recommendation The Authority should be responsible for deciding (after appropriate consultation) which locations should be offered for tender at which time, ensuring that this tendering process is managed so that any negative cumulative impacts (either environmental or commercial) from a series of lagoons can be avoided.	11.3	Page 109
	Recommendation I recommend that the Authority should undertake some of the environmental assessment work for the lagoon locations, or incentivise the Crown Estate to do this on a commercial basis, and seek to recover these costs at financial close within the strike price. The results of these environmental assessments should be made available to those bidding in the tender process, rather than requiring each developer to do this work themselves and individually.	11.3	Page 110

Report heading	Conclusions and recommendations	Section	Page No
	Recommendation The Tidal Power Authority should also drive the process for securing cost reductions from tidal technology. This should follow the example of the Offshore Wind Cost Reduction Taskforce, led by industry, and providing the forum which brings together developers and policy makers. In recent years, these fora (for nuclear, offshore wind and CCS) have been Minister-led and run by Government departments, but I consider that the Authority could achieve more progress, more quickly if run at arms-length from Government, albeit with the closest ties. This is not to say that it could not be done within Government, but I see merits in a dedicated body to perform these tasks. The Authority should set up a Centre of Excellence to give tangible support for innovation in tidal lagoon technology, perhaps in partnership with the Offshore Renewable Energy Catapult , with the aim of developing skills in this sector that can be used in other tidal lagoon developments overseas. The Authority should be responsible for deciding where common criteria are necessary, for example in considering whether it should specify a common turbine design for tidal lagoons, bringing together the expertise and experience of major turbine manufacturers such as Andritz Hydro, GE Renewable Energy, Voith and Toshiba. The limited nature of the supply chain in this field means that it could be an area where industry cooperation is every bit as important as industry competition, as being the best way to move technology forward and achieve cost reductions.	11.3	Pages 110-111
	Recommendation The Authority should also work to foster the UK supply chain. I would urge Government to publicly set out its ambition for the level of UK content that the TPA will seek to deliver. I would recommend that, as with offshore wind, this should certainly be more than 50%.	11.3	Page 111
	Recommendation If projects in early rounds of the programme do not deliver sufficient UK content, the Government may wish not to continue with further rounds.	11.3	Page 111

Report heading	Conclusions and recommendations	Section	Page No
	Recommendation The Government may, following consultation, take steps to wind up the Authority if it has reason to believe the objective has been achieved, as far as possible, or if it cannot be achieved.	11.3	Page 111
	Recommendation I invite government to consider including tidal stream and small scale tidal barrage projects within the Authority's remit.	11.3	Page 111
Government Structures	*Recommendation* The Government will require a period of time to assess these recommendations and to reflect them in their view of the proposals from TLP and their value for money. This work should take account of my conclusion on the very strong case for a pathfinder project and conclusion that cost-competitive larger-lagoons will follow. A Negotiating Strategy will be necessary alongside this, and will form the foundation of any counter-proposal Government might make. This work will need to be undertaken by a lead official with an explicit mandate to deliver on a cross-departmental basis, supported by an enhanced transaction team.	11.4	Pages 111-112
	Recommendation Such is the significance and complexity of the strategic and fiscal considerations in implementing this policy beyond the pathfinder project that I recommend the appointment of a single senior official with sole responsibility for developing the financing structures that will form the basis of the Authority's first competition exercise.	11.4	Page 112
	Recommendation I recommend that the Authority seconds staff into the team led by the single senior official. I further recommend that the Government seconds policy staff into the Authority for the duration of the competition.	11.4	Page 112

Report heading	Conclusions and recommendations	Section	Page No
Financing structures	*Conclusion* Whilst I have seen attractions in a regulatory model, I am persuaded that a CFD model is the most appropriate form of support for a pathfinder project. Transitioning to an alternative financing structure at this stage would have the added disadvantage of introducing delays and uncertainty, at a time when I believe we should move forward quickly. I have not seen sufficient advantages of an alternative funding approach which would justify such delays and uncertainty.	12.8	Page 124
	Conclusion My proposal to provide a period of separation between a pathfinder and subsequent projects and to then approve future lagoons through a competitive tendering process, provides time and opportunity for Government to assess this option [viz. a Regulatory model] in more depth. Such a change of approach would in any case require Government to undertake a formal consultation process and I recommend that time is taken to consider these very important issues in greater detail. However, as stated above for the financing of a pathfinder project, there would need to be a more compelling rationale than I have so far seen to justify moving from the CFD approach to a regulatory model for the wider programme.	12.8	Pages 124-125
Financing structures	*Recommendation* I recommend that the Government should use any grant funding available to this sector to support investment in these new and improved manufacturing facilities, for example in steel and turbine manufacturing technologies and facilities.	12.9	Page 125
Decommissioning	*Recommendation* I recommend that the Government should accept that once built, the seawall of a tidal lagoon should be considered to be permanent for the purposes of decommissioning plans.	13	Page 128

Report heading	Conclusions and recommendations	Section	Page No
	Recommendation The TPA should have a role in advising Government on decommissioning plans. But I recommend that, towards the end of the operating lives of the first lagoons, a decommissioning body should be established to ensure there is ongoing maintenance and repair for lagoons after the end of their operational lives.	13	Pages 128-129
	Recommendation I … recommend that the operators of lagoons should be required by law to contribute to a decommissioning fund over the operating life of the lagoon, starting modestly at an appropriate time after the lagoon begins operating. This fund will provide the necessary resources for long-term maintenance once the operational life of a lagoon is over.	13	Page 129
	Recommendation Once the fund has reached a level agreed by Government (national and local), there should be no need to contribute to it further, although there should be periodic reviews (every five years) to ensure that the fund is adequate for future needs.	13	Page 129

Annexes

A. Terms of Reference of the Government Review on Tidal Lagoons

The Review aims to assess the strategic case for tidal lagoons and whether they could represent value for money for the consumer. The Review will include:

a) an assessment of whether, and in what circumstances, tidal lagoons could play a cost effective role as part of the UK energy mix;
b) the potential scale of opportunity in the UK and internationally, including supply chain opportunities;
c) consideration of a range of possible structures for financing tidal lagoons;
d) consideration of different sizes of projects as the first of a kind; and
e) whether a competitive framework could be put in place for the delivery of tidal lagoon projects.

The Review will take place in consultation with the relevant Government departments, in particular DECC and HM Treasury, but also with devolved offices.

B. Call for Evidence

The Secretary of State for Energy and Climate Change has asked me to lead the independent review into the feasibility and practicality of tidal lagoon energy in the UK. I am seeking evidence and representations that will form the evidence base for the Review.

