HM Government

Department of Energy
and Climate Change

South West RDA

Llywodraeth Cynulliad Cymru
Welsh Assembly Government

SEVERN TIDAL POWER

Feasibility Study Conclusions and Summary Report

OCTOBER 2010

Severn Tidal Power Feasibility Study: Conclusions and Summary Report

Contents

Executive summary

The UK must reduce its carbon dioxide emissions from energy and at the same time enjoy a secure and affordable supply of energy. We are legally committed to reducing our greenhouse gas emissions by 80% by 2050 and to meeting 15% of our energy demands from renewable sources by 2020.

Over the next decade, to achieve our renewable energy goals, the UK must increase the amount of electricity generated from renewables almost 5-fold on 2009 levels. DECC's analysis shows that electricity will play a key role in helping to decarbonise our energy sectors and that overall electricity demand will increase to 2050.

Following a positive recommendation from the Sustainable Development Commission, a 2-year cross-Government feasibility study was launched to inform a decision whether or not to promote a scheme to generate electricity from the tides of the Severn estuary.

The Severn's enormous tidal range could provide up to 5% of our current electricity generation from an indigenous renewable source, and bring new employment opportunity both locally and nationally. But any scheme in the Severn estuary would need to be cost effective compared to other low-carbon energy alternatives. Furthermore, the Severn and some of its tributaries are designated as internationally important nature conservation sites. The study has considered whether Government could support a tidal power project in the Severn estuary and, if so, on what terms.

There are a number of potential Severn power schemes. 10 have been assessed by the feasibility study following a Call for Proposals during 2008. Half of these were judged to be unviable after public consultation in 2009 and were not included in the more detailed – but still high level – consideration that followed. Over the last year the study has looked at the remaining 5 potentially feasible scheme options in outline and assessed their costs, benefits and risks.

The evidence base which is published with this report, the findings of the study, is extensive, particularly the Strategic Environmental Assessment of Severn tidal power. DECC is grateful to all those who have contributed to the development of the evidence base.

The key conclusions of the feasibility study are:

- a tidal power scheme in the Severn estuary could cost as much as £34billion, and is high cost and high risk in comparison to other ways of generating low-carbon electricity;

- a scheme is unlikely to attract the necessary private investment in current circumstances, and would require the public sector to own much of the cost and risk;

- over their 120 year lifetime, Severn tidal power schemes could in some circumstances play a cost-effective role in meeting our long term energy targets. But in most cases other renewables (e.g. wind) and nuclear power represent better value. Moreover as a

Severn scheme could not be constructed in time to contribute to the UK's 2020 renewable energy target, the case to build a scheme in the immediate term is weak;

- the scale and impact of a scheme would be unprecedented in an environmentally designated area, and there is significant uncertainty on how the regulatory framework would apply to it. The study has considered ways in which to reduce impacts on the natural environment and also how to provide compensation for remaining impacts on designated features. It is clear that the compensation requirement would be very challenging, however defined, and require land change within the Severn estuary and probably outside it also;

- a scheme would produce clearer, calmer waters but the extreme tidal nature of the Severn estuary would be fundamentally altered. This means that some habitats including saltmarsh and mudflat would be reduced in area, potentially reducing bird populations of up to 30 species;

- fish are likely to be severely affected with local extinctions and population collapses predicted for designated fish, including Atlantic salmon and twaite shad. This could mean the loss of twaite shad as a breeding species in the UK as 3 of the 4 rivers where it breeds run out into the Severn estuary;

- water levels would also be affected and in order to maintain current flood protection levels in the Severn estuary additional flood defences would be required; these costs are included in the cost estimates for each scheme. In turn, such defences would provide longer-lasting protection to the affected areas;

- overall a scheme is likely to benefit the regional economy with net value added to the economy and jobs created. However these benefits would come at the expense of negative impacts on the current ports, fishing and aggregate extraction industries in the estuary;

- the Cardiff-Weston barrage is the largest scheme considered by the study to be potentially feasible and has the lowest cost of energy of any of the schemes studied. As such it offers the best value for money, despite its high capital cost which the study estimated to be £34.3billion including correction for optimism bias. However this option would also have the greatest impact on habitats and bird populations and the estuary ports;

- a lagoon across Bridgwater Bay (£17.7bn estimated capital cost) is also considered potentially feasible, as is the smaller Shoots barrage (£7bn). The Bridgwater Bay lagoon could produce a substantial energy yield and has lower environmental impacts than barrage options. It also offers the larger net gains in terms of employment;

- the Beachley Barrage and Welsh Grounds Lagoon are no longer considered to be feasible. The estimated costs of these options have risen substantially on investigation over the course of the study;

- combinations of smaller schemes do not offer cost or energy yield advantages over a single larger scheme between Cardiff and Weston. (See map of scheme options in

Figure 5 and an explanation of tidal range technology in Chapter 1);

- in addition, the study funded further work on 3 proposals using innovative and immature technologies. Of these, a tidal bar and a spectral marine energy converter showed promise for future deployment within the Severn estuary - with potentially lower costs and environmental impacts than either lagoons or barrages. However these proposals are a long way from technical maturity and have much higher risks than the more conventional schemes the study has considered. Much more work would be required to develop them to the point where they could be properly assessed. Correspondingly, confidence levels on their yields, costs and impacts (including environmental impacts) are much lower at this point;

- many years of further detailed work would be needed to plan, finance, and assess the impacts of such a large structure as a Severn power scheme before a case could be put forward for planning consent. Even over a period of 2 years this study has only been able to consider feasibility and impact at a strategic level. If consented, the construction times would be between 4 and 9 years depending on the scheme. In addition, any of the schemes would first require new habitats to be created, or species re-introduced, to replace those that would be displaced. These habitats and measures require time to be effective;

- the key indicators of scheme options are shown in table 1.

	Cardiff-Weston	Shoots	Beachley	Welsh Grounds	Bridgwater Bay
Capital Cost (£bn) (ob[1] inc)	23.2 (34.3)	4.7 (7.0)	3.5 (5.1)	6.8 (10.1)	12.0 (17.7)
Energy Generated (TWh/yr[2])	15.6	2.7	1.2	2.6	6.2
Levelised Costs – Investor (10%) - £/MWh[3] optimism bias included	312	335	419	515	349
Levelised Costs – Social (3.5%), optimism bias included	108	121	151	169	126
NPV (£bn)[1], optimism bias included	-4.6	-1.7	-2.1	-4.5	-4.8
Carbon Pay Back (yrs)	2.6	3.5	2.8	6.1	3.2
CO_2 Emissions Displaced During Operation (MT[4])	73	13	7	12	29
Regional GVA[5], £bn	2.4 (-0.8 – 6.1)	0.9 (0.3 – 2.0)	0.5 (0.1 – 1.3)	1.2 (0.4 – 2.7)	2.3 (0.5 – 4.6)
Regional Net Construction employment (central estimate, possible range in brackets)	840 (-1,600 – 5,500)	1,240 (600 – 4,000)	940 (600 – 2,000)	1,740 (600 – 5,000)	3,240 (1,000 – 7,000)
Regional Net Operation employment (central estimate, range in brackets)	120 (-2,000 – 800)	80 (-100 – 250)	-20 (-150 – 150)	-40 (-100 – 250)	290 (-250 – 700)
Intertidal- habitat Loss (km2[6])	118-163	27-37	21-30	61-82	16 26
% Intertidal Habitat lost	40-50%	8-12%	7-9%	19-26%	5-8%
Ha[7]/TWh gen	1,026	1,222	2,250	2,808	403
Fish	Reduction in Wye and Usk for sea and river lampreys, and eel (also in Severn). Possible local extinction of twaite shad and salmon in Severn, Wye and Usk	Possible local extinction in Wye and Severn for salmon, twaite shad, sea lamprey (Wye only) Reductions for eel in Wye and Severn, twaite shad in Usk and Twyi	Possible local extinction in Wye, Severn and Usk for Atlantic salmon and twaite shad, sea and river lamprey (not Severn), reductions in eels	Possible local extinction of Atlantic salmon and twaite shad, reductions in sea and river lamprey in Severn, Wye and Usk.	Reductions in River Usk and Wye sea and river lamprey, for eel (also in Severn). Possible local extinction twaite shad and Salmon in Wye, Usk and Severn
Birds Species-Significant declines	30	17	15	13	9
km[2] land drainage effected	372	97	73	47	243

[1] Taken from Impact Assessment. NPV calculated against 'technology mix' counterfactual where Severn output replicated by one-third coal with CCS, one-third nuclear and one-third offshore wind. Results include Optimism Bias.

Key	Unit/Acronym	Description
1	Ob	Optimism bias
2	TWh	TerraWatt hours
3	MWh	MegaWatt hours
4	MT	Million tones
5	GVA	Gross Value Added
6	Km2	Square Kilometres
7	Ha	Hectares

Table 1: The key indicators of scheme options

In the light of these findings the Government does not see a strategic case to bring forward a Severn tidal power scheme in the immediate term. The costs and risks for the taxpayer and energy consumer would be excessive compared to other low-carbon energy options. Furthermore, regulatory barriers create uncertainties that would add to the cost and risk of construction. The Government believes that other options, such as the expansion of wind energy, carbon capture and storage and nuclear power without public subsidy, represent a better deal for taxpayers and consumers at this time.

However, the Government recognises that factors which will determine the feasibility of Severn tidal power could change over time. There are circumstances in which a future Government may choose to review the case for Severn tidal power. A list of potential triggers is set out in Chapter 9, so that it can be considered by the Committee on Climate Change in the work they will be doing on the amount of renewable energy that is required to meet the UK's 2050 greenhouse gas reduction target. It is not expected that a review would take place before 2015 at the earliest.

The huge scale of a Severn tidal power scheme is unique. The development of tidal range options elsewhere in the UK is being considered separately by the private sector. While we hope the study will be useful to other feasibility studies, it should be noted that its conclusions do not bear on schemes outside the Severn estuary.

How to respond

Given the findings of the feasibility study we are not consulting on the study conclusions. We will however accept any factual comment or evidence which could enhance the evidence base.

If you would like to submit factual comments on the summary report and supporting documents we would be pleased to receive them in the Severn tidal power mailbox severntidalpower@decc.gsi.gov.uk by 17 January 2011.

Related documents can be found on the Severn tidal power website www.decc.gov.uk/severntidalpower

These include the key documents listed below, some of which are in abridged form. If you would like to receive a DVD of the full versions of the reports please email your request to STPfulldocuments@pbworld.com with your full postal address (one copy per enquirer).

Key documents;

- Options Definition Report
- Impact Assessment
- Phase 2 Regional Economic Impacts Study
- Strategic Environmental Assessment (SEA) Environmental Report (including theme reports and topic papers)
- Report to Inform a Stage 1 (Screening) Habitats Regulations Assessment
- Report to Inform a Stage 2 (Appropriate Assessment) Habitat Regulations Assessment
- Severn Tidal Commercialisation Assessment
- Grid Study
- Supply Chain Study
- Severn Embryonic Technologies Scheme Reports

1. Background

- The UK has world class wave, tidal stream and tidal range resources.
- The 14 metre tidal range of the Severn estuary is amongst the largest in the world.
- Following a positive recommendation from the Sustainable Development Commission, a two-year cross-Government feasibility study was launched to gather evidence to decide on whether or not to promote a tidal power scheme in the Severn estuary. A scheme could generate 5% of current UK electricity consumption.
- To decide whether there is a strategic need for a Severn scheme, its potential role in reaching renewable energy and climate change targets, and its cost effectiveness, have been studied.
- The Severn estuary is also an important nature conservation site and careful consideration of the benefits, consequences, risks and costs is required in reaching a decision on whether to take forward any development.
- Five schemes have been studied in outline following a public consultation in early 2009. These include a barrage from near Cardiff to Weston-super-Mare, two smaller barrages further upstream (Shoots and Beachley) and two lagoons (Bridgwater Bay on the English shore and Welsh Grounds on the Welsh shore). A map of schemes can be found at Figure 5 and an explanation of tidal range technology in chapter 2.
- The study has considered the amount of energy that could be generated by each of these schemes, their costs, and ways in which any negative impacts on the environment or region could be reduced. It has looked at:
    - how to build a Severn tidal power scheme;
    - the commercial risks associated with building and operating a Severn tidal power scheme;
    - how the Severn estuary would change with a Severn tidal power scheme, including what effect this would have on the people, wildlife and economy of the surrounding areas (through a Strategic Environmental Assessment (SEA)); and
    - how negative impacts could be mitigated including through provision of compensatory natural habitat.
- The study (through the Severn Embryonic Technology Scheme) has funded the development of 3 immature technologies that may have the potential to be less environmentally damaging.

The UK's wave and tidal opportunity

The UK is a global leader in the development of both wave and tidal stream technologies and has a uniquely rich wave and tidal resource. Work carried out by RenewableUK and the Carbon Trust has suggested the wave and tidal stream resource could meet as much as 15-20% of the UK's current electricity demand once established. Estimates for total UK tidal range potential are that it could meet 10-15% of the UK's current electricity demand.

However, there are uncertainties about the wave and tidal resource not only due to the immature and developing state of much of the industry where it is difficult to make resource predictions far into the future with any accuracy but also the uncertainty in the methodologies used in the resource assessment calculations.

Marine energy is split into three types: tidal stream, wave and tidal range and their resource is mapped in Figures 1-3 below. Wave and tidal stream technologies (and those innovative tidal range technologies included within the Severn Embryonic Technologies Scheme) are not yet developed to a commercially viable scale. The challenge for emerging wave and tidal stream technologies is to prove that they can generate electricity reliably and economically.

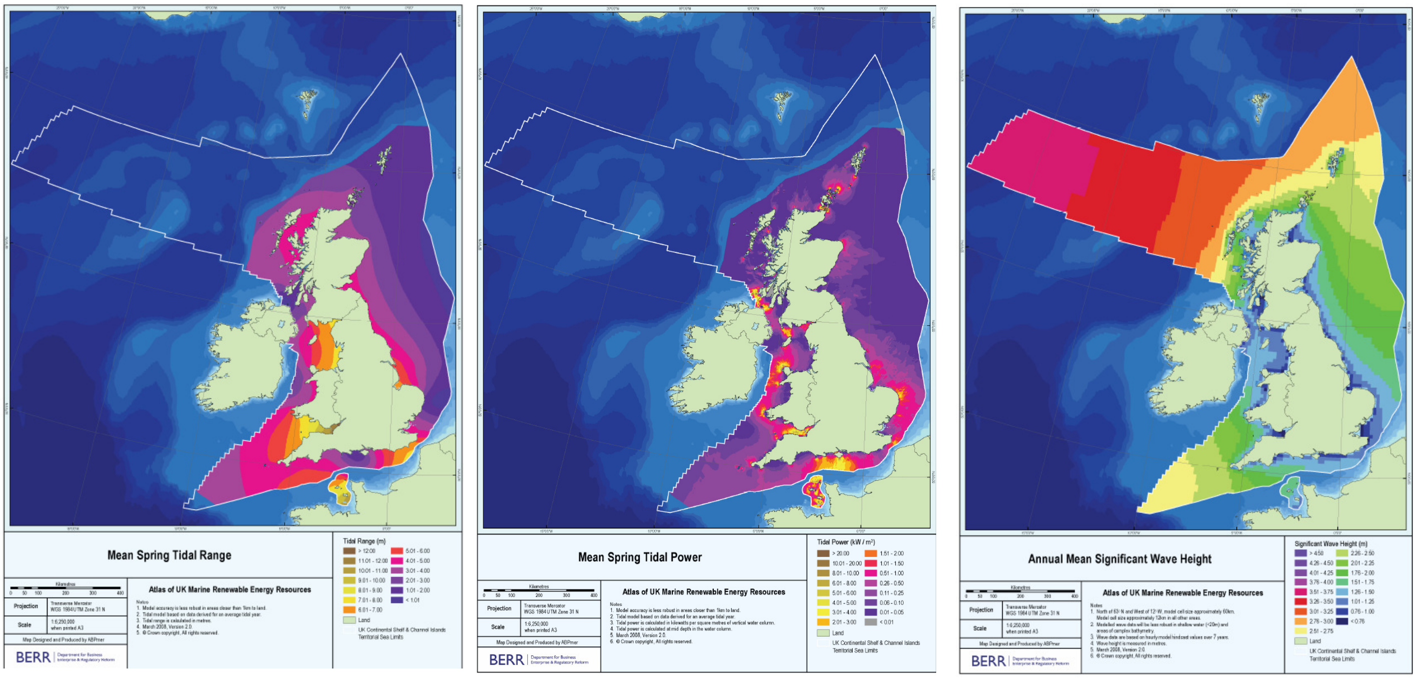

Figure 1: Mean Spring tidal range; Figure 2: Mean Spring tidal stream and Figure 3: Annual mean significant wave[13]

Government is helping to meet that challenge and to introduce measures to encourage the development of marine energy[2]. In discussions with the industry, the Government provided a vision for the marine energy sector in the future, and set out the key steps both industry and the Government will need to take to achieve mainstream deployment of wave and tidal stream energy around the UK's coasts by 2020/2030.[3] The Government is committed to harnessing the benefits which a successful marine renewable sector can bring to the UK and is currently considering the specific measures by which we will achieve this.

The UK is at the forefront of the wave and tidal stream renewable energy industry through its research and development programmes, test facilities and marine and offshore experience gained from the oil and gas industries. The UK Government has provided funding for device development and also shown its support for the industry through the UK's dedicated test facilities - the National Renewable Energy Centre (NaREC) and the European Marine Energy

2 The Coalition: our programme for Government, 2010
3 Department of Energy and Climate Change (2010) *Marine Energy Action Plan*

Centre (EMEC), in addition to WaveHub, a new demonstration facility in the South West that will be commissioned during 2010.[4]

In recent years there has been significant progress in the marine industry with the testing of full-scale prototype devices at sea and the installation of the first grid-connected deep water wave energy device and tidal stream devices.[5] A Strategic Environmental Assessment of offshore energy is also currently underway, including wave and tidal technologies. This, alongside complementary assessment for Scotland and Northern Ireland, should open up UK waters for potential deployment of marine energy devices such as those recently licensed by the Crown Estate.

In March 2010, The Crown Estate announced these first commercial leases of the seabed in the Pentland Firth and Orkney Waters and anticipates the deployment of commercial wave and tidal stream technologies to begin in the period up to 2015.

Tidal Stream

Tidal stream technologies harness the energy from the tides through the sheer velocity of the currents turning the blades of an underwater turbine (the majority of turbine designs are not dissimilar to a submerged wind turbine).

The tidal stream resource is largest off the north eastern coast of Scotland (the Pentland Firth), Strangford Lough in Northern Ireland, The Skerries off the coast of Anglesey, Wales, and the Channel Islands, where constrictions of tidal channels funnel water creating increases in flow velocity.

The development of devices to capture the energy from tidal streams is still a very immature industry and estimates of resource remain highly uncertain. It has been widely quoted that the total UK tidal stream potential is of the order of 17TWh/year.[6] This is derived from a method that provides the most conservative estimate,[7] however other methods of estimating the tidal stream resource have resulted in higher technical potentials of up to 197TWh/year.[8,9] There are still uncertainties regarding these pieces of work but the potential resource they suggest is sufficiently large to justify further research by Government.

Wave

Wave energy is created as winds pass over open bodies of water, transferring some of their energy to form waves, which can then be captured by wave conversion technologies to provide power either on the shoreline or in deeper waters offshore.

4 Carbon Trust(2009) *Focus for Success*
5 British Wind Energy Association, (2006) *Path to Power*
6 Sinclair Knight Merz (2008) *Quantification of Constraints on the Growth of UK Renewable Generating Capacity*
7 Blunden, L. S., Bahaj, A.S., (2006) *Tidal energy resource assessment for tidal stream generators*
8 Houlsby, G.T., Oldfield, M.L.G., Draper, S.,(2008) *The Betz Limit and Tidal Turbines*
9 David J.C. MacKay (2008) *Sustainable Energy - Without the hot air*

Geographically, the largest wave resource is located off the west coast of Scotland and south west England/Wales, where the fetch (the distance travelled by waves without an obstruction) is across the Atlantic.

Estimates indicate that the practical resource level for wave energy in UK waters is in the order of 50 TWh/year, but estimates of the technical potential extend up to 157 TWh/year.[10,11] However, this is dependent on the assumptions relating to the feasible length of a wave farm and the extent to which devices can extract power from the on-coming waves. Those assumptions are difficult to confirm when the technology capability is still developing.

Tidal range

Tidal range is the vertical difference between the high and low tide. Tidal range technologies make use of this height difference to generate electricity by creating a differential in the water levels either side of a structure and then passing this water through turbines. There are currently two main commercially deployable tidal range designs – barrages and lagoons. Barrages work by building a wall or 'barrage' across an estuary, creating a hydroelectric dam. This is achieved by placing a number of large concrete caissons (blocks) across the estuary, some of which would house conventional hydro-electric turbines and others sluice gates with the rest of the structure being embankment.

Electricity is generated by allowing the incoming tide to pass through sluices in the barrage. This body of water is then held as the tide ebbs. When the water level on the seaward side of the barrage is low enough the water behind the barrage is released back to the seaward side through the turbines generating electricity. Lagoons work on similar principles but impound areas of water rather than forming a barrier across an estuary. An alternative mode of operation is called two-way or ebb/flood generation.

Although the technology is available, there are only a small number of tidal range projects in the world, all barrages. This is mostly due to the limited global tidal range resource and high upfront costs. The largest projects are the La Rance 240MW tidal barrage in Northern France which has been successfully operating since the 1960s and the 1984 18MW barrage in Annapolis, Canada. In South Korea, a 254MW barrage is expected to be commissioned in Sihwa later this year, and a 520MW barrage is planned for Garolim Bay. No tidal energy lagoons have yet been built.

There are other technologies being investigated, though much less well developed and more akin to early stage development of tidal stream and wave technologies than conventional tidal range capture. Some of these are discussed in chapter 7.

The UK's largest single tidal range resource is located in the Severn estuary. There are also significant sources in other estuaries like the Solway, Mersey and smaller resources in the Dee, Duddon, Wyre and Conwy estuaries in the West, and the Thames, Humber and Wash in the East. Feasibility studies have recently been carried out for projects in the Solway Firth and Duddon estuaries, and another is underway for the Mersey

10 Carbon Trust (2006) *Future Marine Energy*
11 LEK-Carbon Trust (2008) *Low Carbon Technology Commercialisation Review*

Figure 4: La Rance tidal power plant

Location	Mean Tidal Range (m)	Estimated Maximum Installed Capacity (MW)	Predicted Annual Energy Output (GWh)
Severn	14	13,500	19,700
Solway Firth	5.5	7,200	10,250
Morecambe Bay	6.3	3,000	4,630
Wash	4.45	2,400	3,750
Humber	4.1	1,080	1,650
Thames	4.2	1,120	1,370
Mersey	6.45	700	1,320
Dee	5.95	840	1,160

Table 2: UK Tidal range resource[12]

The Severn

The Severn estuary's 14m (45 foot) tidal range represents a phenomenal source of indigenous, predictable (though intermittent), low-carbon energy. In the 2006 Energy Review

[12] Based on Binnie & Partners 1989 study,(ETSU 1989) and , Professor Burrows (University of Liverpool) and Proudman Oceanographic Laboratory (POL) 2008 study on "Tapping the Tidal Power Potential of the Eastern Irish Sea"

the Government asked the Sustainable Development Commission (SDC) to investigate tidal power opportunities across the UK.

The SDC[13] report published in October 2007 suggests that the majority of the UK's practical tidal range resource is in the Severn estuary, which could produce 5% of the UK's electricity needs. The SDC report concluded, with conditions, that there is a strong case for a sustainable Severn barrage from Cardiff (Lavernock Point) to Weston-super-Mare (Brean Down).

The SDC set a number of conditions on its support. These were that:

- a Severn barrage should be part of much wider action on climate change;
- a scheme must comply with environmental protection legislation and the provision of compensatory habitat should be an integral part of any proposal. Early work on scientific and legal feasibility of compliance and cost should be a priority;
- Government should be willing to own and lead a Severn energy scheme and consider a range of innovative financing mechanisms; and
- a Cross-Government approach should be taken, with open and transparent engagement with key stakeholders.

The report did not recommend tidal stream generation for the Severn estuary due to its early stage of development and the greater potential elsewhere in the UK.

The SDC noted the other potential tidal range sites in the UK (such as the Mersey, Wyre and Thames) but considered that these could go ahead with more limited Government involvement than might be required in the Severn estuary due to their smaller size. This has proved to be the case with several feasibility studies underway for other estuaries, funded by a variety of organisations.

Given this positive recommendation by the SDC, the Government announced a feasibility study on harnessing the renewable energy from the tidal range in the Severn estuary and published its terms of reference in January 2008 (http://www.berr.gov.uk/files/file43810.pdf).

The aim of the feasibility study has been to:

- assess, in broad terms, the costs, benefits and impact of a project to generate power from the tidal range of the Severn estuary, including environmental, social, regional, economic, and energy market impacts;
- if applicable, identify a single preferred tidal range project (which may be a single technology/location or a combination of these) from the number of options that have been proposed;
- consider what measures the Government could put in place to bring forward a project that fulfils regulatory requirements, and the steps that are necessary to achieve this; and
- decide, in the context of the Government's energy and climate change goals and the alternative options for achieving these, whether the Government could support a tidal power project in the Severn estuary and, if so, on what terms.

[13] Sustainable Development Commission (Oct 07) "Turning the Tide, Tidal Power in the UK" http://www.sd-commission.org.uk/publications.php?id=607

The Severn estuary and its tributary rivers the Wye and Usk are all designated as internationally important nature conservation sites. They are designated for the species and habitats that occur in them, including migratory fish and over-wintering birds. The estuary is also designated for its estuarine habitats including mudflat and saltmarsh. These are important ecosystems that form part of a network of European wildlife habitats called Natura 2000.

A tidal power scheme in the Severn estuary would also impact on local communities and industries, as well as energy users and producers across the country.

A Severn tidal power project would bring benefits and costs and risks. An assessment of these is set out in this summary report. Also published are the key supporting documents that have been prepared for the study including those produced by external consultants. Whether or not to go ahead with a Severn power generation scheme needs to be considered in the context of the alternative means of meeting our energy and climate change goals.

Schemes studied

Ten proposals to generate electricity from the Severn estuary came forward from a public Call for Proposals in May 2008 and a strategic review of existing options studied in the SDC's and previous reports. Proposals included barrages, land-connected and offshore lagoons, a tidal fence and a tidal reef. The proposed schemes were in varying stages of development. Some proposals were based on entirely embryonic technologies which have not been prototyped or deployed. Locations varied too, with the largest scheme, the Outer Barrage, spanning the estuary from Minehead to Aberthaw (15 miles) and the smallest lying upstream of the Severn road crossings. Energy outputs also vary with the largest option (the Outer Barrage) estimated to generate up to 7% of UK electricity and the smallest generating roughly the same output as a large fossil fuel power plant.

A public consultation during January-April 2009 considered which of the proposals should be studied further. The aim of scheme selection at this point was to identify scheme proposals that were not feasible, and eliminate them from further investigation. Those short-listed were considered to be potentially feasible, subject to further investigation.

Several factors were used to determine feasibility:

- technical risk;
- construction cost and the cost of energy produced;
- how this cost compared to other ways of meeting our energy and climate change goals; and
- affordability – the burden on taxpayers and energy consumers and the role that Government would have to play in delivering the project.

The following additional factors were used to judge whether more costly schemes presented benefits that justified further study:

- environmental impact – a high-level view, through the undertaking of a Strategic Environmental Assessment (SEA) on schemes' environmental impact. Predicted habitat loss was used as an indicator of the scale of impact and potential 'benefits' were taken as the scope for a reduced detrimental effect on the environment;

- regional impact – a high level view on anticipated impacts on ports, fishing and employment.

The short-listing process did not attempt to establish whether the harm caused to the environment or the regional economy was unacceptable, nor did it rule out schemes on these two grounds. Greater detail on these impacts has been gathered over the later phase of the study.

The schemes short-listed following the public consultation were:

- **Cardiff-Weston barrage –** spanning the Severn estuary from Brean Down to Lavernock Point
- **Shoots barrage –** downstream of the second Severn road crossing
- **Beachley barrage –** slightly smaller and further upstream than the Shoots barrage, and upstream of the Wye.
- **Welsh Grounds lagoon –** impoundment on the Welsh shore of the Estuary between Newport and the Severn road crossings.
- **Bridgwater Bay lagoon –** impoundment on the English shore between Hinkley Point and Weston-super-Mare.

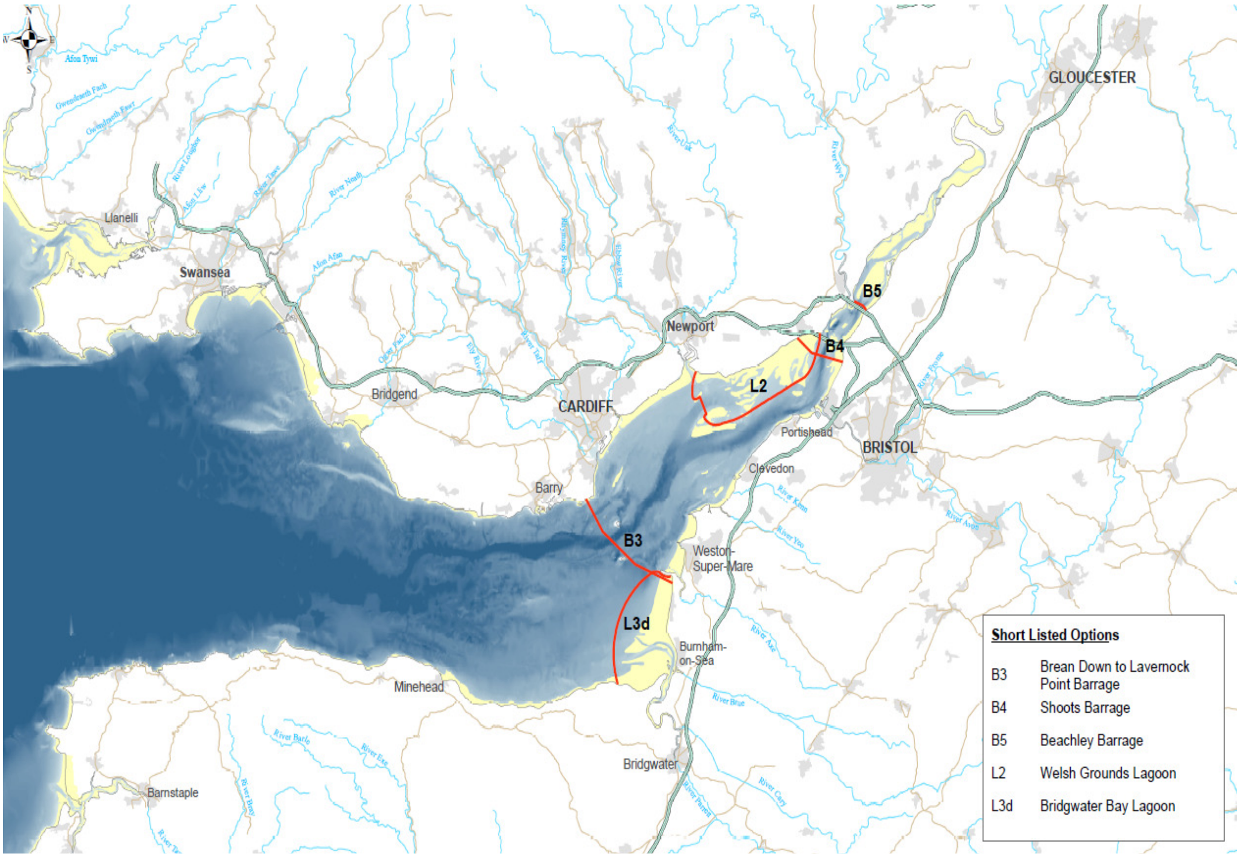

Figure 5: Map of shortlisted schemes

The short-listed schemes use turbine technology that has been tried and tested in hydro-electric dams across the world. There are no technology barriers to their immediate deployment. However, the study also wanted to understand the proposals on the long-list that were less well developed but which could possibly extract energy from the Severn with less environmental impact. These options were not considered feasible because of their high degree of technical risk; they are highly conceptual and need additional work to take them forward. The Severn Embryonic Technologies Scheme (SETS) was established to develop embryonic proposals further to help inform whether the benefits claimed for them could be realised, and when. 3 proposals were funded under the scheme and are discussed in chapter 7.

Progress since public consultation

Since mid 2009, the feasibility study has completed a number of studies to consider what the costs, impacts and risks of a Severn tidal power scheme would be. This includes a strategic consideration of:

- how to build a Severn tidal power scheme;
- the commercial risks associated with building and operating a Severn tidal power scheme;
- how a Severn tidal power scheme would change the estuary, and what effect this would have on the people, economy and wildlife of the surrounding areas; and
- how negative impacts on the natural environment could be reduced or mitigated, including provision of compensatory environmental measures.

A key part of the study process has been the definition of scheme options and consideration of ways to improve the amount of energy generated, costs, and environmental and regional impacts.

As more information on the environmental and social effects of the schemes came through the SEA, measures to prevent or reduce adverse effects were also incorporated to provide the scheme designs that are presented here. As a result the schemes and their costs have evolved since public consultation last year. For example, the Bridgwater Bay lagoon proposal now has a much larger energy yield (and construction cost) than before, although its footprint within the estuary has stayed the same. Energy yield from the Cardiff-Weston barrage has decreased as measures to reduce environmental impacts have been included. In addition, the study moved from an assessment approach of ‘fair basis methodology’ (which used common information that could be applied to all schemes), to one of scheme- specific information (where available) to establish more accurate costs, designs and impacts for each scheme. Energy yields and environmental impacts have been calculated using various methodologies (including computer modelling) appropriate to this strategic level study.

Scheme	Installed Capacity (MW)	Annual Energy Generated (TWh/yr)	Levelised Energy Cost (£/MWh), Optimism Bias included		Intertidal Habitat Loss (km2)
			Investor (10% discount rate)	Social (3.5% discount rate[1])	
Cardiff-Weston Barrage	8640	15.6	312	108	160
Shoots Barrage	1050	2.7	335	121	33
Beachley Barrage	625	1.2	419	151	27
Welsh Grounds Lagoon	1000	2.6	515	169	73
Bridgwater Bay Lagoon	3600	6.2	349	126	25

Table 3: scheme summaries

(1) The discount rate declines over time according to the profile set out in the Green Book.

The Treasury Green Book sets out the core principles and methodology on which all public sector economic assessment of the social costs and benefits of all new policies, projects and programmes is based. These have been used in the feasibility study – including in short-listing options, valuing the costs and benefits, discounting (a technique used to compare costs and benefits that occur in different time periods by using a discount rate to convert all costs and benefits to 'present values', so that they can be compared) and adjusting for both risk and optimism bias.

In order to compare Severn schemes and other low carbon options we have used:

- **Net Present Values (NPV)**: NPV is the net of the Present Value of the benefits and costs of a Severn scheme compared to those of alternative ('counterfactual') generation technologies that might be built instead and which produce an identical amount of electricity over the same time period. We have considered a range of alternative technologies: nuclear; offshore wind; coal with carbon, capture and storage; and a mix of these three technologies. Costs and benefits are discounted at Green Book social time preference discount rates (see below).

- **Levelised Energy Costs (LECs)**: LECs calculate the per unit electricity cost (typically in £/MWh) of a generation technology. Levelised costs are calculated by dividing the present value (PV) of project costs by the PV of the amount of energy the technology generates, using an appropriate discount rate.

The study has used two main discount rates to calculate levelised costs:

- **Social:** Treasury Green Book Social Time Preference Rate (STPR), to assess the attractiveness of different energy technologies from a societal perspective. Social Time Preference is defined as the value society attaches to present, as opposed to future, consumption
- **Investor:** 10%, to illustrate a private sector investor's cost of capital (and Time Preference Rate). This thereby reflects the attractiveness of a technology from the point of view of a private sector investor. It should be noted that the 10% is a purely illustrative cost of capital and not the result of any detailed analysis.