The Terms of Reference can be found here. In summary, the review will cover:

- An assessment of whether, and in what circumstances, tidal lagoons could play a cost effective role as part of the UK energy mix;
- The potential scale of opportunity in the UK and internationally, including supply chain opportunities;
- A range of possible structures for financing tidal lagoons;
- Different sizes of projects as the first of a kind;
- Whether a competitive framework could be put in place for the delivery of tidal lagoon projects.

My review is not targeted at any particular project but, in considering these issues, I am mindful that Tidal Lagoon Power Ltd, the proposed developers of Swansea Bay Tidal Lagoon, are in ongoing discussions with Government about the terms of a potential Contract for Difference that might support the financing of the project. However, I nonetheless wish to receive evidence from both Tidal Lagoon Power Ltd and others about the costs, benefits and opportunities of tidal lagoons.

I am also seeking evidence of other potential sites, developers and opportunities, and the feasibility and practicalities of a wider UK tidal lagoon programme including, but not limited to, environmental and grid issues, navigation and ports impacts, supply chain and export opportunities and financing arrangements.

My team will notify any suitable opportunities for round-table meetings or discussions to those interested. Please register any interest using the contact details below.

In addition to this call for evidence and associated visits and any necessary meetings, I will be consulting with relevant Government departments and with the devolved administrations throughout the Review.

Charles Hendry

How to respond

Please submit any written evidence with a bearing on any of these issues by **31 July 2016.** If necessary I will continue to consider new information into August, but it would be helpful to understand what this would be. The current email address for the Review is:

info@OP1.PSN360.FCOS.GSI.GOV.UK

The review is currently seeking offices. If you wish to submit **information by post** please contact the review team for further information.

If you have suggestions of people or organisations the Review may wish to involve or, sites that might be visited, please respond **as soon as possible** so I can consider the suggestion and make any appropriate arrangements.

If you have any questions my Review team will be happy to help at the above addresses.

Confidentiality and data protection

My Review is independent of Government and is my sole responsibility. The Review team comprises seconded civil servants supporting me in delivering my Terms of Reference and act on my instructions, rather than those of their home department.

Evidence and opinion received will not automatically be shared with Government. However it may be used as part of the report which will be provided to Government and published.

Information provided in response to this document, including personal information, may be subject to publication or disclosure in accordance with the access to information legislation (primarily the Freedom of Information Act 2000, the Data Protection Act 1998 and the Environmental Information Regulations 2004).

If you want information that you provide to be treated as confidential please say so clearly in writing when you send your response with reasons. If we receive a request for disclosure of the information we will take full account of your explanation, but we cannot give an assurance that confidentiality can be maintained in all circumstances.

An automatic confidentiality disclaimer generated by your IT system will not, of itself, be regarded by us as a confidentiality request.

C. Technical Advisers to the Review

We appointed a consortium of ITP (now ITPE Ltd), Energised Environments and Xero Energy, supported by individual experts Professors Roger Falconer and Chris Binnie, as technical advisors to the Hendry Review Team on 12 August 2016, through a tendering process.

Their role was to assess and validate the technical aspects of the evidence received by the Review and identify gaps in the evidence base for a wider tidal lagoon programme in the UK and, where feasible, undertake work to address these gaps. At the end of the process they provided us with a report.

Their main tasks included:

- Reviewing the technical aspects of the potential for a tidal lagoon programme in the UK, including:
  - The value of having predictable, intermittent renewables energy on the system; how are huge amounts of power at times when it is not needed managed
  - The impact of multiple lagoons in the Severn – including grid connectivity issues and cumulative environmental and navigation issues
  - Provide design options for a fleet of lagoons, including optimal size of the programme; potential for delivering power on a 24 hour basis, through a series of connected lagoons in different parts of the country; maximising benefits and minimising cumulative negative impacts
  - A due diligence of potential costs for future lagoons
  - The potential for cost-effective deployment outside the Severn
  - Appraisal of options for decommissioning lagoons.
  - Assess the scale of global opportunities for tidal lagoons and the potential of a global industry.
- Reviewing and conducting due diligence of evidence received in the Call for Evidence, including those related to:
  - The value of having predictable, intermittent renewables energy on the system;
  - The value of flood protection offered by proposed developments
  - The potential for cost reduction from learning and deployment at scale.

During first week of November they submitted their final report. Their report addressed the above technical aspects, and then discussed other detailed issues that have arisen as part of their work, which included considerations of the terms of reference questions being addressed by the Hendry Review team.

D. List of respondents to the call for evidence

ABPmer	Acorn Global
Active Support Group	Admiral Group
AECOM	Afan Valley Angling Club
AKW Technologies Ltd	Allen, Bob
Allen, Mark	Allerdale Borough Council
Allerton Steel	Alun Griffiths (Contractors) Ltd
Amos, Gideon	Anderson, Dr. Stuart
Andritz Hydro	Arup
Associated British Ports	Atkins
Ball, Stanley	BCB International
Bonds Foundry, BEL Valves Ltd and A&P Tyne, joint submission	Binnie, Professor Chris
Blake Morgan	Blue Wave
Boucher, Dan	Boxall, Dr Simon, University of Southampton
Boyd, Kenneth	Bristol Channel and Severn Estuary Energy Group
Bristol City Council	Bristol Port Company
Britain's Energy Coast	Burtt, James
Callaway, Dr. Ruth, Swansea University	Campbell, Dr. John
Campbell, Dr. Sally	Canoe Wales
Cape Farewell	Cass, Andy
Catterson, Nigel	Centrus
Chartered Institution of Water and Environmental Management	The Church in Wales
CITB Wales	Citizens Advice
Coastal Protection and Engineering Ltd	Coates, Richard
Construction Industry Council	Conwy County Council
Cornwall Against Dean Super-Quarry	Cousein, Bruno, Mayor of Berck-sur-Mer
The Crown Estate	Daborn, Dr. Graham, University of Acadia
David Kerr Engineering Consultant Ltd	Davidson, Jane, University of Wales, Trinity Saint David
DavyMarkham Limited	Dawnus
Denbow International Limited	Department for Business, Energy and Industrial Strategy