The cost and energy streams used to calculate costs for Severn schemes come from a different source (Parsons Brinkerhoff) from those for other generation technologies, which are based on assumptions developed by Mott-Macdonald[14]. To make comparisons between Severn and other technologies valid the same drivers of costs are included in both estimates. For example, all costs include adjustments for risk and optimism bias where applicable. The costs for these other generation technologies are for Nth of a Kind (NOAK) plants rather than first of a kind (FOAK) plants, i.e. deployment of the technologies has led to some cost reductions due to learning effects. NOAK has been chosen to reflect that Severn schemes could potentially begin generation between 2018 and 2021, meaning that costs for other generation technologies will have fallen due to learning benefits from other, earlier projects. The choice of NOAK costs also reflects the fact that generating capacity for these technologies tends to be commissioned in fleets, rather than individual plant, meaning that risks related to constructing and running the first plant are spread across the fleet as a whole. To calculate the levelised costs below, we have assumed that generation of these technologies would start in 2020.

Levelised Cost, £/ MWh	Discount Rate			
Counter-factual technology	**Social (3.5%) (Optimism Bias Included)**	**Social (3.5%) (No Optimism Bias)**	**Investor (10%) (Optimism Bias included)**	**Investor (10%) (No Optimism Bias)**
Coal with CCS	133	83	176	110
Nuclear	41	36	79	69
Offshore Wind	102	82	160	129

Table 4: Levelised costs £/MWh of counter-factual technologies, optimism bias included

[14] Mott MacDonald, 'Electricity Generation Costs Update', June 2010.

2. The scale of the challenge

- The UK must reduce its carbon dioxide emissions from energy and at the same time have a secure and affordable supply of energy. We are legally committed to reducing our greenhouse gas emissions by 80% by 2050 and to meeting 15% of UK energy demand from renewable sources in 2020.
- To achieve these goals, the UK must increase the amount of electricity sourced from renewables almost five-fold from current levels over the next 10 years and consider decarbonising our electricity sector almost completely by 2030.
- DECC's analysis shows that electricity will play a key role in helping to decarbonise UK energy sectors so overall electricity demand will increase. This means an expansion of many low carbon technologies particularly energy from nuclear, offshore wind and carbon capture and storage. There are delivery risks for each of these technologies.
- Over their 120 year lifetime, some Severn tidal power schemes represent similar and in some cases better value for society than equivalent investment in coal generation with carbon capture and storage (CCS). As such Severn tidal power could in some circumstances play a cost-effective role in meeting our long term energy targets. Nuclear and offshore wind represent better value than Severn schemes, based on our current estimates of future technology costs
- As it is unlikely that a Severn tidal power scheme could be generating by 2020 and therefore contribute to the UK's 2020 renewable energy target we do not see a case for the Government to bring forward a scheme immediately

2020 – Renewable Energy Strategy

The UK has committed to sourcing 15% of its energy from renewables by 2020 – an increase in the share of renewables by a factor of five (from 2009) in scarcely more than a decade. This is part of EU-wide action to increase the use of renewable energy.

The precise breakdown of the 2020 renewable energy target between technologies will depend on how investors respond to the incentives put in place. However, our modelling suggests that renewables could provide more than 30% of our electricity (compared to around 6.7% today[15]). More than two-thirds of that 30% could come from onshore and offshore wind, but there could also be important contributions from hydro, sustainable bioenergy, marine sources and small-scale technologies. 12% of our heat could come from sustainable biomass, biogas, solar and heat pumps, supplying the equivalent of 4 million households with their current heating demands. Renewable sources could also provide up to 10% of our road and rail transport energy.

[15] Source: Digest of Energy Statistics (DUKES), 2009 renewables share of output

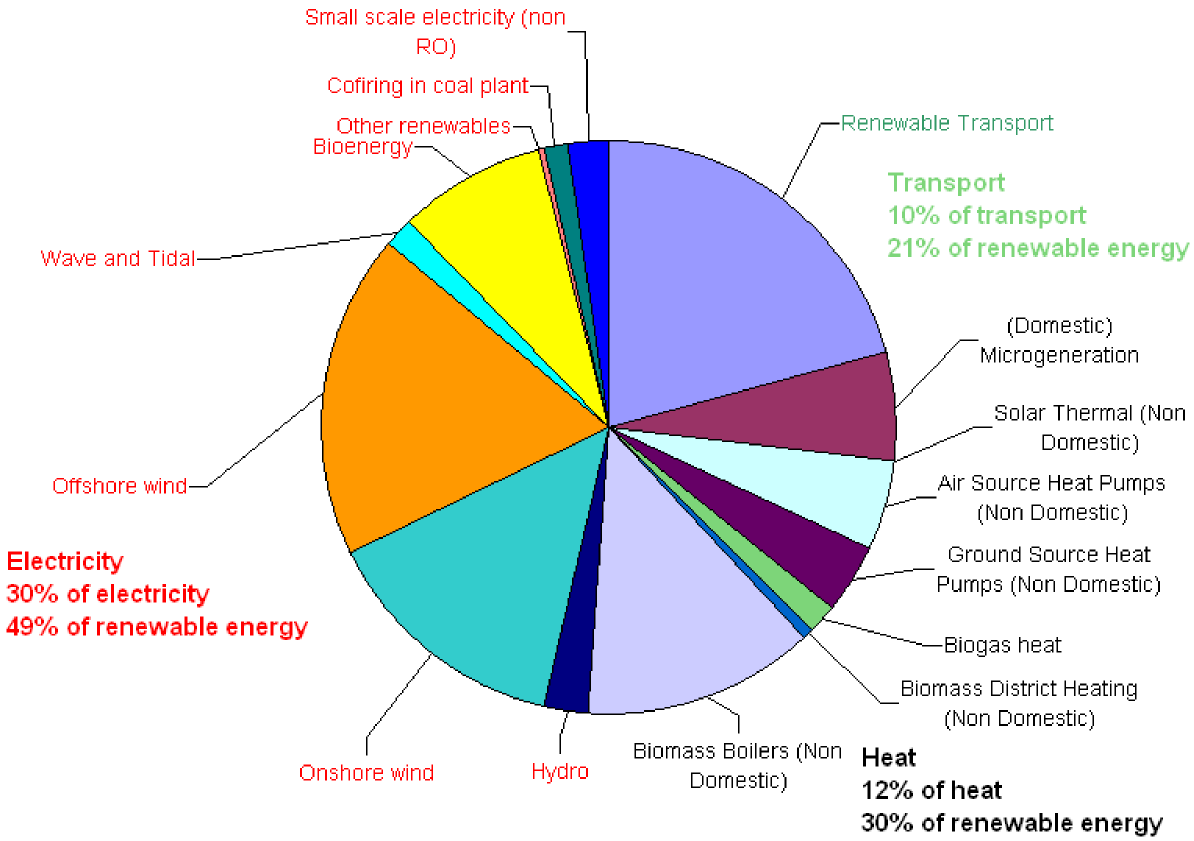

Figure 6: Illustrative mix of technologies in lead scenario for meeting the UK's share of the Renewable Energy Directive

The Renewable Energy Strategy included a Severn tidal power scheme as an option but provided various scenarios in which the UK could meet our share of the European renewable energy target without electricity from the Severn estuary.

The UK submitted in July 2010 a UK National Renewable Energy Action Plan [16] as defined in Article 4 of the European Renewable Energy Directive (2009/28/EC). The Plan is based on a template set by the European Commission, which asks for the trajectory and measures that will enable the UK to reach its target for 15% of energy consumption in 2020 to be from renewable sources.

The 'lead scenario' set out in the UK Plan demonstrates that it is possible to achieve the 15% target and provides one view of the technology mix in 2020. However, this scenario does not represent a target for any particular sector or technology and it should not be seen as an upper limit to the UK's ambition for renewables deployment.

The Government's aims are to secure UK energy supplies through 2020 and beyond, to grow the green economy and to cut harmful greenhouse gases. *The Coalition: our programme for government*[1] sets out a range of proposals to ensure the UK gains full benefit from our renewable energy resources.

16 http://www.decc.gov.uk/en/content/cms/what_we_do/uk_supply/energy_mix/renewable/ored/uk_action_plan/uk_action_plan.aspx

The UK Committee on Climate Change has been asked to review the level of ambition for renewables that is required to meet the 2050 green house gas reduction target. The Committee is expected to report next year. The Government has also committed to give an Annual Energy Statement to Parliament to set strategic energy policy and guide investment in all forms of energy including renewables. At the European level we are pushing for greater leadership in tackling international climate change by supporting an increase in the European Union emission reduction target to 30% by 2020 (from 1990 levels).

2050

The UK has a long-standing commitment to avoiding dangerous climate change and has a legally binding target to cut greenhouse gas emissions by at least 80% by 2050**.** Carbon budgets have been determined for the period to 2022 to prepare the way to meeting the 2050 target. The road from 2022 onwards is less clear. The shape of the trajectory, relative contribution of different sectors, and the potential for imported credits are all uncertain. It is however clear that that in the 2020s, 30s and 40s, we will have to step up the rate of progress, reducing emissions by an average of 4% each year.

DECC's assessment of how the UK can make the crucial long-term shift to a low carbon economy is set out in the 2050 roadmap analysis published in July 2010[17]. This considers a range of plausible ways to reduce emissions and retain a secure and reliable energy system, whilst maintaining a strong economy and protecting the most vulnerable. The analysis does not attempt to provide answers but sets out some of the choices that we, as a country, will need to make. It describes the key challenges, opportunities, trade-offs and uncertainties faced, including how much can be achieved through energy efficiency and potential lifestyle changes.

85% of current greenhouse gas emissions are produced by burning fossil fuels to produce energy[18]. Therefore, reducing emissions means finding different, practical ways in which the UK can power homes, businesses and transport using low carbon forms of energy. One of these ways is to provide more energy from electricity which is generally accepted to be easier to de-carbonise than other energy sources. Even with energy efficiency measures in place, the UK will need to produce significantly more electricity than at present – the scenarios set out in the 2050 pathways analysis show a 60 – 100% increase.

The key sources of low carbon electricity are nuclear, gas/coal generation with carbon capture and storage (CCS) and renewables. This could mean deploying about 12,000 offshore-wind turbines (5 MW each), 8,000 onshore wind turbines (2.5 MW each) and a quadrupling of nuclear generating capacity quadrupling from today's levels by 2050. In 2050, the UK may need the equivalent of about 30 nuclear power stations (assuming capacity of 1.4 GW) and 30 combustion plants fitted with CCS (assuming a capacity of 1.5 GW each).

These supplies must also be secure. Reserves of domestic oil and gas are declining and without action, the UK will become increasingly reliant on imports at a time when world

[17] http://www.decc.gov.uk/en/content/cms/what_we_do/lc_uk/2050/2050.aspx
[18] UK GHG Inventory (2007)

primary energy demand is set to increase by 17-30% by 2030[19]. Increasing proportions of imports leave us dependent on geopolitical events for our energy and vulnerable to rising prices. Other countries – e.g. USA, China, South Korea are also investing heavily in renewables and nuclear to keep their energy secure. The UK must continue to respond to these global energy challenges.

In March 2010, in conjunction with the Treasury, DECC set out initial conclusions on the capacity of the electricity market to deliver clean, secure and affordable supplies of electricity in the long-term in an Energy Market Assessment[20]. The market is already delivering investment in the new infrastructure necessary to decarbonise and ensure continued security of supply to 2020. But the challenges of the decades ahead will be significant as the UK seeks to move to a low carbon economy. All low carbon technologies require large upfront capital investment. This investment will not be forthcoming unless we deal with major constraints that go across all technologies:

- while the EU Emissions Trading System is delivering emissions reductions via its effective cap across the UK and Europe, the carbon price it sets has not been sufficient in giving stable, long-term signals to generators and has therefore not been incentivising the required levels of new low carbon investment;
- the structure of the electricity market does not support the scale of new investment required;
- it can be hard to tap into the financial markets to catalyse private sector investment.

Tackling these issues is central not only to our energy security, but to enabling UK businesses to seize the economic opportunities of the move to a low carbon energy supply. First, underpinning all low carbon generation technologies, we need a stronger carbon price signal. The Chancellor set out in his Budget in June 2010, plans for public consultation in the Autumn on reforming the climate change levy to provide more certainty and support to the carbon price. Subject to that consultation, the Government will bring forward relevant legislation in Finance Bill 2011.

The Government is also conducting a detailed appraisal of the way the electricity market should be designed. The Electricity Market Reform project will assess the role that supporting the carbon price, emissions performance standard, revised Renewables Obligation, Feed-in Tariffs, capacity mechanisms and other interventions could play in delivering a system that supports the delivery of a secure, low carbon, affordable electricity mix for the 2020's and beyond. It is vital that industry, Ofgem and others are fully involved in this process.

The Electricity Market Reform project will issue a consultation document in the Autumn and a White Paper in Spring 2011.

Is there a role for the Severn?

The feasibility study has calculated the cost of the energy generated by each of the Severn schemes and how they compare to the other measures necessary to meet our energy and

[19] IEA (2009),World Energy Outlook, 2007-2030 growth rates, as set out in "450 Policy" and "Reference" scenarios.
[20] http://www.hm-treasury.gov.uk/d/budget2010_energymarket.pdf

climate change goals. This helps determine whether there is a strategic case or need for a Severn tidal power scheme.

The work shows that it would be extremely challenging for any of the schemes to be generating electricity in time to contribute to the 2020 renewable energy target. All the scheme options are all substantial engineering projects and it takes time to plan, finance, source the materials and build such large structures. The construction times alone would be between four and nine years. In addition, pursuant to our obligations under the Habitats and Bird Directives, all of the schemes are expected to require new habitats to be created, or species re-introduced, to replace those that would be displaced. These habitats take time to establish and the other measures require time to be effective. Considering these challenges it would take at least 10 years to complete even the smallest of the Severn schemes, assuming planning consent were given (which itself would be a process lasting 2-4 years). As such, we do not believe that a legally compliant Severn tidal power scheme could be built in time to generate electricity by 2020.

However, if the UK is to play its part in the global fight against climate change it is essential that we move to a low carbon economy. The initial findings of the DECC 2050 Pathways analysis has highlighted the challenges and trade-offs of doing so[21]. Decarbonising the economy will require scaling up of existing technologies and implementing new ones.

Most low-carbon generating technologies are capital intensive, i.e. they require high levels of investment during construction. A private sector investor would then look to recoup these construction costs from electricity sales revenues over their investment timeframe, which can be up to 40 years in length. However, investors in low-carbon generation face the risk that they will not be able to recover the construction costs over their investment timeframe.

Severn schemes tend to have higher up-front construction costs than other low-carbon generating technologies. This means that a investor would require higher electricity revenues in order to recoup the initial investment over the investment timeframe. This is captured by the ‘investor’ levelised costs presented in the table below. ‘Investor’ levelised costs indicate the average per unit electricity price which a private sector investor would need to earn to recoup their initial outlay in an electricity project. As the chart indicates, Severn schemes have significantly higher ‘investor’ levelised costs than other low-carbon generation technologies, i.e. they are likely to be considered less attractive investments by the private sector.

However, unlike other low-carbon technologies, a Severn scheme will continue to provide benefits to society as a whole in the form of low-cost, low-carbon electricity for around 80 years beyond the typical timeframe of a private sector investor. In order to capture these longer-term benefits we have also calculated levelised costs at ‘social’ discount rates, which take account of the electricity produced beyond a private sector investment timeframe, and give a clearer indication of the attractiveness of Severn schemes relative to other low-carbon alternatives from the perspective of society as a whole. As the chart below shows, Severn schemes’ ‘social’ levelised costs are generally comparable with those for CCS, slightly higher than those for offshore wind, and still significantly higher than those for nuclear.

[21] HM Government, ‘2050 Pathways Analysis’, July 2010

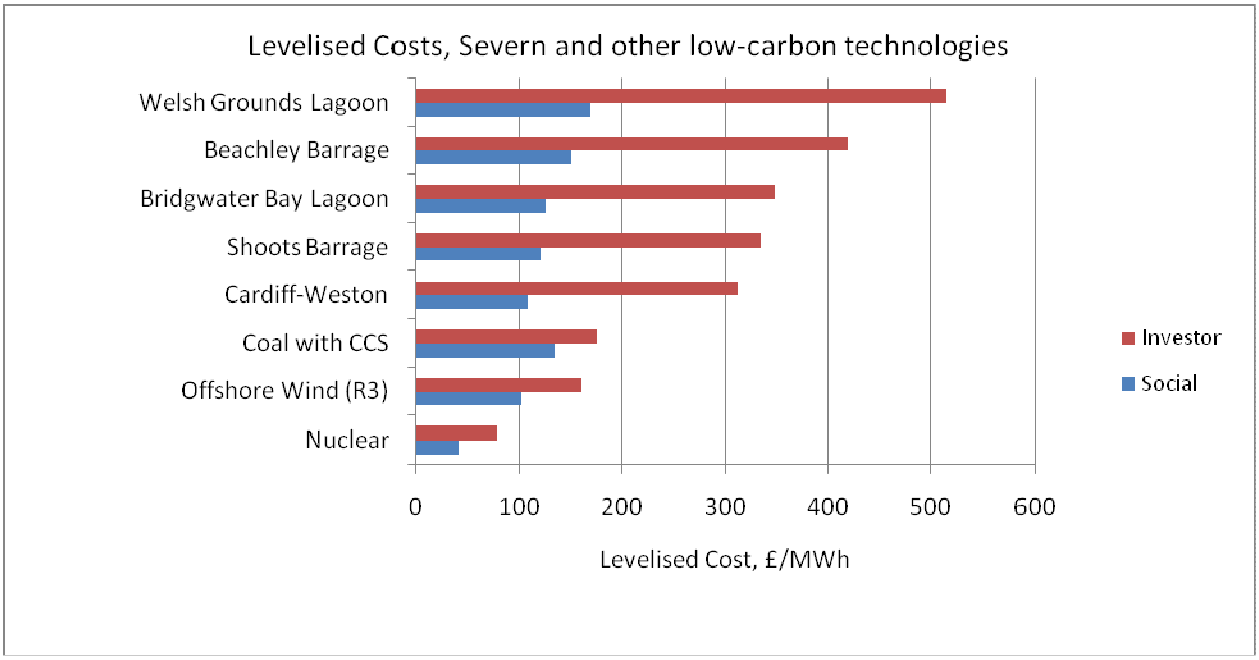

Figure 7: Levelised Energy Costs for Severn tidal power and other technologies, optimism bias included.