Department for International Trade	Department for Economy, Northern Ireland
Devon and Severn Inshore Fisheries and Conservation Authority	Drax
Ecotricity	EDF Energy
Electrical Contractors' Association	Eilon Associates on behalf of Tidal Electric
Energy Technologies Institute	Envenio
Environment Agency	Evans, David
Falconer, Professor Roger, Cardiff University	Fish Legal Solicitors
Fly 2 Wales Ltd	Francis Brown Ltd
Franklin, Patrick	GE
Glandwr Cymru	Glas Cymru
Goodwin International	GPG Gwyrddio Penarth Greening
Greenpeace	Griffiths, Barry
Gruffydd, Llyr, Member of the National Assembly for Wales	Ham, Philip
Hayman, Sue–, Member of Parliament	Hornbill Engineering & Industrial Training
Howard, Chris	Hulsbergen, Kees
Industrial Communities Alliance Wales	Infracapital
InfraRed Capital Partners Limited	Institute of Directors
Institution of Civil Engineers, Royal Academy of Engineering and the Institution of Mechanical Engineers joint submission	Institution of Civil Engineers Wales Cymru
Iorwerth, Rhun ap, Member of the National Assembly for Wales	Jenkins, Bethan, Member of the National Assembly for Wales
Jethwa, Nilesh	John, Robert
Johnston, Dominic	Jones Bros. Ruthin Co. Ltd
Jones, Professor Calvin and Munday, Professor Max, Welsh Economy Research Unit, Cardiff Business School	Kavanagh, Michael
Kelly, Chris	Kepler Energy
Lamelliere, Pierre-Marie, ASA "Vivre avec la mer"	Ledwood
Liverpool City Council	Local Partnerships
LongBay SeaPower	Mackay, Andrew
Mantzaris, Ioannis, Manzaris Aioliki Epidavrou Co.	Marine Conservation Society
Marine Energy Pembrokeshire	Masters, Dr Ian, Swansea University
McGregor, Alison	Mineral Products Association

Moller, Vicky	Mott MacDonald
MUFG Securities (EMEA) Plc.	Mumbles Active Supporters Group
Mumbles Development Trust	Murphy, Chris
National Grid	National Infrastructure Planning Association
Natural Energy Wyre	Natural England
Natural Resources Wales	North Wales Tidal Energy & Coastal Protection Co Ltd
North West Energy Squared	NSA Afan
Ocean Energy Europe	Office of the Future Generations Commissioner
Offshore Renewable Energy Catapult	ORJIP Ocean Energy
Oxford Oceanics	Peel Energy Ltd
Pembrokeshire South East Energy Group	Perpetuus Tidal Energy Centre
Phillips, Professor Michael, University of Wales, Trinity Saint David	Pleasure Anglers and Kayakers Association
Pollock Associates	Pontardawe and Swansea Angling Society Ltd
Port of Milford Haven	Power, Professor Anne, London School of Economics
Prosser, Dr Havard	Red to Blue Ltd
Regen SW	Renewable Energy Association
Renewable Hydrocarbons Limited	RenewableUK
Residual Land Ltd	Robinson, Nigel
Robinson, Patrick Edwyn	Rossi, Remo
Royal Town Planning Institute	Royal Society for the Protection of Birds
Seaforth - Geosurvey	Selwyn's Seaweed Ltd
Severn Tidal REEF group, Evans Engineering	SgurrEnergy Limited
Sheffield Forgemasters International	Shire Oak Quarries
Smith, Andrew, University College London Energy Institute	Snowdon, Nigel
Society for Underwater Technology	Southall, Matt
Stevens, Professor Heather	Sueur, Marthe, Mayor of Ault in Picardie, France
Swansea Bay Business Club	Swansea Bay City Region
Swansea City Centre Business	Swansea Watersports Ltd
TATA Steel	The Severn Trust
Thomas, Simon - Welsh Assembly	Thomson Project Management Ltd
Tidal Bell Power	Tidal Energy Limited
Tidal Lagoon Power	Tidal Power Wales

Tidetec	Toland, Joseph
Transmag UK Ltd	Venables Consultancy
VerdErg Renewable Energy Ltd.	Wales Green Party
Welsh Assembly	Welsh Conservative Group at the National Assembly for Wales
Welsh Government	Welsh Local Government Association
White, David	The Wildlife Trusts
Wolf, Professor Judith and Brown, Dr Jenny (National Oceanography Centre, Liverpool), Plater, Professor Andy and Leonardi, Dr Nicoletta (University of Liverpool, School of Environmental Sciences) and Li, Dr Ming (University of Liverpool, School of Engineering)	Woloszczuk, Nikolus
Wooliscroft, Jon	

E. Supply chain facts and figures

Detail of labour requirement for TLSB twelve main turbine component parts

Items	Number required	Manufacturing method	Estimated Labour Demand FTE
Draft Tubes	16	Metal fabrication	36
Runners	16	Steel Casting	45
Runner Blades & Hubs	16 Hubs 48 Blades	Steel Casting	196
Turbine Housing	16	Metal fabrication	51
Sluice Gates & Turbine Stop Logs	40	Metal fabrication	194
Bulb Nose & Cones	16	Metal fabrication	26
Shafts	16	Steel Forging	130
Discharge Rings	16	Metal fabrication	32
Distributors	16	Metal fabrication	88
Hydraulic Balance of Plant (BOP)	1	Metal fabrication	25
Hatch Cover & Frame	16	Metal fabrication	20
Generator	N/A	Varied	80

Source: Taken from the Miller Research and Semta Report 'A study to forecast the manufacturing and labour requirements for the Swansea Bay Tidal Lagoon'

Top five construction occupations for TLSB

Occupations	**% of total labour demand for TLSB**
Plant Operatives	17
Specialist Building Operatives	15
Wood trades and interior fit-out	11
Labourers	11
Maritime-related occupations	11

Source: Taken from the CITB and Whole Life Consultants Ltd Report 'A study to determine the construction labour and skills demand, supply and gaps associated with the creation of the Swansea Bay Tidal Lagoon'

Further details on University of Wales Trinity Saint David specialist centres

Advanced Materials and Manufacturing

Non-destructive testing (NDT) and evaluation is a key area of expertise at UWTSD. It is involved in research with a number of companies including (TWI Wales Ltd), development and manufacturing (Silverwing UK Ltd), advanced inspection services (Oceaneering Asset Integrity). Other companies such as TATA Steel, Calsonic, Team Precision, TIMET also use NDT technologies. There are major opportunities here linked to the development of Tidal Lagoon technology and developing appropriate skills and expertise in the region.

Manufacturing and Mechanical Engineering

UWTSD's expertise includes developing engineering skills for the automotive, motorsport, mechanical and manufacturing industries, collaborating with such companies as Ford Motor Company, Visteon, Calsonic Kansei, Belron and Tata Technologies, ensuring that teaching, research and knowledge transfer is always informed by industry, contemporary industrial challenges and best practice. There are major opportunities here linked to the development of Tidal Lagoon technology.

Construction and the Built Environment

UWTSD has longstanding links with the construction sector. Its specialist areas include sustainable construction, construction waste and building conservation. UWTSD is establishing Wale's first National Construction College with Construction Industry Training Board (CITB), leading a pan-Wales consortium developing a new applied approach to training. A new practice-oriented School of Architecture will be opening in the Swansea Waterfront Innovation Quarter in 2018. There are major opportunities here linked to specialist construction of the Tidal Lagoon fleet.[

Energy & Natural Environment

UWTSD has world-leading research in Environmental and Marine Sciences, Coastal Conservation and Management, Archaeology, and Climate Change. Knowledge transfer activity includes large scale projects which help to build a sustainable marine energy sector. Collaborative partners include Tidal Lagoon Swansea Bay and Stenor Environmental Services Ltd.[

Financial & Professional Services

The Faculty of Business and Management's specialist fields include HRM, Accounting and Finance, Marketing, Purchasing and Supply. Customised training packages can also be accredited for delivery at the work place across all sectors. The Swansea Business Campus is a host to many organisations and professions' CPD events and strategic meetings (http://www.uwtsd.ac.uk/business-management/)

The Wales Centre for Advanced Batch Manufacturing (CBM)

Situated in Swansea's maritime Quarter, CBM is a core component of UWTSD's ambitious plans to develop a Swansea Waterfront Innovation Quarter in the city's SA1 region. A commercially focused research and development facility. CBM's offering is unique, interfacing academic research and knowledge transfer with commercial exploitation. CBM's research and development activities are centre on the creative application of advanced manufacturing technologies across a wide range of manufacturing sectors including marine, automotive, aerospace, medical engineering and craft sectors. Driving innovation, creativity and entrepreneurship among small companies engaged in low-volume manufacture, the Centre also works with large international organisations in the development of new products, processes and materials. In-house advanced manufacturing and reverse-engineering processes, together with a highly skilled team of design engineers, enable the Centre to deliver fast, accurate, cost-effective solutions to a wide range of manufacturing requirements. There are major opportunities here linked to the development of Tidal Lagoon technology.

Table showing selection of potential of UK suppliers for the hydro turbine mechanical components

Supplier name	Country	Manufacturing Process
A & P Group	England	Welding / Steel Structures
Bonds	England	Casting
BEL Engineering	England	Machining
Goodwin International Ltd	Endland	Casting / Machining
H.I. Quality Steel Castings	England	Casting
Harris Pye Engineering	Wales	Welding / Installation
Ledwood Engineering Ltd	Wales	Welding / Steel Structures
Mabey Bridge Ltd	Wales	Welding / Steel Structures
Mii Engineering Ltd	Wales	Installation
Sheffield Forgemasters	England	Casting / Forging / Machining
William Cook	England	Casting
DavyMarkham	England	Welding / Machining
Bradken	England	Casting
Francis Brown	England	Welding / Steel Structures

Source: Taken from evidence submitted to the Review by Andritz Hydro.

Excerpts from written evidence from potential supply chain relating to cost reduction

"The level of investment will additionally contribute to improvements in efficiency and quality of support for existing projects and customers.

This first project will also provide the starting point for cost reductions. Costs will only go in one direction as technology is adopted, efficiencies of scale realised and learnings/best practice adopted from across the supply chain.

BEL Engineering

"Experience from other capital intensive projects is the real savings come from improving and optimising existing design and learning from involvement of the supply chain during implementation."

DavyMarkham

"The cost effectiveness of sub-tier suppliers improves with run size and forward order planning and continuity enabling better tooling, jigging and production efficiency investment in optimal manufacturing only if there is a committed long term agreement and agreed schedule… A more efficient way forward is that adopted where certainty is assured as in the case of the Submarine programme."

Goodwin

F. Excerpts from written evidence, particularly relating to impacts on the environment and other uses of the waters

Excerpts from the written evidence are provided in alphabetical order of the author's or organisation's name.

Bristol City Council

"Tidal lagoons are an important emerging technology that could play an important role in the UKs energy mix and provide the UK with an opportunity to be at the forefront of marine technology as part of its industrial strategy. Within the Bristol Channel, large scale infrastructure proposals must be considered alongside existing and planned environmental and socio-economic assets and any assessment of the role of tidal lagoons should consider the in-combination impacts of these projects. In addition, any tidal lagoon projects within the Severn Estuary European Marine Site will need to take account of the Habitats Regulations as a statutory requirement and would almost certainly require compensatory habitat provision with significant associated costs and ecological implications.

"In this respect, first of a kind projects should consist of small scale structures and be built out incrementally so that the individual and accumulative impacts and risks can be understood and mitigated. Consequently, Bristol City Council is supportive of the proposed Swansea Bay Tidal Lagoon (SBTL) but opposed to plans to construct larger lagoons at Cardiff and Newport until the impacts of the SBTL are known in relation to other marine technology deployment, environmental, national and socio-economic assets."

Bristol Port Company

5.7 Based on the very limited information currently available (including data from TLP, the Severn Tidal Power SEA studies and initial advice from our specialist consultants HR Wallingford), specific – and highly detrimental - effects during and after construction are predicted to include:

5.7.1 a loss of water level at high water (estimated at between 0.3m and 1.0m, depending upon the number of lagoons);

5.7.2 an increase in water level at low water (estimated at between 0.3m and 1.5m, depending upon the number of lagoons);

5.7.3 a loss of energy in the water column resulting from the reduction in tidal range (estimated at between 0.6m and 2.5m, again depending upon the number of lagoons) causing greater and long-term deposition of sediment (as a result of the loss of sediment from suspension and changes in the shape of the estuary as it adjusts over time to the large scale lagoon structures) and a loss of water depth;

5.7.4 increased currents and changes to patterns of currents, particularly in the vicinity of the DSCT; and

5.7.5 a loss of intertidal area to both subtidal and terrestrial habitats caused by the reduction in tidal range.

5.10 Any reduction in water depth, caused by a loss of water level at high water and increased siltation from sedimentation, would mean that:

5.10.1 the number of tides on which the Port can handle deep draft vessels would reduce, causing an overall reduction in the number of vessels able to use the Port;

5.10.2 the duration of tidal windows affording access to the Port would reduce, meaning that the overall number of vessels with shallower drafts able to be safely handled on a single tide would also reduce; and

5.10.3 the severity of the preceding effects would be exacerbated by a greater reduction in water depth.

5.16 In addition, the proposed Bridgwater Bay lagoon would specifically cause the loss of intertidal habitat from our approved habitat creation scheme on the Steart Peninsula in Bridgwater Bay. The scheme, which covers 130ha, together with the Environment Agency's neighbouring Steart Marshes, is one of the largest compensation schemes in the UK and Europe. The loss of intertidal habitat would result in the site failing to meet its compensation requirements under the Habitats Regulations for the purposes of the DSCT development. This would mean that the DSCT could not be developed unless replacement compensatory habitat could be purchased and an acceptable alternative scheme created.