A more complete comparison of the Severn schemes to other electricity generation technologies is to compare the net present value (present value of benefits minus present value of costs) that society would get from them. This analysis shows that some of the Severn schemes (Shoots barrage, Bridgwater Bay lagoon and Cardiff-Weston barrage) would be better long term value in terms of the costs of their energy supply and the benefits of their carbon savings and avoided air quality impacts than investment in coal generation with carbon capture and storage to produce an equivalent amount of electricity. Although it is important to note that we have not valued some of the wider benefits of CCS, e.g. its innovation benefits, for the other Severn schemes they represent less value than alternative low carbon forms of generation, based on current estimates of their future costs. The Impact Assessment published alongside this document provides a more detailed comparison of costs and benefits.

Large increases are needed in offshore wind and CCS will need to pass from the planned demonstration projects to mass deployment. Although the Government has put in a place policies to support this growth, other means or larger contributions from other areas will be required should it not occur – including potentially a Severn scheme. Offshore wind and CCS are likely to be more affordable than power from the Severn, but a Severn scheme could still be needed at some point in the future.

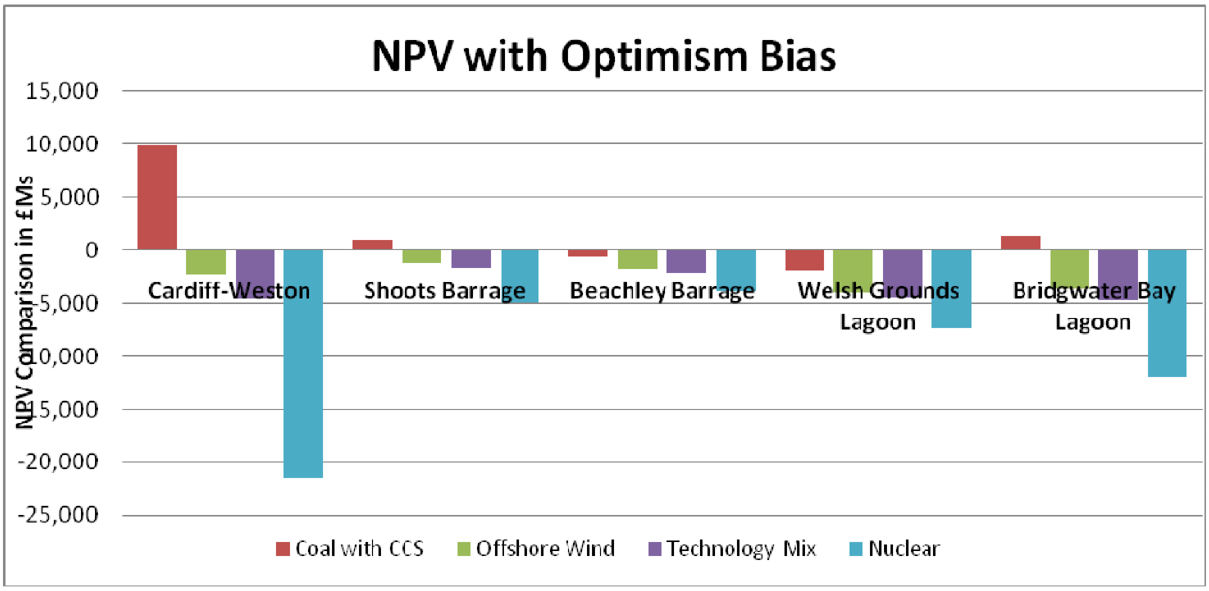

Figure 8: Graph showing the net present value (NPV) of Severn Tidal Power against a range of low carbon technologies.

So, although a scheme will probably not play a role in helping us meet our 2020 renewable energy targets, the conclusion of the study is that it should not be ruled out for the future. The Committee on Climate Change (CCC) an independent body established under the Climate Change Act to advise the UK Government on reducing greenhouse gas emission came to a similar conclusion (see box below) in a report last year. This took the view that even if a small Severn scheme were cost-effective and could be built to contribute to 2020 targets, it might not be desirable to proceed given the need for a larger scheme to be built for 2050 cannot be ruled out.

Committee on Climate Change

The Committee on Climate Change published Meeting Carbon Budgets - the need for a step change in October 2009. In this report on the UK's progress towards the first Carbon Budget, they concluded that a Severn tidal power scheme could provide low carbon electricity at a low cost but that it is relatively expensive compared to other low carbon options currently available. As such, a Severn tidal project could form part of 'clearly affordable low-carbon strategy' if other options were not available e.g. nuclear, CCS and other renewables. With these options available, a Severn tidal project is not clearly attractive as there are limited learning effects (and following costs reductions). They noted that nuclear, CCS and other renewables carry their own delivery risks, and the option of constructing a barrage at the Severn in future should therefore be kept open. As such, even if building a smaller barrage or lagoon proves more cost-effective it may not be desirable to proceed with this option if it rules out the addition of a large barrage in the future.

3. Regional and environmental impacts

- The study carried out a Strategic Environmental Assessment (SEA) and a Regional Impact Assessment to assess the environmental and social effects of each of the short-listed schemes.
- Although a scheme would produce clearer, calmer waters, the extreme tidal nature of the Severn estuary would be much reduced. This would mean that some habitats including saltmarsh and mudflat would be reduced in area, probably reducing bird populations.
- Fish would probably be severely affected with local extinctions and population collapses for designated fish from all three Special Areas of Conservation (SACs), which would be directly affected: the Severn Estuary/Môr Hafren, the River Usk/Afon Wysg and the River Wye/Afon Gwy. Designated fish include twaite shad which could be lost as a breeding species in the UK as 3 out of the 4 rivers in which it breeds run into the Severn estuary.
- Water levels would also be affected and in order to maintain current flood protection levels in the Severn estuary additional flood defences would be required and have been included in the costs of each scheme. In turn, additional flood defences would provide longer-lasting protection to the affected areas with appropriate maintenance.
- Any scheme would be the largest brought forward in an area protected by the Habitats and Birds Directives. The study has considered ways to reduce environmental impacts but also how to provide compensation for remaining impacts on designated features including habitats, fish and birds.
- Compensation would be very challenging and for habitats and birds would require land change within and probably outside the Severn estuary.
- Overall a power scheme is likely to benefit the regional economy with value added to the economy and jobs created. However, these benefits come at the expense of negative impacts on the existing ports, fishing and aggregate extraction industries.
- Impacts are presented in ranges and likely direction of travel as it has not been possible to predict with complete certainty how the Severn estuary and its wildlife would respond to a scheme.

The Severn estuary is of international, European and national nature conservation significance. For example, it is:

- a *Special Protection Area (*SPA) under the Birds Directive for the number of water birds that use the Severn estuary;
- a Special Area of Conservation (SAC) under the Habitats Directive for the unique and highly dynamic conditions and the special range of habitats and species this supports, including sandflats, mudflats, saltmarsh and rare marine life; and
- a Ramsar Wetland of International Importance.

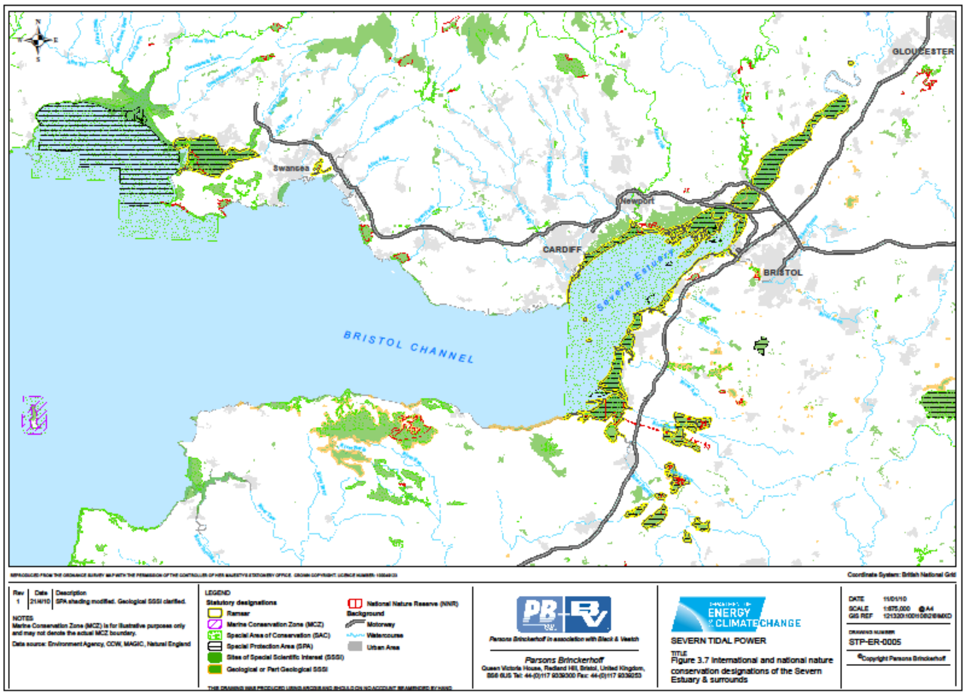

Figure 9: map of designations in the Severn estuary area

The Rivers Wye and Usk, which flow into the Severn estuary, are also designated as SACs. Together, they represent around 1.3% of all the UK's designated SAC habitat. These rivers provide important spawning habitats for species of migratory fish, including five species protected under the Habitats Directive (allis and twaite shad, sea and river lamprey and Atlantic salmon) which travel up the Severn estuary on the way to these spawning grounds. At least six waterbird species occur in internationally important numbers (ringed plover, curlew, dunlin, pintail, redshank and shelduck), and are protected as part of the SPA and Ramsar site designations. The overall waterbird assemblage using the Severn estuary during winter has been calculated to be approximately 73,000 birds.

The area also contains Sites of Special Scientific Interest (SSSIs), Scheduled Ancient Monuments (SAMs) and Areas of Outstanding Natural Beauty (AONBs) . A Severn tidal power scheme would impact significantly on natural and historic conservation sites both upstream and downstream of any scheme. The landscape and seascape of the Severn estuary would be significantly altered with the addition of a scheme.

As well as a home for wildlife, the Severn estuary also supports fishing, aggregate extraction, shipping businesses and attracts tourists and recreational users.

To study the environmental and social effects of the short-listed schemes a Strategic Environmental Assessment (SEA) has been carried out. An SEA ensures that significant effects arising from plans and programmes are identified, assessed, mitigated, or offset where possible. It looks at a plan, in this case to generate energy from the Severn tidal range, and reasonable alternatives to achieving the objectives of that plan. For the purposes of the Severn tidal power feasibility study SEA, the plan's objectives were:

- to generate electricity from the renewable tidal range resource of the Severn estuary in ways that will have an acceptable overall impact on the environment and economy both locally and nationally, will meet our statutory obligations and provide benefit to the UK; and

- to deliver a strategically significant supply of renewable electricity, which is affordable and represents value for money compared to other sources of supply, in the context of the UK's commitments under the forthcoming Renewable Energy Directive and the Climate Change Act, as well as our goal to deliver a secure supply of low-carbon electricity.

The SEA uses objectives to compare the effects of the schemes. These reflect the appropriate environmental protection objectives at international, European and national level rather than the objectives of building a scheme. It therefore follows that these objectives are stretching, and the degree to which they are or are not achievable provides a way of identifying preferences. Impacts are presented in ranges and likely direction of travel as is not possible to predict with complete certainty how the Severn estuary and its wildlife would respond to a scheme.

The SEA also sets out what the Severn estuary might look like in the future. The estuary is already being affected by climate change – by 2000 water levels in the region had already increased by between 2.5 and 3.5cm from 1990 levels. By 2020, it is predicted that water levels could be around 10cm higher than 1990, 20-30cm by 2050, and by 2095 (when a tidal scheme if built would still be generating) they could have increased by between 50-90cm[22]. In addition, water temperatures are also predicted to rise by almost 4℃ by 2140 and salinity could increase as fresh water flowing into the river Severn from snow melt and rainfall is predicted to decline.

These changes have been factored into the study's analysis of how much energy could be generated and the impacts on the environment of a Severn tidal power scheme. They also highlight that the estuary is gradually changing because of climate change. How the Severn estuary, its rivers and those species that occur there will respond to long term effects on climate change is uncertain. For example, bird species using the estuary may change as some migratory birds are already believed to be remaining on the east coast of Britain in response to warmer winters. However, whilst the species which use the Severn estuary may change it will undoubtedly remain an important site for wintering and passage birds and, at times of severe weather, for birds currently wintering further east.

The Severn estuary is highly dynamic. A large volume of sediment is moved around in the estuarine waters which is then deposited at different points throughout the estuary, with a constantly varying distribution of mudflats being revealed at low tide. This dynamic quality has made it impossible to predict the impacts of the tidal power schemes with absolute certainty. Quantitative data has been used where appropriate - however a large amount of data is qualitative, based on computer modelling, or work from previous field studies. Typically, the results have established general trends and direction of travel on potential effects, e.g. the extent to which species might be affected within a particular percentage range. This leaves some uncertainty as to where the effects might fall within that range. The SEA has also

[22] Figures derived from UKCP09 data (Marine Grid ID 23478 (Newport/Casnewydd)) and Defra 2006 guidance – data refers to the South West and Wales region. For more information on the climate change scenarios used in the Severn Tidal SEA please read Severn Tidal Power – Phase 2 SEA Climate Change Scenarios – published for information alongside this report.

identified what additional work could be done to reduce these uncertainties or to inform any project level Environmental Impact Assessment (EIA). An EIA would need to undertake further study of how fish move in the estuary and more sophisticated modelling (3D rather than the 2D modelling undertaken as part of this study) on changes to water and sediment movements.

The feasibility study has also considered ways in which the predicted impacts of tidal power schemes could be reduced. The SEA Directive describes this hierarchical process of considering measures to first avoid or prevent, then reduce and then offset impacts:

Prevent/ Reduce Measures	These include changes in operating mode (ebb-only generation compared with ebb-flood generation), turbine numbers and sizes, sluice capacity, and changes in alignment. For example, adjusting alignments to avoid specific habitats and artificially creating new mudflats in the Severn estuary.
Offsetting measures	Measures that make good for loss or damage without directly reducing that loss/damage. For example, issuing new aggregate licenses or altering existing licenses.

These measures have knock-on impacts of their own – for example on cost and the amount of energy a scheme generates. The energy generation potential of a Cardiff-Weston barrage decreased from 17.1TWh to 15.6TWh as prevent/reduce measures were included in its design. The study has therefore had to strike a balance between which measures to include, their likely degree of success and the impact they will have on energy generation potential and its cost. As a result, it has been appropriate to incorporate some of these prevent/reduce measures into the designs of the schemes and how they operate, but not all.

A number of specialist studies have been undertaken to inform the SEA and wider feasibility study. These include desk based reviews of existing literature, and consideration of similar sites (such as barrages in La Rance (France), Annapolis Royal (Canada), the storm surge barrier in the Eastern Scheldt (the Netherlands) and three sites in the Severn estuary including the Cardiff Bay barrage). Studies also included the development of numerical models to represent baseline conditions and then the application of these models to each of the schemes. In addition, qualitative assessments were undertaken using expert judgement, utilising outputs from other parts of the SEA.

Technical input and advice was provided by Government bodies and statutory advisors, non-governmental organisations, industry and academia. Advice was given on the approach to the SEA, the process for identifying likely significant effects, baseline and future baseline data including any uncertainties, SEA objectives, predicted effects of schemes and the interpretation of the results.

The information gathered in the SEA is set out in an Environmental Report (plus detailed topic annexes), published alongside this summary report. The scope of the Environmental Report was defined following public consultation between January and April 2009.

Social and economic impacts

Regional jobs and the economy

The overall benefit to the regional economies of the South West of England and Wales of a Severn tidal power scheme is estimated to be positive in terms of gross value added (GVA) and employment. GVA measures the contribution of an industry, sector or people to the economy – in this case the GVA relates to the benefits and costs to regional economies from a Severn tidal power scheme. It is difficult to predict exactly what would happen so a number of possible outcomes have been tested which are reflected in the ranges around the figures presented. These represent best and worst case scenarios around a central estimate. The figure below shows the impact each scheme would have on GVA in low, central and high scenarios:

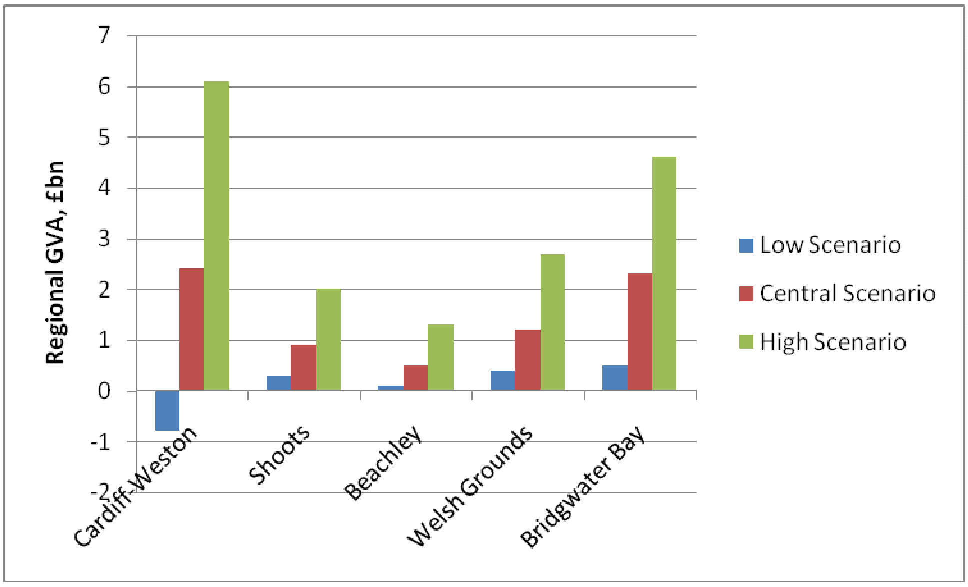

Figure 10: Regional Net Gross Value Added for South West of England and Wales (£ billion) across high, central and low scenarios for each scheme

A major source of value to the regional economy would be the several thousand jobs created in construction and support services, of which some (between 20-40%) will be taken up by those living in the region. A supply chain study (published alongside this report) has informed what adjustments should be made to these figures to provide an estimate of how many of those jobs would be realised in Wales and the South West of England. Results show that an annual average of 3,000 additional construction and associated services jobs would be created in these areas (with a range of 2,000 to 7,000) as a result of a Cardiff-Weston scheme. The difference in gross and regional job figures reflects the expectation that given there is no UK hydro-manufacturing facility, turbines are likely to be sourced from world-wide manufacturers.