Crown Estate

“Successful implementation of a policy which supports cost effective and efficient tidal range infrastructure requires an understanding and management of the extent of physical interactions between future projects. This may require combinations of locations to be established for future schemes, together with a sequence of developments. This would ensure that projects are offered to market and built out in an order which optimises use of the energy resource. Project development sequenced in an ad-hoc manner with insufficient attention to project interactions potentially results in inefficient use of the resource stock and poor cost-effectiveness.”

“There are a finite number of sites that could be commercially developed; therefore, there is a requirement for a long term strategy in order to maximise the benefits and minimise inefficiencies due to project interactions and to take account of other marine users.”

Environment Agency

“As demonstrated by the results of the Severn Tidal Power Study, tidal barrage and lagoon developments will face significant challenges in achieving compliance with Natura 2000 protection requirements, particularly in respect to migratory fish and inter-tidal habitats.”

“Where lagoons will impound tributary rivers they will create physical barriers to migratory fish attempting to migrate to and from the freshwater stage of their lifecycle. Passage would only be possible via turbines, or possibly fish passes or fish-ways. Disrupted migration could lead to the collapse of stocks and local extinction of species.”

“Impounded waters will also be influenced by solar radiation, leading to increased water temperatures in lagoons and complex changes in the overall heat distribution within estuaries and coastal areas. Such changes could have many effects on fish, including direct mortality and reduced migration, and could favour some species over others.”

Fish Legal

“Since the DCO was granted in summer 2015, however, the argument we have been making has in effect been accepted by NRW Marine Licensing and its expert advisers including the Government’s fisheries scientists CEFAS, with the result that the migratory fish impacts have been re-modelled and are now assessed as likely to be “significant” (in the region of 5% mortality or more).”

“…significant public funding…should now be devoted to researching the many aspects of the relevant environment about which so little is presently known, including in relation to the potential cumulative impacts with the further lagoons proposed for the Severn Estuary.”

Marine Conservation Society

“MCS has serious concerns about the impacts of tidal lagoons on sensitive coastal habitats and species. Due to the nature of tidal range technology, such renewables are designed to operate in areas where the difference between high and low tide (the tidal range) is the greatest, and are therefore most effective in estuaries and bays. … Artificially controlling the tides in areas where habitats and species have adapted to current conditions over thousands of years could have significant and irreversible consequences;…”

National Grid

“In our assumptions however it is assumed that the lagoon will operate at the maximum power output that the tidal flow will allow. It is also assumed that to deviate from this optimal power output of the lagoon that a payment will need to be made to the lagoon in order to provide the relevant service.”

“South Wales is currently a heavily congested part of the network as there has been a large increase in embedded generation, both renewable and non-renewable. This means that until such time as the currently connected conventional power plants close between now and 2025 there is limited capacity available over and above the contracted Swansea Bay connection. From an initial assessment there will be multiple network enhancements required to connect the full proposed 4GW of tidal lagoon generation.”

“The ability to predict tidal cycles and the generation potential a long way in advance is not necessarily an advantage to the System Operator. On the day the System Operator matches generation to a demand profile - adding the assumed generation from tidal power will change the shape of the curve but the problem of matching generation and demand would be approached in essentially the same way. It would be expected that the majority of the energy from the tidal lagoon would be sold and bought through bilateral contracts with suppliers rather than the balancing mechanism and the long term predictability provides increased certainty for the generator and supplier."

Natural England

"In our experience to date, the delivery of compensation measures, are also likely to be time-consuming, expensive, and are often contentious. This is likely to be amplified for tidal lagoons as the scale of compensation required is likely to be substantially larger and more complex than anything to date…

"Mitigation and compensation measures for tidal lagoons also need to be considered over the life time of the development (120 years) and take into consideration the impacts of climate change."

Natural Resources Wales

"For any major infrastructure project, the challenges posed by cumulative and in-combination effects (whereby the impacts of multiple projects or activities create an additive effect greater than that of an individual project) are complex and significant.

"Understanding the challenges posed by such assessments are complex for a number of reasons:

- there is no well-established approach to undertaking cumulative impact assessments (for example how to decide which projects/activities to include);
- the uncertainties about project level impacts (for example potential collision risk to mobile species and habitat loss) are amplified;
- the current 'building block approach' to consenting can result in projects with larger environmental impacts receiving consent, whilst at the same time making it more difficult for more beneficial, but less environmentally damaging, projects to obtain consent subsequently."

RSPB

"The ecological impacts of tidal lagoons are not well understood, as there are currently no constructed projects anywhere in the world. However, we are clear that tidal range technologies in general, of which this is one, have the potential to cause significant adverse impacts to key wildlife sites such as the internationally important intertidal habitats of the Severn Estuary."

"If it cannot be ascertained that a project will not have an adverse effect upon a site listed as a Special Protection Area (SPA) for birds, or a Special Area of Conservation (SAC) for other species and habitats of European conservation importance, then it may only proceed if there are no alternative solutions and imperative reasons of over-riding public interest for it, and only then if the functional loss to the site is offset by the provision of compensatory habitat. We consider these tests are sound tests of the sustainability of development projects that represent the minimum we would expect in any civilised society as being necessary to conserve nature…

“Given many of the most suitable sites for tidal lagoons are designated, these are challenging, but not necessarily impossible tests for tidal lagoon power to pass.”

“In an ideal world, a pilot tidal lagoon would be constructed, and then comprehensively monitored and the results shared, such that all parties had a comprehensive understanding of the economic, social and environmental costs and benefits of the new technology.”

“A key concern with the Government’s approach to tidal lagoons is that it appears developers are being asked to achieve very rapid deployment, to achieve a relatively low ‘bundled’ CFD strike price that is seen as competitive with other more established technologies including fossil fuels. We consider this both undesirable and unrealistic. It means that learning from early projects is unlikely to be applied to later projects. Project deployment is likely to depend excessively on unproven modelling, with the result that deployment will be accompanied by significant uncertainty, which will result in unmeasured impacts, the cost of which is likely to fall on the public purse, or loss to unmarketed public goods.”

Severn Trust

“In our view, it is, as yet, far from clear that tidal lagoons can be built and operated a) without unacceptable damage to the environment, and b) on a basis that offers value for money to the tax payer.”

“These schemes would be highly likely to affect internationally designated features, the complex movements of sediments and the rich inter-tidal habitats of the inner estuary.”

Welsh Government

“Any future tidal range scheme should at the very least not cause flood risk detriment in their construction or operation and should work alongside the Shoreline Management Plans that set out the long-term proposals for managing our coastline.”

The Wildlife Trusts

“We do not believe that development of renewable energy should be at the expense of the biodiversity which reducing the effect of climate change is meant to support.”

“We have serious concerns that there are plans for a potential three lagoons in the Severn Estuary;”

“It is already considered highly likely that a development on the scale of the proposed Cardiff tidal lagoon would result in significant impacts to the site and be difficult to consent in a manner compatible with the Habitats and Birds Directives.”

“Whilst we welcome the efforts Tidal Lagoon Power is going to in developing an ‘Ecosystems Enhancement Programme’ to meet the compensatory measures requirement, we have concerns as to its feasibility. Not only would it require intertidal habitat creation on an unprecedented scale, but would also require measures for impacts on migratory birds and fish and measures for impacts on subtidal habitats.”

G. Habitats and Birds Directives and Adaptive Environmental Management

Habitats and Birds Directives

In relation to wildlife and nature conservation, two key Directives have been adopted by the European Union, namely:

- Directive 2009/147/EC on the conservation of wild birds (Birds Directive); and
- Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora (Habitats Directive).

These Directives have been transposed into UK law as the Conservation of Habitats and Species Regulations 2010. The Birds Directive provides for the identification of Special Protection Areas (SPAs) for rare or vulnerable species, as well as for all regularly occurring migratory species, paying particular attention to the protection of wetlands of international importance. The Habitats Directive provides for the designation of Special Areas of Conservation (SACs), intended to contribute to a coherent European ecological network of protected sites. Together SACs and SPAs make up the Natura 2000 network of sites.

The Directives require competent authorities (those with decision making powers) to assess the impact of projects that would be likely to have a significant effect on these sites. Normally, competent authorities cannot consent to a project if their assessment is it will have an adverse effect on the integrity of a European site.

However, article 6(4) of the Habitats Directive provides that even if there is a negative assessment, a project may go ahead if three tests are met:

1. There must be no feasible alternative solutions to the plan or project which are less damaging to the affected European site(s)
2. There must be “imperative reasons of overriding public interest” (IROPI) for the plan or project to proceed
3. All necessary compensatory measures must be secured to ensure that the overall coherence of the network of European sites is protected.

The Government has produced guidance on the application of article 6(4).

Compensation is normally achieved by replacing protected habitats on a like-for-like basis as close to the location of the damaged habitat, though other options will be considered where this is not viable.

Sites covered by the Ramsar Convention (which designates wetlands of international importance) are treated as Natura 2000 sites by the Regulations as a matter of policy. Sites of Special Scientific Interest could also be of relevance to the development of tidal lagoons.

Adaptive Environmental Management

As part of the process of seeking development consent, a project such as a tidal lagoon would need to conduct an Environmental Impact Assessment (EIA). The EIA process aims to identify significant impacts a project might have on the environment, and propose ways that these impacts could be avoided, mitigated, or if necessary compensated for.

Even following a robust EIA process it is possible that developers will be unable to identify and address all potential environmental risks definitively, and residual uncertainties may remain. Where this is the case it may be possible to apply the principles of adaptive environmental management, meaning that a rigorous scheme for monitoring environmental impacts and a pre-defined validated package of appropriate corrective measures would be identified. Such measures would provide for the adjustment of mitigation or compensation measures in light of the reality of the impacts, to make sure that initially unforeseen adverse effects are handled appropriately.

In her development consent decision letter for Tidal Lagoon Swansea Bay, the Secretary of State agreed that an adaptive environmental management approach was a reasonable and pragmatic way to deal with the currently uncertain environmental impacts of the Swansea project. Nevertheless she supported the view that, “in general, an adaptive approach should not replace clear, upfront and enforceable mitigation plans”.

H. Energy system modelling

An approach to consider the circumstances in which tidal lagoons could play a cost effective role in the UK's energy mix is to assess what would be required in cost and performance terms for lagoons to be a part of a "least-cost" energy system transition to delivering the UK's energy targets.

Energy system models can be used for this purpose. The Energy Technologies Institute (ETI) has undertaken analysis for the Review using its Energy System Modelling Environment (ESME)[58] to identify the capex levels at which tidal lagoons would need to be built for them to be part of a least-cost pathway to deliver the UK's statutory target to reduce greenhouse gas emissions in 2050 by 80% from 1990 levels[59].

The derived capex values are expressed in £ per kW of installed tidal lagoon capacity and have been calculated using fixed assumptions for lagoon load factors, operating costs and other performance parameters. A flat 8% cost of capital for investors and financiers was assumed for all technologies. These capex values can be considered to be target values needed to enable tidal lagoons to be commercially viable as part of the lowest-cost energy system transition to 2050 without subsidy.

ETI has analysed a range of energy scenarios - a "baseline" case, a "low nuclear case", a "no CCS" case and a "low nuclear and no CCS case" – that capture some of the uncertainties around future deployment (see below). In each of these scenarios, successive runs were conducted with different lagoon capex values, to assess the impact on lagoon capacity deployment. Results of this analysis are summarised below.

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[58] Please refer to the following link for further information: http://www.eti.co.uk/programmes/strategy/esme.

[59] Climate Change Act 2008, Chapter 27 http://www.legislation.gov.uk/ukpga/2008/27/contents.

Energy Technologies Institute – economic transition ranges for tidal lagoons

In our **baseline** case, with all technology options on the table, capex of £1,200/kW is required before tidal lagoons are deployed from the 2020s as part of a least-cost pathway to the UK's 2050 carbon emissions target. Even when lagoons are deployed here, their advantage is short-lived once nuclear becomes available (from the late 2020s).

In the **low nuclear** case (limited to a total of 9.4 GW of Large Gen III Reactors built out to 2030), Lagoons are deployed in the 2020s at a marginally higher capex level of £1,300/kW, and further capacity is added in later years given the lack of nuclear.

In the **no CCS** case there is an economic opportunity for tidal lagoons from a capex level of £1,800/kW. Much below this level, maximum deployment occurs up to the 20 GW limit. Above this capex level, other options prove more attractive.