	Cardiff-Weston	Shoots	Beachley	Bridgwater Bay	Welsh Grounds
Construction Period	9 years	5 years	4 years	6 years	6 years
Gross construction phase jobs created	15,500 (12,000 – 38,000)	5,500 (3,000 – 12,000)	4,500 (3,000 – 11,000)	13,000 (7,000 – 30,000)	6,500 (3,000 – 15,000)
Regional construction phase jobs created	3,000 (2,000 – 7,000)	1,500 (1,000 – 4,000)	1,000 (1,000 – 2,000)	3,500 (2,000 – 7,000)	2,000 (1,000 – 5,000)
Regional operational phase jobs created	1,000 (500 – 1,500)	200 (100 – 250)	100 (50 – 150)	450 (250 – 700)	200 (100 – 250)

Table 5 : Summary of regional jobs created for each scheme, central scenario (high and low scenarios in brackets)

Maintaining and operating schemes would also generate regional employment. For the largest barrage this is centrally estimated as 1,000 annual average jobs created in the South West of England and Wales (with a range of 500 – 1500) and 100 (with a range of 50-150) for Beachley, figures for the other schemes are presented in table 5.   Although not quantified, there are also likely to be further regional employment opportunities through tourism and consequential development that a scheme might attract.

However, the benefits described above must be balanced against potential job losses in the region that would result from the impact schemes would have on the Severn estuary and the businesses that use it. These include the estuary's ports, aggregate extraction and commercial fisheries, also existing tourism around the Severn Bore may be impacted.

The ports in the Severn estuary handle a significant proportion of UK trade and support a large number of regional jobs. This sector, and in particular the ports at Bristol, Cardiff, Newport and Sharpness might be significantly affected by a tidal power scheme. Barrage options have the greatest impact on ports upstream of them as port traffic would be required to pass through locks to access port facilities. Changed water levels as a result of schemes, including the Bridgwater Bay lagoon, would also affect the access opportunities for vessels. For the ports a scheme could therefore mean;

- longer timescales for ships to reach them if they have to pass through locks;
- fewer opportunities for vessels to travel up the estuary as the higher tides that the larger ships need to reach the ports are reduced;
- sediment may collect in navigation channels which would need to be regularly dredged; and
- potentially greater impacts on larger ships which bring the most value to the ports.

Provision of locks and dredging would reduce the impact of the schemes on ports. These have been included in scheme design and costs. For example, the inclusion of a lock and dredging navigation channels for the Cardiff-Weston scheme is around £2.4 billion (excluding optimism bias) and for a smaller scheme like the Shoots barrage £220 million (excluding optimism bias). Although locks and dredging would largely mitigate the navigational impacts presented by barrages, port customers may still consider possible delays as a risk, thus potentially impacting on the competitiveness of the ports.

In a scenario where a power scheme displaced 60% of port activity, job losses at the ports in the Severn estuary could rise to a peak of 3,900 during the nine year construction period for Cardiff-Weston. This means that in a typical construction year port-associated employment could be 2,100 (1,400 – 3,500) lower than it would otherwise have been (ranges represent 40% and 100% displacement). For a Bridgwater Bay lagoon displacement is assumed to be lower and average losses are centrally estimated to be 200 (0 – 1000) and for the other schemes 200 (0 – 400).

The Bristol Port Company (BPC) have recently been granted consent for a major new Deep Sea Container Terminal Development (a £600 million investment). If these expansion plans are realised the figures on benefits and jobs for Cardiff-Weston are likely to change. We estimate that the net benefit to the region is reduced to £1.9bn (£-1.5bn - £5.5bn) GVA for a Cardiff-Weston barrage since job losses during the construction period are estimated to be 2,500 (1,600 – 4,100).

The marine aggregates industry is another important commercial activity in the Severn estuary supporting around 1,100 regional jobs. Like the ports this sector would be affected by the impact of schemes on water levels, how sediment is moved and deposited and the necessity to pass through locks. The Welsh Grounds lagoon and Cardiff-Weston barrage would affect access to currently licensed areas and access to landing ports could result in annual average employment being 90 and 180 (respectively) lower than it would have otherwise been.

Commercial and other employment generating fishing and angling in the estuary and surrounding rivers within the study area are estimated to support around 100 jobs. Any tidal power scheme has the potential to significantly disrupt both nursery areas and the passage of fish up the estuary which for some species may lead to the collapse of the associated fisheries. For all schemes around 60 fisheries jobs are expected to be lost. The impact that a development might have on offshore fisheries is un-quantified.

The figure below shows the net job impact on the region[23] taking into account both jobs created in the construction sector and those that could be lost in the ports, aggregates and fisheries sectors for low, central and high scenarios.

[23] Note that the net job impacts for the UK economy as a whole are uncertain because, for example, jobs created in one region could displace jobs in another region.

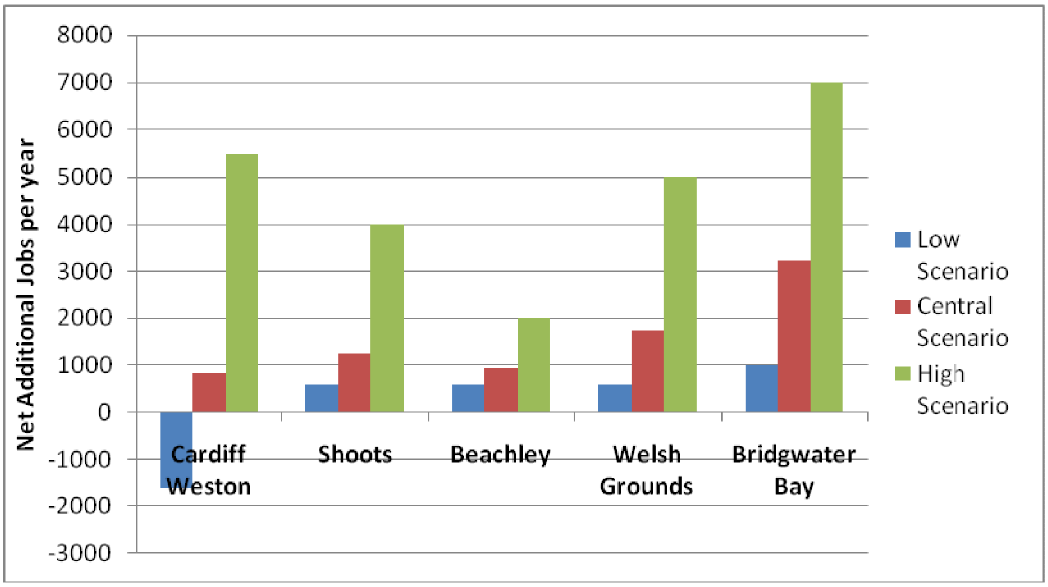

Figure 11: Net jobs per scheme for the construction phase realised in the region (low, central and high scenarios)

More detail on the employment and GVA impacts can be found in the Regional Economic Impacts Study which follows on from a study by DTZ commissioned early in the feasibility study and which was subsequently peer reviewed.

Infrastructure and services

The SEA has considered how schemes could affect other activities and the people that live around the Severn estuary and particularly those close to the possible scheme landfall points.

Any of the schemes would change the estuary landscape both as a result of the structure itself and the consequential impacts on the environment such as water levels. It is possible however that any structure could become an accepted, and appreciated, part of the landscape/seascape – like the second Severn crossing or the La Rance barrage in France.

There would be an increase in heavy goods vehicle traffic during the construction phase of all schemes despite the large quantities of materials required to build schemes being brought to site on ships or via the rail network. The Highways Agency agrees with the study's conclusion that this would not have a significant effect on the motorways and main roads in the South West of England but has flagged possible impacts on smaller local roads. Impacts on local road traffic congestion, noise and air quality would be managed through transport planning and consultation with local authorities and community groups.

In-migration of population is expected as a result of all schemes as some incoming temporary construction workers are likely to settle in the area with their families. This is not expected to have a significant effect on the population characteristics, the housing market or access to facilities and services in those areas as the numbers are low compared to the existing population. For a Cardiff-Weston barrage, which as the largest scheme would have the largest impact; the number of people anticipated to settle in the region from both construction and operation would be less than 0.5% of the current population – which is estimated to be 2.2 million in 2017.

All of the schemes have the potential to have both a positive and negative influence on sustainable estuary based tourism through a reduced sediment supply to sandy pleasure beaches as well as increasing mud deposition at these sites. The extent of this effect is likely to be greatest for a Cardiff-Weston barrage, with beaches located along the Bristol Channel coastline potentially at risk. Effects to pleasure beaches such as Brean from the remaining schemes are considered to be less and are largely restricted to those sites in the Severn estuary and Bridgwater Bay. Any reduction in beach sediment supply could be countered through a coordinated programme of beach replenishment although this has not been quantified. All three barrage schemes are likely to prevent the formation of a 'surfable' Severn Bore.

All schemes are expected to provide an opportunity for development within the local area. Barrage schemes would result in calmed water conditions upstream of the structure and, for lagoon schemes, within the lagoon itself. The resulting increased potential for water-based recreation could benefit the 30 boat clubs (with a membership of around 9,000) around the estuary and increase the wider tourism potential of the estuary.

The Severn estuary and Bristol Channel are important for marine waste disposal. The estuary contains a number of waste disposal sites, a large number of sewage and industrial discharges are made using the dilution and dispersion driven by the high tidal range and a number of power stations (Hinkley, Oldbury, Uskmouth and Aberthaw) abstract and discharge cooling water. All options would disrupt this activity to varying degrees and may require a reassessment of the current consents to discharge.

Transport links

Some commentators have suggested that a barrage across the Severn estuary should carry a new road or rail link. Such a link would be expensive as it would need to be elevated to provide adequate clearance for vessels to pass through locks. Such a development would not necessarily be less expensive than a separate construction structure. The feasibility study has commissioned work by Network Rail and the Highways Agency[24] and has found no evidence that the existing road and rail infrastructure is inadequate or unable to meet anticipated traffic for at least the next 15-20 years.

It is possible that new transport links will be needed beyond 2025-30. With this in mind it would be feasible to accommodate suitable foundations either as part of the design of a barrage or subsequently by developing a design that adapted the existing structure for a future transport link. Issues associated with new transport links are not considered further in this report as further specific assessments would need to be undertaken at that time.

---

[24] Severn Barrage Railway Infrastructure, Feasibility study by Network Rail, August 2008 (http://www.dft.gov.uk/pgr/rail/pi/)
Severn Barrage Highway Infrastructure, Feasibility study by the Highways Agency, August 2008 (http://www.dft.gov.uk/pgr/roads/network/strategic/researchtechnology/)

Environmental impacts

Carbon

The following sections summarise the predicted changes and impacts of a Severn tidal power scheme on the environment. Alongside these changes, a Severn scheme would bring environmental benefits through generating carbon-free electricity. The SEA has looked at both the carbon dioxide a scheme would save through the amount of energy generated but also those generated by building and operating a scheme. This includes the making of the various components, the transportation of them to site and their installation but also the disruption to the natural carbon sinks within the estuary. Any potential carbon dioxide impacts from transport switches is not included.

The Severn estuary supports a range of habitats, including large intertidal areas (areas of mud and sand flats which are exposed at low tide) which both store carbon and nitrogen and interact with atmospheric levels of greenhouse gasses (GHG) (principally carbon dioxide) through the capture of carbon from the atmosphere. This holistic approach known as carbon footprinting has allowed us to calculate the number of years it would take for each scheme to pay back the carbon debt of its construction – see table 6.

Cardiff-Weston	Shoots Barrage	Beachley Barrage	Welsh Grounds Lagoon	Bridgwater Bay Lagoon
2.6	**3.5**	**2.8**	**6.1**	**3.2**

Table 6: Carbon Payback period (years) for each Scheme (central estimates)

Flood risk and land drainage

All schemes would affect water levels in the Severn estuary bringing both positive and negative effects on flood risk.

The tidal floodplain of the Severn estuary is currently protected from flooding by extensive tidal defences on both banks. These protect existing property, infrastructure and agricultural land. Some 90,000 properties and commercial assets are at risk of flooding in over 500 km^2 of low lying tidal floodplains of the Severn estuary (approximately 35,000 properties in Wales and 54,000 properties in England) with high concentrations in the urban centres of Cardiff, Newport, Burnham on Sea and Weston-super-Mare. The standard of flood protection provided by existing defences varies throughout the estuary, but generally property and infrastructure assets are protected to a standard of at least a 1 in 50 year level (i.e. a flood predicted to occur on average every 50 years). In some rural areas, the flood defence standard is as low as 1 in 5 years.

As a scheme holds back water before generating electricity, the mean high water levels will rise and land may take longer to drain in the event of rain and high tides. This, as well as the potential for faster erosion of existing defences, will increase fluvial flood risk. A Cardiff-Weston barrage could therefore potentially increase the current flood risk for an estimated

370 km^2 of land containing 45,000 residential properties, 3,400 non residential properties and 28 critical infrastructure assets.

However, extensive mitigation methods to maintain existing protection levels for land on both sides of the estuary have been included in the scheme's costs, including measures to up-grade land drainage systems and improve flood defences. This would be in line with the Environment Agency Severn estuary Flood Risk Management Strategy http://www.severnestuary.net/frms/index.html

Improved flood defences would last longer than existing defences and would provide an increased level of flood protection to cope with the predicted sea-level rise in the Severn estuary over the next 100 years. Land upstream of barrages would benefit from a lower risk of tidal storm surges as the highest tides would be reduced by, for example, 1.5m for a Cardiff-Weston barrage and 0.3m for a Shoots barrage. These improved flood defences

Computer modelling has also shown that water levels could be affected beyond the Severn estuary itself. A Cardiff-Weston barrage is likely to have the greatest impact with a predicted increase in high tide levels on the largest Spring tides of up to 30cm along parts of the West Coast of Wales, as far north as the Llŷn Peninsula and along the North Devon coastline, and of up to 10cm off parts of the East coast of the Republic of Ireland. Costs for reducing these impacts in the UK through raising sea defences have been included in the scheme costs. Measures to prevent effects on Ireland have not been incorporated into costs because the smaller water level rise of 10cm is similar to the minimum change in water level that can be reliably measured within these SEA studies (±10cm). All other options show some predicted changes in water levels further afield that are below this threshold, with the exception of an isolated area around the Llŷn peninsular where the model predicts a change for some options of more than 10cm. This change affects a short length of coastline and since the magnitude is close to the limit of measurable effects, it is not considered significant.

Migratory and estuarine fish

Over 100 different species of fish have been recorded in the Severn estuary, including a number of species of migratory fish (those which move between fresh and sea water at different stages of their lifecycle). Some of the migratory species (Atlantic salmon, twaite shad, allis shad, sea lamprey and river lamprey) are designated as species of community importance by the Habitats Directive, and their presence is part of the reason for designation of the Severn estuary and the Rivers Wye and Usk Special Areas of Conservation (SACs). In addition, species such as Atlantic salmon and eel currently support fisheries with significant economic, social and cultural value.

Many of these migratory fish features are currently classified as being in an unfavourable condition under the Habitats Directive. This means that their populations are below a certain level and need to increase irrespective of whether a tidal power scheme is built. The feasibility study has assumed that measures to increase populations have been taken and are effective with fish populations for all affected species at favourable levels.

All designated fish populations (including eels) are likely to be adversely affected by a Severn tidal power scheme. This is because as fish move around the estuary they may pass through one of the tidal schemes. The volume of fish likely to pass through a scheme is linked to the scheme's location - fish may be more at risk from an upstream schemes like Beachley barrage or Welsh Grounds lagoon which is near their river of origin than a larger scheme further downstream such as the Cardiff Weston barrage or the Bridgwater Bay lagoon. The assessment shows the risk of population collapse or extinction for a greater number of designated species for Beachley and Shoots barrages - There are also substantial reductions predicted for other species such as eels.

Relatively little is known about how migratory fish move and behave within the Severn estuary prior to moving out to sea or up rivers. This has introduced uncertainty into the severity of impacts reported within the SEA of estuarine and migratory fish. The possibility that Atlantic salmon and twaite shad could become extinct locally as a result of a Severn tidal power scheme cannot be ruled out.

Waterbirds

The Severn estuary is an internationally important site for its numbers of overwintering waterbirds – regularly supporting 73,000 waterbirds including waders and wildfowl (ducks, geese and swans). These birds make use of a range of intertidal habitats, including saltmarsh, sand flat and mudflat, for feeding and roosting. There have been changes in the numbers of waterbirds using the Severn estuary over the past 25 years, with some species increasing and others decreasing in numbers – this is in part linked to the general trend of warmer winters which has led to the decrease in numbers of certain wader species in southwest Britain as these birds are able to remain along the East Coast. However, the number of species qualifying for SPA designation has remained stable.

For all schemes, the habitats where these birds feed and roost would be reduced, which would lead to declines in the numbers of birds that they can support. The operation of a tidal power plant would mean that water levels would remain high for longer than during the current tidal cycle and low tide levels will be higher. This means that much of the mudflat that birds currently feed on will be permanently submerged, leading to a reduction in the number of birds in both the Severn estuary and in the case of a Cardiff-Weston barrage to adjacent sites such as the Somerset Levels and Moors SPA. There is also a risk of reducing bird numbers at sites away from the Severn which the same birds that use the Severn estuary make use of at different times of the year. There is uncertainty about the effect on the overall total number of waterbirds, so change has been quantified within percentage bands rather than precise numbers.

Measures have been incorporated to reduce the impacts on birds which include:

- the management of sluicing to increase the area of intertidal area exposed on spring tides for Cardiff-Weston for example, possibly by 200-500 hectares;
- pumping on flood tides to minimise the decrease in high water levels to reduce effects on salt marsh and help maintain its quality; and
- ebb-flood generation – the operational method which was studied for the Bridgwater Bay Lagoon.

As a result, we estimate each scheme will cause significant declines for the following number of species:

Cardiff-Weston	Shoots	Beachley	Bridgwater Bay	Welsh Grounds
30	17	15	9	13

Table 7: Number of Bird Species expected to experience significant declines

Habitat

The Severn estuary supports different sorts of habitats:

- intertidal habitats such as mudflats and sandflats that are not covered by seawater at low tide, Atlantic salt meadows, sandbanks that are slightly covered by seawater all the time and are designated habitats for birds; and
- subtidal *Sabellaria alveolata*- reefs built by a worm.

As low water levels would be raised behind or upstream of a tidal power scheme, some of these habitats will be permanently covered by water. Others may increase in area, for example salt marsh. Over the lifetime of a scheme we expect the following losses of habitat to occur because of each scheme:

Scheme	Estimated area loss of designated intertidal habitat *after* application of potential measures to prevent or reduce significant adverse effects		Percentage Loss Baseline
	Potential Lower-bound Loss (km^2)	Potential Upper-bound Loss (km^2)	
Cardiff-Weston	118	163	40-50%
Shoots	27	37	8-12%
Beachley	21	30	7-9%
Welsh Grounds	61	82	19-26%
Bridgwater Bay	16	26	5-8%

Table 8: Inter-tidal Habitat Lost for each Scheme

We have looked at ways to create replacement habitat for the inter-tidal area that would be lost. There may be potential to create replacement intertidal habitat within the Severn estuary, or further afield. Some birds, such as dunlin, have very specific habitat requirements and it is likely to be difficult to artificially recreate these.

Ways to create habitat include:

Topographic modification	Creating new intertidal area in the Severn estuary by creating the conditions for new intertidal habitat to be formed. This is a relatively new technique and untried at this scale. The new habitat is in the same area as the lost habitat so wildlife already using the estuary may be more likely to make use of it than new habitat that's further away from it. This is thought to be the most promising option for creating significant areas of mudflat within the Severn.
Managed re-alignment of flood defences of the Severn estuary	This is a relatively well -tested technique albeit at a smaller scale than would be required for a Severn scheme. It could be used to create significant new areas of saltmarsh as compensatory habitat for all schemes except a Cardiff-Weston barrage. Managed realignment involves existing flood defences being moved further inland and can therefore offer longer term and more secure protection for an area, although there will be a change in land use. It is generally much less costly than 'holding a line.' Managed realignment in the Severn would mean the land between the old and new defences would likely revert to its previous state of salt marsh and therefore be habitat for birds.
Managed re-alignment away from the Severn	Managed re-alignment could also be used to create habitat outside the Severn estuary. This could be useful as part of a wider climate change adaptation strategy, and be designed as compensation for a range of species. More research and modelling would be needed to develop a strategy that relied on compensatory measures for birds outside the Severn.

Other biodiversity and geodiversity

All the schemes have the potential to damage other habitats and species situated in the marine, terrestrial and freshwater environment, including Biodiversity Action Plan (BAP) species and habitats; largely due to their location near the footprint of options and their landfalls. Disturbance during construction and operation could also pose negative effects. Impacts are larger for the larger options, particularly the Cardiff- Weston barrage, where a range of Sites of Special Scientific Interest with both biological and geological features could also be affected. Careful timing of construction activities and management of water levels could help prevent or reduce impacts. All tidal power options also have the potential to bring in non-native, invasive, species to the Severn estuary and surrounding area.

4. Legislative framework

The implementation of the Habitats and Birds Directives applies to the designated habitats and species in and around the Severn estuary, including the Rivers Usk and Wye. There are many other pieces of legislation (over sixty) that apply to the Severn estuary and surroundings which could be relevant to a tidal power scheme. Examples include: the Water Framework Directive, the Wildlife and Countryside Act 1981 (as amended), the Countryside and Rights of Way Act 2000 and the Natural Environment and Rural Communities Act 2006, the Bathing Waters Directive (2006/7/EC) and the European Eel Regulations (1100/2007/EC). Those on which a Severn tidal power scheme would have a large impact are discussed below.

Habitats and Birds Directive

In accordance with the Habitats and Birds Directives and Regulations, the study has gathered some of the information necessary for a strategic level Habitats Regulations Assessment (HRA) for each of the schemes. This includes a Report to Inform Stage 1 (Screening) HRA and a Report to Inform a Stage 2 (Appropriate Assessment) HRA, both of which are published alongside this summary report. These reports assess the potential impact of any of the tidal power options within the Severn estuary on any site designated as a Special Protection Area (SPA) or Special Area of Conservation (SAC). The HRA process has a number of stages;

- screen for likely significant effects on European Sites;
- fully assess implications of a scheme if likely significant effects cannot be ruled out;
- consider measures to avoid or mitigate any adverse effects;
- if adverse effects cannot be fully avoided or mitigated, determine whether there are alternative solutions;
- if there are no alternative solutions, determine whether a scheme is necessary for imperative reasons of over-riding public interest; and
- if there are shown to be such reasons, take any necessary compensatory measures to protect the coherence of the Natura 2000 (see box) network of European protected sites.

In line with Government policy this process has been extended to cover Wetlands of International Importance (known as Ramsar sites).

Habitats Regulations Assessment

The Habitats and Bird Directives require a precautionary approach to assessment of whether and how many SACs and SPAs *might* be affected. The table below shows the number of sites where we could not rule out that their integrity *would not* be adversely affected:

	SAC	SPA	Ramsar
Cardiff Weston	19	5	5
Shoots	14	2	4
Beachley	13	1	2
Welsh Grounds	14	1	2
Bridgwater Bay	13	1	2

Table 9: Potential Impacts of Severn schemes on Internationally Designated sites

Out of these, a definite conclusion of adverse effect on site integrity has been shown for three sites for all schemes: the Severn estuary/Môr Hafren SAC and SPA, River Wye/Afon Gwy SAC and River Usk/Afon Wysg SAC. These represent approximately 3% of the land area designated under the Habitats Directive and 1.3% designated under the Birds Directive in the UK. In addition, the study could not rule out indirect effects on a further 100 sites which the same birds may use when they are not in the Severn estuary. Further investigation would be needed to investigate possible effects on these sites, either to rule them out or to identify how those effects might be mitigated or compensated for.

Natura 2000 is a coherent, European wide ecological network of protected sites recognised as supporting the most important wildlife habitats and species of animals and plants in Europe.

Each country within the European Union has the responsibility to designate sites as Special Areas of Conservation under the Habitats Directive, for sites supporting specific habitats and/or species, and Special Protection Areas under the Birds Directive, for sites with priority bird species. So far the network consists of over 26,000 protected areas across Europe. The European-wide nature of the network aims to ensure sufficient areas of each important natural habitat are protected to enable the conservation of the full range of species associated with that habitat. Furthermore, different environmental sites in the network work together to support migratory and mobile species.

Together these sites are charged with the long-term conservation of the specific features for which they have been designated, and form Europe's biggest contribution towards the aim of halting and reversing global biodiversity loss. The conservation status of each site within the network has to be maintained and improved and environmental quality has to be monitored.

Compensatory measures

To secure the ecological coherence of the Natura 2000 network (see box), the Habitats Directive requires that compensatory measures are provided where a proposal would result in residual adverse effects on site integrity. This is normally done by replacing the protected habitats affected on a 'like for 'like' basis as close as possible to the location of the negative effect. The feasibility study has included consideration of possible compensatory measures in this context, a report of which is published alongside this summary report.

Any of the Severn schemes are likely to be the largest development within a designated site in the UK and perhaps anywhere in Europe. The feasibility study has shown that even after the application of mitigation measures it is highly probable that all schemes would require compensatory measures, including for intertidal habitat, birds and fish. For example, the Cardiff-Weston barrage would require measures to compensate for the loss of up to 16,300 hectares of habitat whist the requirements for a Bridgwater Bay lagoon are likely to be more modest. We have considered types of compensation that might be provided for the designated features. We have focused on areas where the compensation requirement is likely to be largest or most challenging – inter-tidal habitat, fish and birds. If a scheme was to be implemented more detailed studies would be needed to cover the full range of designated features, including white-clawed crayfish and brook lamprey that maybe affected and other gaps in our knowledge.

The Habitats Directive does not stipulate how to provide compensation but the European Commission has published guidance on the Directive which includes compensatory measures. As this represents best practice, we have followed the guidance from the Commission as far as possible.

We commissioned the Sustainable Development Commission (SDC) to investigate whether it would be possible to provide compensatory measures that are outside Commission guidance but within the requirements of the Habitats Directive. The work, published alongside this report, included a consideration of whether it would be possible to offer 'substitute' measures where it is not possible to directly replace a habitat or species, for example, offsetting the loss of mudflat by the creation of another related coastal habitat. They concluded that such a measure might be feasible, albeit involving an unprecedented level of challenge, and applied after due consideration of conventional measures. They propose a series of principles and tests which could begin to form the basis of a new methodology. The SDC recommend that more thorough research would need to be undertaken together with public and stakeholder engagement.

Elements of this approach are similar to biodiversity banking. Biodiversity banking is an established approach in some parts of the world, for example in Australia and parts of the United States, and involves establishing a system of biodiversity credits which can be traded to offset the loss of biodiversity. The credits usually take the form of measures such as habitat creation and species enhancement provided by a supplier (the biodiversity bank). This approach is not yet established in Europe but is attracting some interest in biodiversity policy circles.

The feasibility study's key conclusions on compensation are:

Inter-tidal habitats: Compensation for loss of habitat is usually provided in excess of the amount lost as it would not have the same initial value for wildlife -the study has used a 2:1 ratio as a base case. The ratio used for a project could be higher or lower than 2:1 and would need to be determined after detailed investigation. For example, a Cardiff-Weston barrage would result in an upper limit loss of 16,300ha but using a 2:1 ratio we would need to create around 33,000 hectares. This is unprecedented in terms of scale - 60 times greater than the largest existing UK compensation project.

The study shows that scaling up inter-tidal habitat creation to achieve the amount required for any option is technically feasible but poses significant delivery challenges. Although it would be a scaling up of known practice, this would nonetheless be a substantial and complex civil engineering project. It could also provide benefits in helping areas of coastline adapt to climate change.

Birds: As per the above, the feasibility study has indicated that inter-tidal habitat supporting birds could be created within the estuary at a 2:1 ratio for Bridgwater Bay and at a 1:1 ratio for all other schemes bar a Cardiff-Weston barrage. Very high compensation ratios should not need to be applied as some of the lost inter-tidal areas are relatively unproductive as bird feeding habitat. Habitat may be created through mitigation (e.g. topographic modification) or compensation (e.g. managed re-alignment at a site away from the Severn estaury).

Estuary: The Severn is designated in part for its extreme tidal range and the unusual ecology that this gives rise to. These 'hyper-tidal' features would continue to exist outside an STP impoundment but would be substantially changed within a scheme, although to a lesser extent with the ebb-flood Bridgwater Bay scheme. It is not feasible to re-create these unusual conditions elsewhere and they would therefore be replaced within the Natura 2000 network by less extreme or more typical estuarine conditions. The modified Severn estuary would continue to be a Natura 2000 site albeit with different characteristics. It is possible that a combination of habitat creation around other estuaries alongside possible additional notification and management of the modified Severn estuary could be considered as protecting the coherence of the Natura 2000 network. This is most feasible for the smaller options as they leave more of the existing characteristics of the estuary intact.

Migratory fish: Compensating for all effects on migratory fish is particularly challenging. A number of measures have been identified and proposed to increase or give more protection to fish populations in rivers elsewhere in the UK. These include 'experimental' introductions of twaite shad and measures to improve other rivers for freshwater species. There are significant uncertainties about the effectiveness of most of these measures. All of them would require further investigation to determine their feasibility or to quantify their possible effects.

In conclusion, it is not impossible that compensation under the Habitats Directive might be achievable for all schemes, although it is likely that this would require development of measures outside Commission guidance, but which would meet the requirements of the Habitats Directive.

Water Framework Directive

The Water Framework Directive (WFD) (2000/60/EC) aims to improve and integrate the way water bodies are managed throughout Europe. It enables Member States to plan and deliver a better water environment, with particular emphasis on ecological status. The Directive helps to protect and enhance the quality of the following water body types:

- surface freshwater (including lakes, streams and rivers);
- groundwaters;
- groundwater dependant ecosystems;
- estuaries; and
- coastal waters out to one mile from low-water.

To achieve the aims of the WFD, England and Wales has been split into 8 River Basin Management Districts. A Management Plan for each District has been published, setting out environmental objectives for each of the defined water bodies within the plan area. The Severn estuary falls within the Severn River Basin District, which contains 860 water bodies.

The status of surface waters is defined, in WFD terms, according to the condition of a number of biological, chemical and physico-chemical components. The physical and hydrological characteristics of the Severn estuary must be able to support the right chemical and biological components that are characteristic of the water body.

A Severn tidal power scheme would change the condition of many of the components that define the status of the transitional and coastal water bodies in the river basin, and may alter some of the freshwaters too. As set out above, impacts have been considered and mitigation measures given consideration.

If the environmental objectives cannot be met then consideration of Article 4(7) of WFD can occur. Article 4(7) provides that a Member State shall not be in breach of the WFD if environmental objectives for the waterbodies cannot be met subject to the following conditions;

1. all practical steps are taken to mitigate the adverse effect on the status of the body of water;
2. the reasons are explained in the River Basin Management Plans
3. the reasons are of overriding public interest and/or the benefits to the environment and to society of achieving the objectives are outweighed by the new modifications to sustainable development; and
4. the beneficial objectives cannot, for reasons of technical feasibility or disproportionate cost, be achieved by other means which are a significantly better environmental option

European Eel Regulations

The European Commission has initiated an Eel Recovery Plan to return the European eel stock to more sustainable levels. Each Member State is required to establish national Eel Management Plans (EMPs) which set a long-term target of 40% of the potential production, in the absence of man-made effects, of adult eels returning to the sea to spawn every year. The current Eel Management Plan for the Severn catchment envisages improving facilities for both upstream migration of elvers (young eels) to waters in which they can grow and downstream migration of silver eels to the sea. The Severn catchment is also a major contributor of eels within the UK for conservation purposes such as restocking eels into the Rivers Trent and Thames and as a food source i.e. the RSPB are restocking eels as Bittern food.

A Severn tidal power scheme is predicted to reduce eel numbers and therefore additional measures would probably need to be taken.

Consenting

Our market testing work and our work on legislation relevant to Severn tidal power has indicated that given the risks, including those presented by the planning and consenting process, a hybrid Bill may be the preferred consenting route for a scheme. Hybrid Bills have been successfully utilised in connection with a number of recent UK infrastructure projects that government has put to market in recent years e.g. Channel Tunnel, Dartford Crossing, Crossrail and others.

Alternatively, the successor unit to the Infrastructure Planning Commission (IPC) could lead on consenting for all of the schemes and report to the relevant Secretary of State who would take the planning decision. The Secretary of State would need to confirm that the compensatory measures put forward related to European designated sites were considered adequate to ensure the overall coherence of the Natura 200 network. Separate consents would need to be sought in Wales for ancillary works such as grid infrastructure and access roads and also compulsory purchase for compensatory habitat which would be likely to fall under the Town and Country Planning Act and which would add risk and time to the delivery of a project.

It is possible for Welsh Ministers to consent offshore energy projects in territorial waters adjacent to Wales under the Transport and Works Act 1992 (TWA) if applicants apply to them rather than the IPC. Under the Act a scheme promoter could apply to the Welsh Assembly Government for schemes entirely in Wales and to both the Secretary of State and Welsh Assembly Government for cross-border schemes.

5. Construction and financing

- The feasibility study has included detailed reports on construction and financing.
- This includes an Options Definition Report which sets out the technical make-up of each scheme from how much energy it would generate to how much it would cost to build. The report also details how schemes have evolved over the course of the feasibility study taking into account energy generation and how to reduce negative impacts.
- A risk assessment of around 13-17% and optimism bias of around 30% have been added to the costs presented in the ODR to account for a demonstrated tendency for project costs to over-run.
- The Supply Chain study details where the material needed to build a scheme would come from. For the smaller barrages, it should be possible to obtain most of the materials, equipment and labour from regional, national or near-European sources, but for a Cardiff-Weston barrage and the lagoons it would be necessary to look further afield and to establish new construction yards and manufacturing facilities locally.
- The Grid Study sets out the costs and how each scheme could be connected to the Grid.
- A market testing exercise carried out as part of the Commercial Assessment indicated a general reluctance from the market to invest in a Severn scheme in immediate timescales but that several commercial structures and subsidy mechanisms could be used.

A Severn tidal power scheme would be a significant engineering project. The study has considered the components of the different schemes, how it would be built, where the materials might come from, how it could be financed and connected to the electricity grid.

Options Definition Report

The Options Definition Report has been prepared by a Parsons Brinckerhoff-led consortium (PB) for the cross-Government feasibility study. It describes in detail the technical aspects of each of the short-listed schemes – how much energy it would generate, the number of turbines/sluices, the capital and operational costs, the costs of energy and how long it would take to build.

The report also describes how over the second phase of the study, the schemes have evolved. The form of the schemes as initially short-listed (termed the 'original' schemes) did not necessarily represent the most favourable or optimal form taking into account cost, energy yield and environmental and regional effects. Therefore the schemes have been taken through a preliminary optimisation process to enable the SEA to focus on the most appropriate form of each scheme to be studied.

As part of this process, the original schemes and a number of modifications to the original schemes were tested to evaluate their regional and environmental effects and energy output. Scheme costs and energy cost were also evaluated.

As a result, we considered changes of:

- operating mode (single phase ebb generation compared to two phase ebb flood generation);
- turbine numbers and sizes;
- sluice capacity; and
- alignment.

The form of each scheme chosen for further study in the SEA was the one which was generally favourable in all or most respects.

As more information on the environmental and regional effects of the schemes came through the SEA, measures to reduce these were also incorporated to provide the final scheme designs.

If a scheme were built it would require an Environmental Impact Assessment which will look in more detail into ways in which impacts could be reduced.

The report also reviews whether any of the more detailed work on energy yields and costs for the short-listed schemes would have a sufficiently positive impact on the energy yield and costs of long-listed schemes that were ruled out earlier in the feasibility study. As with the short-listed lagoons, optimal installed capacity energy yields for both on and offshore lagoons could rise. However, as scheme costs have risen for the short-listed schemes (between 14-400%) so they have risen for the excluded schemes including the lagoons. This confirms the view taken early in the feasibility study that these schemes are not feasible for the Severn estuary - levelised costs are still significantly higher than the short-listed schemes and the optimisation process did not remove any of the technical uncertainty problems that existed in relation to relevant excluded schemes.

Accuracy of cost estimates

Sometimes projects turn out to be more expensive than originally appraised. This is due to the occurrence of some events that were not accounted for during project appraisal and whose occurrence increased both the final expenditure and the time for delivering the project.
For example, costs could turn out to be higher if closer examination of a construction site's geography presents some unexpected features which require (expensive and time consuming) changes to the plans. If the possibility that this event occurs is not accounted for, the appraisal systematically underestimates the final expenditure.