In the **low nuclear + no CCS** case, where the energy system is heavily constrained, the pattern of the economic transition range for Lagoons is a little different:

- A capex level of £1,800/kW or below ensures an early and rapid rollout to the 20 GW limit, as in the no CCS case. But this time further nuclear capacity is unavailable beyond 2030, and therefore other technologies are deployed, including Lagoons.
- However as Lagoon capex is increased, deployment is pushed back to the 2040s.
- This may seem counterintuitive given that a flat capex profile should always offer Lagoons a comparative advantage in the near-term vs other technologies, but this demonstrates the value of a whole systems perspective as in ESME: without CCS or nuclear, the other options available (including wind, solar, biomass etc) all have upper limits of their own or offer diminishing marginal utility at high levels of penetration (more and more storage, backup etc required).
- It is the wider system costs of accommodating any more of those technologies that make Lagoons attractive in the 2040s even at higher capex levels.

The target capex levels for tidal lagoons in ETI's ESME model can be compared to levels derived for particular projects from ITP's analysis (as discussed in Chapter 6). The table below presents capex per KW figures for the top six sites in this analysis in the far right column.

Ratios of capex to installed capacity					
	Tidal range	**Installed capacity**	**AEP**	**Capex after reductions**	**Capex after reductions / Installed capacity**
	metres	**MW**	**GWh**	**£m**	**£ per KW**
Tidal lagoons at pathfinder scale (<500MW)					
Swansea Bay	6.2	320	570	1,300	4,060
Tidal lagoons at large scale (>500MW)					
Stepping Stones	7.7	790	1,410	2,592	3,280
Blackpool	6.1	2,600	4,100	7,300	2,810
Wyre	6.5	3,045	4,700	8,163	2,680
Cardiff	8.6	3,240	5,530	8,694	2,680
Newport	8.6	1,440	2,600	4,032	2,800
Bridgwater	8.1	6,480	11,730	17,262	2,660
Total		**17,595**	**30,070**	**48,042**	**2,730**

Source: ITP Technical Report and Hendry Review analysis.

Capex is estimated to be c.£2,700 - £2,800 per KW for Cardiff, Newport and Bridgwater (net of a 10% cost reduction to reflect the role of a pathfinder project). This compares to targets in ETI's ESME for tidal lagoons ranging from £1,200 per KW in a "baseline" case to £1,800 per KW in a "low nuclear and no CCS" case.

I do not consider that the shortfall between estimated capex levels for large scale lagoons and ETI's targets illustrate that lagoons cannot be cost effective. Rather, the variances indicate the importance of the role of a financing structure in driving down subsidy requirements, which are the key criteria for projects to be cost effective.

The analysis also draws attention to challenges in comparing tidal lagoons to other low carbon projects on a 'like-for-like' basis. ETI's ESME model focuses on a pathway to 2050, whilst, as I have discussed, tidal lagoons have the potential to operate for a very significantly longer period of time. The "CFD cost per MWh" approach that I have discussed is more appropriate for appraising this potential (although I note that other technologies with forecasts for long operating lives, including nuclear and heat networks, are deployed within ESME because they are deemed to be a cost effective way to meet targets).

I. Assumptions overview

Table 6

Potential tidal lagoon sites in the UK					
Site	Tidal range (1)	Installed capacity (2)	Enclosed area (2) (3)	Seawall length (2)	Ratio of enclosed area to seawall length
	metres	MW	km^2	km	km^2 per km
Severn Estuary					
Swansea Bay	6.2	320	11.5	9.5	1.2x
Stepping Stones	7.7	790	18.0	10.6	1.7x
Cardiff	8.6	3,240	71.8	21.0	3.4x
Newport	8.6	1,440	40.2	17.5	2.3x
Bridgwater Bay (4)	8.1	6,480	243.2	34.1	7.1x
North Wales and Liverpool Bay					
Conwy	5.2	740	40.0	16.5	2.4x
Colwyn Bay	5.5	3,200	119.8	22.8	5.3x
Sefton	6.1	2,600	101.9	27.7	3.7x
Wirral / Liverpool	6.3	1,600	67.1	21.9	3.1x
North West					
West Cumbria	5.6	2,200	92.1	22.4	4.1x
Blackpool	6.1	2,600	96.3	24.5	3.9x
Wyre	6.5	3,045	120.0	19.9	6.0x
Barrow in Furness	6.5	1,600	56.8	23.2	2.5x
East Coast					
The Wash	4.5	695	50.0	18.8	2.7x
East Lincs Coast	4.7	1,940	120.0	29.9	4.0x
South East					
Sheerness	4.2	1,310	100.0	28.6	3.5x
Thames Estuary	4.3	515	50.0	19.0	2.6x
Sussex Coast	4.6	2,415	160.0	34.8	4.6x

Source: ITP Technical Report and Hendry Review analysis.
Notes:

(1) ITP estimate of the mean of Spring and Neap tidal ranges.
(2) ITP's table includes TLP's assumptions as at August 2016 for ten sites – Swansea Bay, Cardiff, Newport, Bridgwater, West Cumbria, Barrow, West Lancashire, Sefton, Wirral and Colwyn Bay. For the remainder, ITP has calculated installed capacities by applying a scaling factor (a ratio of installed capacity to maximum energy available from the tidal lagoon over one year) derived from TLP's more advanced tidal lagoons and calculated enclosed area and seawall lengths using other resources that take into account site constraints.
(3) Basin area at Highest Astronomical Tide.
(4) Bridgwater Bay prohibits a tidal lagoon at Minehead.

Table 7

Ratios of capex to AEP					
	Tidal range	**Installed capacity**	**Capex (1)**	**AEP (2)**	**Capex / AEP**
	metres	**MW**	**£m**	**GWh**	**Ratio**
Pathfinder scale (<500MW)					
Swansea Bay	6.2	320	1,300	570	2.3x
Large scale (>500MW)					
Stepping Stones (3)	7.7	790	2,880	1,410	2.0x
Blackpool	6.1	2,600	8,110	4,100	2.0x
Wyre	6.5	3,045	9,070	4,700	1.9x
Cardiff	8.6	3,240	9,660	5,530	1.7x
Newport	8.6	1,440	4,480	2,600	1.7x
Bridgwater	8.1	6,480	19,180	11,730	1.6x
Total		**17,595**	**53,380**	**30,070**	**1.8x**

Source: ITP Technical Report.
Notes:

(1) ITP's capex estimates for Swansea Bay and Cardiff are based upon TLP data for these projects and ITP's own analysis. For the remaining large scale sites, ITP has assumed a linear relationship between capex and installed capacity for all cost items except the seawall and derived this relationship from its data points for Swansea Bay and Cardiff. Seawall costs are based on TLP's unit cost estimates for Cardiff. Potential cost reductions following a pathfinder and unique site factors that may affect the capex of individual tidal lagoons have not been considered. These figures should only be used as a high level guide. Capex figures are stated as 2015 prices.
(2) ITP has used a high level, 0-D numerical model to calculate electricity generation. More comprehensive 2-D modelling has tended to predict reductions compared to 0-D model results. Environmental issues and cumulative impacts are not considered.