The Treasury Green Book refers to the difference between the actual expenditure for a project and its appraised total cost as 'Optimism Bias' (OB), which is due (according to the Green Book,) to "a demonstrated, systematic, tendency for project appraisers to be overly optimistic". It requires that in project appraisal, cost estimates are uplifted to account for this tendency.

For Severn schemes, the study has addressed this by;

- undertaking a Risk Assessment, which consisted of identifying, through a series of expert workshops, a list of project-specific risks which may affect the final costs; and assessing the likelihood of their occurrence and their impact in terms of cost increase and time delays, should they occur; and

- estimating the appropriate residual uncertainty by performing an Optimism Bias analysis, given the risks already accounted for, adopting the methodology recommended by the Green Book.

Each project's risks were assessed separately. All risks were assessed before and after the adoption of some mitigation strategiesaimed at reducing either the probability that risks may occur or their impact (on costs and time) should they occur. The costs of these strategies have been included in cost estimates. The study then estimated the likely effect of these risks on each project's cost and duration. This process led to an overall risk adjustment to costs of between 13-17%.

Given their size and the construction environment, Severn tidal power schemes can be classified as a mix of "non-standard" and "standard" civil engineering components, which according to Green Book guidance have upper-bound optimism bias uplifts of 66% (non-standard) and 44% (standard) to capital costs. The extent of uncertainty around project costs – and the extent to which these upper-bounds for the standard and non-standard components of costs can be reduced - depends on the quality of cost estimates, understanding of stakeholder requirements, and the risk management strategies employed. After accounting for these factors, and those areas of uncertainty already accounted for in the risk assessment, the optimism Bias uplifts have been calculated as approximately 30% for each scheme. both the risk and optimism bias uplifts have been added to give a total uplift on costs.

Scheme	Risk Assessment	Residual Optimism Bias	Total Uplift
Cardiff-Weston	17%	30%	47%
Shoots	14%	31%	45%
Beachley	13%	31%	44%
Welsh Grounds Lagoon	13%	31%	44%
Bridgwater Bay Lagoon	14%	30%	44%

Table 10: Adjustments to Severn tidal power scheme costs

Optimism bias has also been applied to the costs of alternative technologies. Optimism Bias at 60% has been applied to coal with CCS (which is not yet proven)- this is in accordance with previous DECC appraisal practice. 24% has been applied to offshore wind (which will need to be deployed in more challenging offshore sites than currently). This reflects the fact that there is currently no contractual information available for coal with CCS projects, or for offshore wind projects in deeper water- contractual information should eliminate the need to apply optimism bias, since firms are incentivized not to understate costs in contracts as they will bear the risk of the project coming in at above the quoted cost. For nuclear costs, we have applied optimism bias at 15%. We have done this even though nuclear cost estimates are based on recent contractual information in areas with similar regulatory regimes to the UK, in order to reflect recent experiences on nuclear projects e.g. overruns on the Okiluoto project in

Finland. More details on how optimism bias uplifts have been derived are available in the Impact Assessment which accompanies this report.

Risk assessment and optimism bias refer to the *accuracy of cost estimates*, not to the *riskiness of the project* from an investment perspective. It could be the case that cost estimates are very accurate (thus requiring low risk assessment and optimism bias uplift) but the project is very risky (for example due to low or very uncertain expected revenues) and *vice versa*.

Supply chain

Building a scheme, especially one of the larger options, would require a large amount of material and equipment as well as large scale innovative construction design and installation processes, as well as many skilled people. The feasibility study included a supply chain study to see what would be needed and where it might come from. The study is based on the responses to a specific questionnaire sent to Trade Associations, manufacturers, contractors, ports and other bodies, and also on existing reports.

Materials

Each of the schemes requires a range of materials including sand, gravel, crushed rock and armour stone to build the embankments. Large concrete caissons built of aggregates and cement are needed to house the turbines and the generators. The table below shows the materials required for each scheme. The lagoons require more material than the barrage schemes as their embankment lengths are generally longer e.g. the embankment for the Welsh Grounds lagoon is 28 km whilst the length of the embankment for the Cardiff-Weston barrage is 16.2 km.

	Cardiff-Weston	Shoots	Beachley	Welsh Grounds	Bridgwater Bay
Aggregates	44.7	15.6	2.8	71.7	82.4
Armour Stone	9.8	2.2	0.2	11.3	7.3

Table 11: Construction Materials Required (Million Tonnes)

The UK has good resources of primary aggregates (including marine dredging) and could meet the demand for most of the schemes. For the large barrage and lagoons, additional dredging licences could be required in order to meet the demand for sand and gravel. The reuse of dredged materials for foundation preparation works for the scheme and possible navigation channels could be used to reduce the demand and increase sustainability. As rock armouring cannot be sourced in large quantities in the UK, a significant increase in the delivery rate of existing rock quarries (e.g. Glensanda in Scotland) would need be combined within overseas imports (e.g. Norway) to meet the demand. The use of secondary and recycled aggregates could also make a significant contribution to the supply of ballast (e.g. china clay and slate waste).

Turbines

As only three European turbine manufactures have the expertise and capacity to deliver large numbers of bulb turbines, there are risks of low delivery rates for large schemes. A Cardiff-Weston barrage would require 216 40MW turbines (approximately 9 metres in diameter), Bridgwater Bay lagoon 144 turbines at 25MW, whilst the other schemes would require 50 turbines or less. For the smaller schemes, the turbines could probably be delivered by a consortium of the three European manufacturers. For a Cardiff-Weston barrage and a Bridgwater Bay lagoon the larger number of turbines required on a short timescale would probably require the establishment of a new plant or assembly facility in the local area, in addition to potential supply outside the EU under European supervision.

Vessels

A Severn scheme would require many dredgers, tugs and crane-barges for the installation of caissons and equipment. These types of vessels are unlikely to compete with the demand for vessels for offshore wind deployment. Most of the vessels required are available on the UK and European market but orders would have to be placed well in advance (from one to two years) to ensure availability at the required times. Due to the harsh conditions of the Severn estuary, some existing vessels would have to be adapted and new dedicated vessels could be envisaged to meet specific requirements such as deep dredging.

Skills

According to existing surveys and information from respondents to the supply chain questionnaire, there may be a shortage of workforce in the following areas: marine and civil engineering, mechanical and electrical installation and site supervision. The various energy projects scheduled/proposed in the UK in the period to 2030 (nuclear plants, wind farms etc.) would all be competing for similarly skilled people. The current economic downturn brings about many skills transfers across the industry and construction sectors and a significant shortage of labour and skills in the energy sector might be expected when the economy recovers. However, locating the caisson construction yards in various sites in the UK (or in Europe) would minimise labour shortages and international joint-ventures set up for construction of a Severn may well mitigate the remaining labour problems.

The Regional Economic Impact Assessment, discussed earlier in this report (chapter 3), contains details on what proportion of the jobs are likely to be realised in the South West and Wales.

Conclusions

Innovative construction design and installation processes may be required. Although most of the turbine technologies and construction design are proven and mature, the sheer scale of the largest schemes would require a multi-national joint venture.

The most sensitive items in the supply chain, which could stall the project and/or increase the costs and lead time are: vessels, aggregates, concrete, caisson construction yards, turbines and generators, and the availability of skilled labour. As for the other construction materials and mechanical or electrical equipment (e.g. sluice-gates, cranes, transformers, cables, switch gear), even for the larger schemes, the magnitude of the demand is not considered as a major concern on the international market. Provided the procurement process is adequately managed, securing these materials and equipments should not be a particular problem either on the UK market or on the international one.

For the smaller barrages, it should be possible to obtain most of the materials, equipment and labour from regional, national or near-European sources, but for a Cardiff-Weston barrage and the lagoons it would be necessary to look further afield and to establish new construction yards and manufacturing facilities locally. Most of the potential supply constraints could be overcome by forward planning, pre-ordering, multi-national joint ventures and skills training.

Grid study

Each of the Severn schemes would need to export the power it generates into the National Grid. The electricity then goes on to be used in homes and businesses. The grid can cope technically with so much electricity going into it but as new power stations are built in different areas, new lines and upgrades to existing parts of the grid are required.

National Grid were asked to consider how a project could be connected to the grid and whether this would require any new infrastructure or uprating of existing infrastructure. They studied a representative large scheme (the Cardiff-Weston barrage) and a representative small scheme (the Shoots barrage, though at a higher installed capacity to cover the two proposed lagoons).

The study concluded that for a Cardiff-Weston barrage the optimum solution was for an equal amount of power (4.32 GW) to be taken off on the English and Welsh sides. It identified three options – one with no transmission cables across the barrage, and two with cables (one AC and one DC). They have similar costs of between £2.25 billion and £2.35 billion, though the option with no cable across the barrage could take at least 3 years longer to complete because that option may need a 125km new overhead line to the South Coast.

For the Shoots barrage the most cost-effective option is to take the power off on the English side, and the low output meant that there would be no requirement for new transmission substations, with only changes to existing substations and only a minimal length of new overhead lines – hence the lower cost of £290 million and shorter completion time than for the Cardiff-Weston barrage.

The results were extrapolated from these two representative schemes to the other shortlisted schemes. Beachley barrage, with less output than the Shoots barrage, could have its transmission works completed within the costs and timescales identified for Shoots. The Welsh Grounds lagoon could be connected on the Welsh side, but because of limited transmission export capacity out of the transmission system in South Wales it may be necessary to connect back to the English side via a subsea cable. The latter could pose a risk of time delay but the cost would be in the same range as for the Shoots barrage. The biggest difference from the early feasibility study estimates of scheme output was for the Bridgwater Bay lagoon, increasing from 1.6GW to 3.6GW. This makes the reinforcement requirements similar to those needed for the English side of the Cardiff-Weston barrage without the transmission cable across, i.e. costing £500m - £1bn and potentially taking 3-4 years longer to complete the work than for the barrage with the transmission cable. This is likely to require a new overhead line as unlike for a Cardiff-Weston barrage there is no option to connect into the Welsh transmission system.

Financing

The cost of each of the schemes runs into the billions. The feasibility study considered if and in what way the schemes could be brought forward by the private sector[25] and sought the views of potential financiers, builders, operators and owners of a scheme. The full Commercial Assessment is published alongside this report, and the key issues are summaried below:

Appetite for investment

A commercial market testing exercise was undertaken including a broad range of market participants who might be involved in delivery of a tidal power project including electricity suppliers, construction companies, engineering consultants and finance providers. The market testing exercise indicated a general reluctance from the market to invest in a Severn scheme in immediate timescales for the following reasons:

- **Capital availability** – In the current economic climate even the smaller of the tidal projects has significant financing requirements at a time when there is reduced liquidity.
- **Construction risk -** While the solution itself is not be considered technically complex and relies on proven engineering techniques, the size of the project heightens construction risk.
- **Planning and environmental issues –** There is concern over the scale of planning risk and a preference for this process to be Government led or Government funded.
- **Competitive technologies –**The scale of the construction, the long pay-back period and its relatively unique nature compares less favourably with other investment opportunities.
- **Off-take risk** – The relatively limited flexibility over energy generation profiles may be problematic in terms of the management of off-take risk i.e. an agreement for a party to buy any electricity generated even at times of low demand

Commercial structure conclusions

A range of commercial structures from private sector delivery to public sector delivery were considered (see box below).

[25] Financing and Ownership Study http://www.decc.gov.uk/en/content/cms/consultations/stp_phase1/stp_phase1.aspx

Fully Private Sector Led: This commercial structure is the traditional approach used in the market for delivery of electricity infrastructure.

Public Private Partnership (PPP) Structure: A PPP structure would assume the scheme would be constructed by the private sector and operations would be managed through structure concession for a limited period (PPPs are typically 25-35 years). At the end of this term, the asset would revert to Government ownership. A payment for the residual value for the asset could be payable by Government so that the entire construction cost did not need to be amortised over the 25-35 year period (however the cost of this future obligation would need a commitment from Government to facilitate a reduction in the financial cost, this liability would need to be provided for in Government accounts). At the end of the PPP concession, Government may then let concessions to operate the asset or privatise it.

PPPs are used to deliver a broad range of infrastructure across Government departments but have not been used in the energy sector to date. For this reason, there may be a natural nervousness about the use of this structure in the energy market. Key benefits of PPP include clear allocation of risk, established delivery structure albeit not within the energy market (except indirectly from waste contracts with energy elements), and ability to capture the residual value of the asset for the public sector through the concession arrangement and hand-back of the asset.

Regulated Concession Structure: This structure would be an arms-length body with representatives from public and private sector in its board structure. It would be a regulated structure and could be owned by the private sector, by Government or by a combination of the two. Examples of other regulated concession structures in the market include: Network Rail, National Grid and Channel Tunnel Rail Link ("CTRL").
The structure would be capable of managing the scheme for the duration of the asset life.

Public Sector Led *:* Under this structure the Government accepts there is significant integration risk associated with construction and it is not value for money to transfer such a risk (likely for a Cardiff-Weston barrage or potentially for a Bridgwater Bay Lagoon scheme). This structure is public sector sponsored and led. It may be that such a structure still transfers significant levels of risk to the private sector through the use of Engineer, Procure & Construct contracts for example or the appointment of an integrator to manage the competition of contracts and absorption of some integration risk. Where firm priced contracts are not considered to be optimal, contracts could include target cost incentive fee structures to incentivise contractors to manage cost overruns.

The scale of delivery risk increases in proportion to the capital cost of the project itself as it influences the ability of the private sector to manage the financial penalties associated with failure to deliver. For the larger schemes the delivery risk is higher and therefore the level of commercial risk that can be transferred to the private sector will be lower.

The commercial assessment concluded that the smaller schemes could be delivered through a privately-led option provided the capital costs of the scheme remain below ca. £5bn. PPP structures would also be possible. Larger schemes (such as a Cardiff-Weston barrage or Bridgwater Bay lagoon) could be delivered through a PPP (with Government support /

participation), a Government-led option or a Regulated Concession structure. Larger schemes will require Government support either through direct funding / equity participation or guarantees, this will increase the commercial risk retained by Government.

Revenue support

Like the vast majority of renewables, costs are not competitive with current fossil fuels derived energy. There are currently three separate incentives or revenue/price mechanisms for renewable electricity - the Renewable Obligation, the Levy Exemption Certificate (LEC) and a feed-in tariff (FIT) scheme for small scale renewable electricity,.

As such, the study has looked at what might be the most appropriate incentive for a Severn tidal power scheme. The options considered were:

Renewables Obligation	The Renewables Obligation (RO) is the primary support mechanism for large scale renewable schemes in the UK. The RO works by placing an obligation on licensed electricity suppliers to produce a specified number of Renewables Obligation Certificates (ROCs) per MWh which increases annually, or pay a penalty. Generators receive different numbers of ROCs depending on the technology. Generators sell their ROCs to suppliers or traders which allows them to receive a premium in addition to their electricity. Suppliers present ROCs to Ofgem to demonstrate their compliance with the obligation. Where they do not present sufficient ROCs they have to pay a penalty known as the buy-out price. Money from the buy-out fund is recycled to suppliers who presented ROCs on a pro-rata basis, this effectively gives an additional premium for the ROCs purchased where obligation levels are met.
Severn Obligation	This would be designed in the same way as the RO, the operator would sell their output on the wholesale market and all suppliers would be obliged to purchase either a proportion of their output from Severn tidal power or Severn Obligation Certificates or pay into a buy-out fund. The buy-out price and obligation level would be set to ensure a certain level of subsidy per MWh.
Feed-in Tariff	The operator would sell their power in the market under normal trading arrangements and receive in addition a fixed price premium per unit output. The cost of this subsidy would be levied on suppliers and subsequently passed on to consumers. A premium FIT would give the operator a fixed rate payment in addition to the energy value sold on the market.

For a smaller scheme, because the scale of off-take risk is manageable it is likely that a revenue support structure that transfers electricity price risk would be appropriate i.e. a Premium Feed-in-Tariff / Renewable Obligation[26] / Severn Obligation. Use of this approach

[26] Where the Renewable Obligation was used, it would need to be amended to extend the term of support available.

may limit participation to utilities, and may not be the cheapest pricing structure for the Consumer because of the premium payable for the electricity price risk transfer. A fixed price support structure would also be possible but is inconsistent with current market mechanisms.

The off-take risk associated with the larger schemes may be significant so it is unlikely that the operator could manage the risk. This indicates the potential need to manage risk through a guaranteed offtake mechanism, i.e. an availability / fixed FIT approach. The off-take could need to be managed through placing an obligation on the suppliers to take the electricity generated in proportion to their participation in the market at a fixed price. This could cause market issues as the Severn Scheme becomes a “must run” asset because the suppliers are obliged to purchase the output. It is possible for Government to retain the off-take risk and sell the electricity through shorter term contracts funding the difference between the price paid to the operator and the market sales through a levy on suppliers. This would allow the sale of electricity to happen within existing market structures but the residual risk of off-take would remain with Government.

Any revenue support mechanism would need to be structured to avoid excessive cost to the Consumer while also not distorting the electricity market; this will be a difficult balance to achieve for a larger scheme where off-take risk is high. Further, high levels of revenue support for a scheme could distort the market if there were incentives to sell at a sub-market or negative price. A larger Severn scheme may therefore require alteration to the current market arrangements in order to be viable.

Any consumer support mechanism is likely to be classified as a tax and spend policy. Any decisions on levels of taxation are taken at fiscal events (such as the Budget). As such, any decisions relating to a mechanism to support a Severn scheme would need to be made at such a time. In taking a decision, Government would need to consider both the wider fiscal position and the impact on consumer energy bills.

6. Scheme assessment

- 10 proposals to generate energy from the Severn estuary came forward to the feasibility study. 5 of these were assessed as not feasible, following public consultation in 2009. The feasibility study has re-considered that assessment in the light of its learning over the past year, but it has not changed.
- The remaining 5 proposals were short-listed for consideration in more detail – though still at an outline strategic level – by the feasibility study. This chapter sets out the results of that assessment.
- Costs of the Beachley barrage and Welsh Grounds lagoon have risen on examination over the course of the study and neither is considered to be feasible.
- A Cardiff-Weston barrage barrage is the largest scheme of the 5 short-listed and has the lowest cost of energy. As such it offers the best value for money and should be included in any future review of Severn tidal power.
- The barrage would however have the largest total impacts on habitats and birds.
- The second largest scheme, the Bridgwater Bay lagoon is also worthy of further review. It has the lowest environmental impacts and the largest gains in terms of regional employment and the second largest regional GVA benefit.
- The Shoots barrage has a significantly smaller energy yield, alongside intermediate impacts. It should also be included in any further review.
- Combinations of smaller schemes do not offer cost or energy yield advantages over a single larger scheme such as a Cardiff-Weston barrage.
- New technology options are discussed in the next chapter.