(3) ITP has identified Stepping Stones as a potential First of a Kind scheme. However, this site does not appear to be under active project development and a working assumption for this analysis is that a pathfinder tidal lagoon would be less than 500MW.

Table 9

TLP illustrative analysis of Strike Price requirements				
2012 prices		**Cardiff**	**Newport (1)**	**Bridgwater**
Installed capacity	MW	3,240	1,440	6,480
CFD contract term	Years	90	90	90
First Operating Year	Date	2027	2030	2030
Starting Strike Price (2)				
Strike Price before cost reductions	£ per MWh	140.1	148.0	129.9
Strike Price after cost reductions	£ per MWh	113.0	141.7	110.1
First Operating Year Strike Price				
Strike Price before cost reductions	£ per MWh	115.6	120.4	105.7
Strike Price after cost reductions	£ per MWh	96.1	115.3	89.6

Source: TLP data.

Notes: The Review provides no assurance of these figures and has not reviewed in detail all of the underlying project assumptions and calculations. Strike Prices are stated as "real" values, i.e. they are adjusted for the effect of inflation. Inflation is based on an independent inflation curve to 2020 and 2.5% per annum thereafter. Indexation levels are based on TLP's proposal for Swansea Bay.

(1) TLP anticipates that the CFD proposal for Swansea Bay could be optimised for Newport to significantly reduce Strike Price requirements from the figures presented here, which are on the basis of applying the exact proposal for Swansea Bay.

(2) The base date for the Starting Strike Price is 31 December 2015.

Table 10

TLP illustrative analysis of CFD Equivalent values				
2012 prices		**Cardiff**	**Newport**	**Bridgwater**
CFD Equivalent before cost reductions	£ per MWh	85.0	89.4	77.8
CFD Equivalent after cost reductions	£ per MWh	70.4	85.4	66.0

Source: TLP data.
Notes: CFD Equivalents give rise to the same NPV of CFD payments as the partially indexed Strike Prices presented in 7.1. Discount rates are based on guidance in HMT's Green Book.

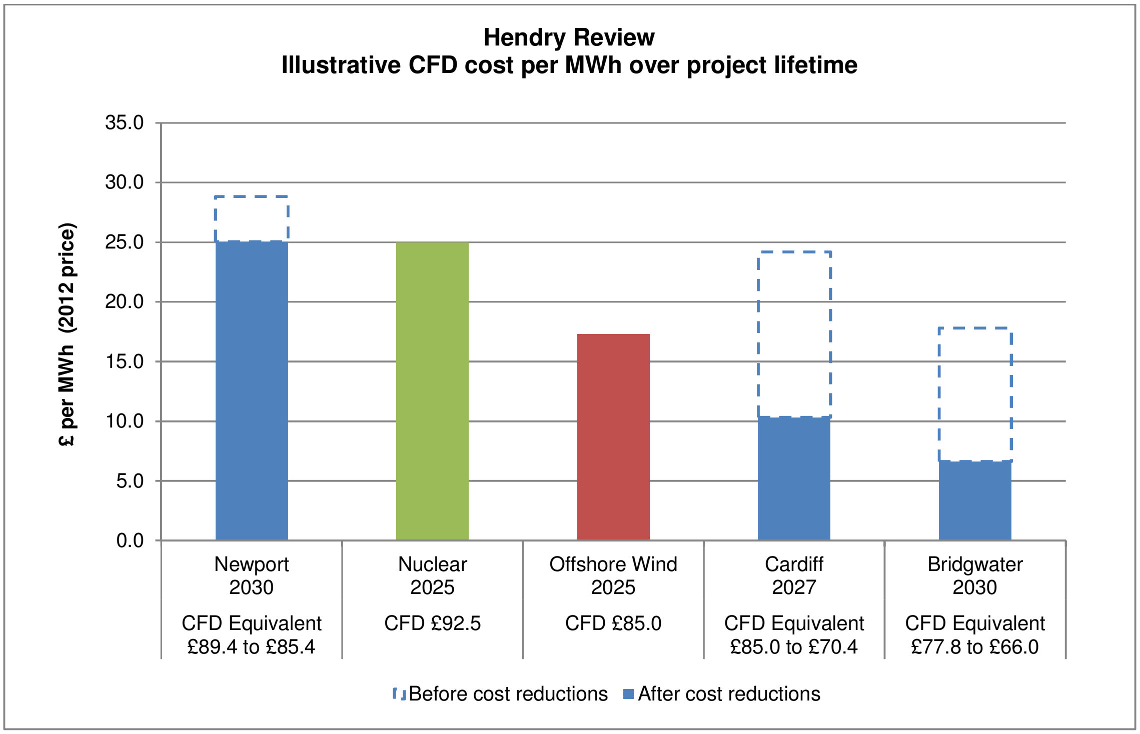
Table 11

Hendry Review – illustrative impact on bills					
2016 prices	**Annual**	**Annual cost per household**			
	Electricity	**Years 1-5**	**Years 1-15**	**Years 1-30**	**Years 1-60**
	Generation	**average**	**average**	**average**	**average**
	GWh	**£2016**	**£2016**	**£2016**	**£2016**
Pathfinder scale					
Tidal Lagoon	550	0.43	0.37	0.31	0.18
Offshore Wind	550	0.17	0.17	0.10	0.05
Nuclear	550	0.23	0.22	0.24	0.14
Large scale					
Tidal Lagoon	5,500	2.10	1.86	1.41	0.49
Offshore Wind	5,500	1.55	1.75	1.06	0.54
Nuclear	5,500	2.10	2.29	2.39	1.40

Source: Hendry Review analysis.
Assumptions include:

- First Operating Years of 2022 for pathfinder scale and 2027 for large scale projects (ramp up of generation from "first power on" not considered).
- Illustrative inflation assumption of 1.5% in 2016, increasing by 0.25% each year to 2.5% in 2020, fixed at this level thereafter.
- Power prices based on *DECC Energy & Emissions Projections - November 2015*. Whilst there is a rationale to assume that prices captured by Offshore Wind would be materially lower than those for Nuclear, the Review has not explored the case for capture prices for Tidal lagoons in detail and has therefore not included any "cannibalisation" adjustment in this analysis.
- Electricity statistics based on *DECC 2015 UK Energy Statistics 2015 & Q4 2015*.

Figure 5



Source: Hendry Review analysis.
Notes: Costs per MWh reflect forecast CFD payments. Tidal lagoon calculations are based on TLP's reported CFD Equivalent values.