This chapter pulls together a number of studies carried out by the feasibility study to provide information on the impacts of each short-listed scheme. See also the map of schemes in chapter 1.

	Cardiff-Weston	Shoots	Beachley	Welsh Grounds	Bridgwater Bay
Cost (£bn) (Optimism Bias (OB) included)	23.2 (34.3)	4.7 (7.0)	3.5 (5.1)	6.8 (10.1)	12.0 (17.7)
Energy Generated (TWh/yr)	15.6	2.7	1.2	2.6	6.2
Levelised Costs – Investor (10%) - £/MWh, ob inc	312	335	419	515	349
Levelised Costs – Social (3.5%), ob inc	108	121	151	169	126
Net Present Value (£bn) compared to alternative technology mix	-4.6	-1.7	-2.1	-4.5	-4.8
Carbon Pay Back (yrs)	2.6	3.5	2.8	6.1	3.2
$C0_2$ Emissions Displaced during generation (MT)[27]	73	13	7	12	29
Regional GVA (£bn)	2.4 (-0.8 – 6.1)	0.9 (0.3 – 2.0)	0.5 (0.1 – 1.3)	1.2 (0.4 – 2.7)	2.3 (0.5 – 4.6)
Regional Net Construction employment (central estimate, range in brackets)	840 (-1,600 – 5,500)	1,240 (600 – 4,000)	940 (600 – 2,000)	1,740 (600 – 5,000)	3,240 (1,000 – 7,000)
Regional Net Operation employment (central estimate, range in brackets)	120 (-2,000 – 800)	80 (-100 – 250)	-20 (-150 – 150)	-40 (-100 – 250)	290 (-250 – 700)
Intertidal- habitat Loss (km2)	118-163	27-37	21-30	61-82	16- 26
% Intertidal Habitat lost	40-50%	8-12%	7-9%	19-26%	5-8%
Ha/TWh gen	1,026	1,222	2,250	2,808	403
Fish	Reduction in Wye and Usk for sea and river lampreys, and eel (also in Severn). Possible local extinction of twaite shad and salmon in Severn, Wye and Usk	Possible local extinction in Wye and Severn for salmon, twaite shad, sea lamprey (Wye only). Reductions for eel in Wye and Severn, twaite shad in Usk and Twyi	Possible local extinction in Wye, Severn and Usk for Atlantic salmon and twaite shad, sea and river lamprey (not Severn), reductions in eels	Possible local extinction of Atlantic salmon and twaite shad, reductions in sea and river lamprey in Severn, Wye and Usk.	Reductions in River Usk and Wye sea and river lamprey, for eel (also in Severn). Possible local extinction twaite shad and Salmon in Wye, Usk and Severn
Birds Species- Significant declines	30	17	15	13	9
km2 land drainage effected	372	97	73	47	243

Table 12: Scheme summaries

[27] Assuming a Severn scheme would replace a mixture of CCS, Nuclear and Offshore Wind

Figure 12: Second Severn crossing – near the site of the proposed Beachley barrage

The Beachley barrage is the smallest scheme studied. It uses a smaller proportion of the energy resource of the Severn, producing 8% of the energy that a Cardiff-Weston barrage would. As well as using less of the Severn's large resource the scheme was initially thought to have the least environmental impact due its location upstream of the River Wye (SAC).

However, further study has shown that despite its small size, it would have a disproportionately large impact on the environment. For example, the Bridgwater Bay lagoon produces over five times as much electricity as a Beachley barrage but has lower habitat loss and a lesser impact on fish and birds (with fifteen species significantly effected in comparison with nine). Local extinctions have been predicted for four species of fish – the greatest out of all schemes.

Although there would be expected to be 940 net additional regional jobs in the four year construction period, it is unlikely there would be any net gain in regional employment post construction with estimates showing the net impact being a loss of 20 jobs.

In addition, costs of the scheme are high due to the need for increased dredging to reduce the expected buildup of sediment behind the barrage. This factor also affects the energy that could be generated by the scheme. Ground conditions have proved to be less favourable than envisaged which has also contributed to rising cost estimates. Increases in capital costs in turn have affected the cost of the electricity produced. The estimated cost of energy from this scheme is so great that we do not believe it could compete against other methods of producing energy and lowering carbon emissions.

Given the scale of damage caused by the Beachley barrage against the high costs and more limited energy it generates, we do not believe that it is feasible.

Shoots barrage

The Shoots Barrage is the second largest barrage scheme studied. The location is near the second Severn road crossing. Its basic design has changed little over the course of the feasibility study. The landing point on the Welsh side was slightly re-aligned from initial designs to avoid a defence practice area, but this has not impacted on its generation capacity.

Environmental impacts are estimated to be greater than the Bridgwater Bay scheme – which generates over twice as energy. For example, nearly double the amount of birds species would be significantly affected. Total habitat loss however is broadly comparable. Proportionate to energy generated the habitat loss is greater than Cardiff-Weston and Bridgwater Bay lagoon but less than half that of Welsh Grounds lagoon and Beachley barrage. The scheme would impact on ports in the Estuary though the scheme would be upstream of Bristol Port.

Levelised energy costs are the second lowest out of all schemes and comparable to those of CCS when calculated from a societal perspective. The Shoots barrage is the only feasible scheme (without costs adjusted for risk and optimism bias) that could potentially be financed solely by the private sector (with appropriate Government support on planning and subsidy mechanisms). Taking into account the impacts and costs, we believe this scheme should be retained for future review if a scheme of this size were required. Its energy yield is significantly less than the following proposals.

Cardiff-Weston barrage

The Cardiff-Weston barrage was the largest scheme studied – it could provide almost 5% of the UK's current electricity need–more than double the amount of electricity generated by on and offshore wind in 2008. Estimated energy yield has decreased as measures to reduce the impact on the environment and navigation have been included. The annual energy yield however is still more than double the next largest scheme, Bridgwater Bay. Energy costs still remain the lowest out of all schemes – levelised costs calculated at social rates are competitive with both coal with CCS and offshore wind. The value society receives from a Cardiff-Weston scheme in NPV terms is estimated to be greater than coal with CCS. The carbon payback period is the shortest out of all schemes – with all the carbon dioxide released through the building of the scheme and its components repaid in just over two and half years. We consider the scale of the energy generation and cost have the strongest strategic case out of the schemes.

However, the impact on the inter-tidal habitat is the largest out of all schemes, with 40-50% of the current habitat lost. This also means that the effect on birds is the greatest with 30 species experiencing significant declines, over triple the number that would be effected by Bridgwater Bay. Impacts on fish are however the second lowest out all the schemes as the schemes further upstream may cause local extinctions for sea and river lamprey. In common with all other schemes, possible local extinctions could occur for twaite shad and salmon. Providing compensation for these impacts on designated features will be the most challenging.

There is likely to be an immediate reduction in flood risk, which would negate the majority of the effects of sea level rise over 100 years, with around 250km of coastal defences likely to need replacing 55-105 years later than currently planned.

The impact on the Estuary ports particularly Bristol in a worst case could lead to closure of the port and in a central case lead to 2,100 fewer jobs.   As a result net regional job increases for both construction and operation are no higher than other scheme. However, the net GVA to the region is the highest at a central estimate of £2.4billion.

The benefits of the highest output and lowest costs energy needs to be carefully weighed up against the generally higher regional and environmental impacts in a future review. In addition, it is important to bear in mind the financing challenge that funding a Cardiff-Weston scheme's very high upfront capital costs would represent.

Bridgwater Bay lagoon

The Bridgwater Bay lagoon would be located on the English shore between Hinkley and Weston-super-Mare. The design has evolved significantly over the course of the feasibility study: the generating capacity has increased through modifying the design to allow for operation on both the ebb and flood tides and through including more turbines. This has led to a large increase in installed generating capacity from 1.36GW to 3.6GW although the footprint of the scheme within the Estuary has remained the same with the embankment 16km long. This is about the same length of Cardiff-Weston's embankment.

As it is in a natural bay and downstream of some of the major areas of intertidal habitat, habitat loss from this scheme is the smallest out of all schemes. It follows that the impact on waterbirds is also relatively low though nine species would be expected to suffer a significant decline. It may be the scheme that is easiest to compensate for residual environmental impacts on protected features – although this task would still be challenging.

As the lagoon is further downstream of the tributary rivers Usk and Wye, it is predicted to have the lowest impact of all schemes on fish. In common with all other schemes, possible local extinctions could occur for twaite shad and salmon.

Although the lagoon does not form a barrier across the estuary, its location downstream of Bristol Port means that impacts on the port will be relatively large. Impact on the ports is the same as for smaller schemes on lower and central estimates (0-200 jobs) but the upper bound rises to 1000 compared to 400. However, as the impacts will not be as large for Cardiff-Weston, the net regional job gains are predicted to be the largest- with 3,240 jobs created during the 6 years of construction and 290 during operation. The regional economy is anticipated to benefit by £2.3bn.

Whilst impacts on land-drainage are the second highest, conversely flood risk benefits are also the second highest as more improved flood defences will be built earlier as part of the scheme.

Levelised energy costs are greater than Cardiff-Weston and Shoots but lower than the two other schemes. They are similar with coal with CCS at Green Book discount rates although upfront capital costs are larger than for CCS. This means significant Government involvement would be required to take forward a scheme.

The relatively lower level of impacts, smaller challenge to provide compensation and medium energy cost make this scheme a candidate for future review.

Welsh Grounds lagoon

The Welsh Grounds lagoon covers a 28km length of the Welsh shoreline, upstream of Cardiff. Poor ground conditions have meant that the Fleming tied-wall design is no longer considered suitable for most of its length, and the size of turbine has had to be reduced by half because of constrained channels.

The energy costs of this scheme have risen beyond that which we consider feasible i.e. they are beyond being competitive with other low carbon schemes and Severn counter-parts. In addition, the scheme would have the second largest overall habitat loss and the greatest proportionate habitat loss for the energy produced – over 5 times that of Bridgwater Bay lagoon.

Impacts on dredging jobs are greater than all schemes bar Cardiff-Weston as it encloses current dredging grounds with 90 job losses predicted. Impacts on ports may be slightly lower than all other options.

The far greater costs and impacts of this scheme relative to the similarly sized Shoots scheme, in terms of energy yield, show that this scheme should not be considered a viable option.

Combinations

The study has considered whether each of the short-listed schemes could be combined to work in tandem with another. The benefits could be that costs and impacts of two smaller combined schemes might be lower than one larger individual scheme.

A high level assessment of schemes in combination has shown that:

- schemes in combination produce less energy than the sum of their individual totals;
- individual schemes offer lower levelised energy costs - combinations can offer greater energy yields than smaller schemes but at higher cost;
- on volume of energy and levelised energy costs alone, a Cardiff-Weston barrage is more promising than any combination of other schemes; and
- a Cardiff-Weston barrage and a Bridgwater Bay lagoon could be combined, which would smooth the energy generation profile with the most attractive £/MWh and greatest energy yield out of all the combinations but the highest capital cost

From the previous chapters, we know that the schemes that hold the most promise are the Cardiff-Weston and Shoots barrages and the Bridgwater Bay lagoon. Of these, Bridgwater Bay lagoon could be combined with either of the barrages but the two barrages could not work in tandem with each other. The Options Definition Report, published alongside this report, gives a more detailed a breakdown of costs and yields of possible combinations.

The study suggests that the environmental impact of combinations would be greater than the largest scheme alone. Given that, and that there is no energy or cost advantage in any combination that does not include a Cardiff-Weston barrage, it seems that a larger single scheme would make better use of the estuary's resource and be more cost effective.

7. Severn Embryonic Technologies Scheme

- The feasibility study has shown that established tidal range technologies would have significant impacts on the people and wildlife of the Severn estuary.
- A small number of proposals for innovative conceptual schemes came forward to the feasibility study through a Call for Proposals in 2008. These were not sufficiently developed for an assessment to be made of their costs or impact, but they appeared to be less environmentally damaging than conventional technologies.
- The Severn Embryonic Technologies Scheme (SETS) was created to allow designs for these schemes to be developed further within the feasibility study sp their potential and future development paths could be better understood.
- 3 schemes were funded: a tidal fence, a tidal bar and a spectral energy convertor. This chapter sets out the high-level findings of the work.
- Of the 3 schemes, 2 showed promise for deployment within the Severn estuary in the future – with potentially lower environmental impacts and costs.
- However, these options are a long way from technical maturity and have much higher risks than the other schemes the feasibility study has considered.
- More work would be required to develop the technologies on which they are based, to confirm their environmental impact could be realised. The progress of these options should be considered in any future review of Severn tidal power.

The Severn Embryonic Technologies Scheme (SETS), a £500,000 cross-Government fund supported by Defra, DECC, the South West Regional Development Agency (SWRDA) and the Welsh Assembly Government (WAG), was created to allow less mature but potentially less environmentally damaging schemes to be developed further within the feasibility study.

The fund attracted interest from established consortia through to small developers, with 17 proposals received. 3 proposals met the Scheme criteria to have the potential to:

- generate a strategic amount of electricity in the Severn estuary;
- cause less damage to the natural environment than more conventional schemes; and
- have potential for deployment within a realistic timescale (typically by 2025).

The public funding was matched by the scheme proposers and the work took place over six months. Final reports from the proposers and development route maps have been published alongside this summary report.

Whilst the proposals did develop under the scheme, the outputs still carry high risks and lower confidence levels on yields, costs and impacts. The schemes were not sufficiently advanced for their impacts to be considered within the process of Strategic Environmental Assessment and so the possibility that these schemes could be less environmentally damaging remains uncertain. Two of the embryonic technology proposals showed promise for future deployment ; these would require support to develop further, including modelling, testing, prototyping and detailed design. As a comparison, costs for the conventional schemes assessed by the feasibility study increased by between 14-238% during the course of the work, and correcting for optimism bias raises costs by up to a further 66%. Optimism bias and risk adjustment costs are not included in the quoted findings for the innovative proposals so direct comparisons with the costs of conventional schemes should not be made. It should also be noted that a higher level of optimism bias would apply to these schemes as the technologies and costs are more uncertain. Furthermore, levelised costs for these scheme have been calculated using different discount rates from those used for the short-listed schemes.

Severn Tidal Fence

A proposal from the Severn Tidal Fence Consortium received funding from SETS. The scheme is a dual row fence containing tidal stream turbines stretching across the Estuary from Minehead to Aberthaw. The tidal stream resource of the Severn is much less than the tidal range resource but it was hoped that sufficient energy could be harnessed to make a tidal stream configuration workable in the Severn. A key attraction of the Severn Tidal Fence scheme was a the potential to change the tidal regime by a far less amount than conventional barrage/lagoon schemes. However further study through the SETS has revealed that even by using existing turbines matched to the flow of the Severn it is not possible to generate strategic amounts of electricity in this way. In turn this puts energy costs at the extremes of the renewables envelope.

Installed Capacity (MW)	Annual Output (TWh)	Capital Cost*	Energy Cost (£/MWh)**	Construction Time***	Potential Environmental Impacts
383	0.88	£1.9bn (STFC Quoted range £1.66bn - £2.14bn)	226 STFC quoted range 204 – 259	7 years	0.5% change to intertidal area and low fish

Table 13: Summary details - Severn Tidal Fence

* Costs include comp habitat@ 2:1 and contingency @15%but exc optimism bias)
**Energy costs have been calculated at a 8% discount rate for the financing period and 3.% thereafter. These discount rates will give lower cost figures than the 10% ‘investor’ discount rate used for the shortlisted Severn schemes. This means that Severn Tidal Fence energy cost cannot be directly compared to those for the shortlisted Severn schemes.
***The time to build the energy scheme once the technology is sufficiently developed, does not include time to provide compensatory habitat which may extend the overall project length

As such, we do not believe that a tidal stream scheme in this format is feasible or would represent a strategically significant use of the estuary's resource. It should be noted that this assessment is specific to the Severn estuary: the concept may have greater utility in locations around the UK where the tidal stream resource is much larger.

Spectral Marine Energy Converter

The Spectral Marine Energy Convertor proposed by VerdErg is an innovative fence arrangement comprising a series of vertical columns on the Cardiff-Weston alignment. Flow between the columns induces a secondary flow in the columns themselves. This secondary flow drives a cluster of turbines which generates energy. A key part of the SETS work has been running physical tank tests to verify a computer model of the convertor to help understand water flows and gauge energy outputs. Work on developing the structure has also been undertaken.

Installed Capacity (MW)	Annual Output (TWh)	Capital Cost*	Energy Cost (£/MWh)	Construction Time**	Potential Environmental Impacts
7500	11.7 [7.5-11.7]**	£9.85bn *[£11.8bn – £17.2bn]** *	68 [113-257]**	7 years	1,775 ha of bird habitat lost

Table 14: Summary details – Spectral Marine Energy Converter

* Costs include compensatory habitat@ 2:1 and contingency @15% but exc optimism bias.
**Energy costs have been calculated at a 8% discount rate for the financing period and 3.% thereafter. These discount rates will give lower cost figures than the 10% 'investor' discount rate used for the shortlisted Severn schemes. This means that Severn Tidal Fence energy cost cannot be directly compared to those for the shortlisted Severn schemes.
***The time to build the energy scheme once the technology is sufficiently developed, does not include time to provide compensatory habitat which may extend the overall project length
[x] Indicates independent assessment of SETS proposals

The table shows both the proposer findings and an independent assessment. It indicates that if the upper predictions of output and lower predictions of cost were achievable the scheme could have comparable viability with more conventional schemes. However, more work needs to be carried out to confirm if these figures could be achieved. It was felt that environmental effects of a Spectral Marine Energy Converter remain significant, but some advantage might be gained over equivalent conventional tidal barrages in terms of loss of inter-tidal habitats. Impact on fish is uncertain with more work being required on fish passage through the Venturi and the secondary circuit. A significant amount of further development and a small scale concept demonstrator would be needed in order to provide more confidence for commercial deployment.

Tidal Bar

The Tidal Bar was proposed by Rolls-Royce/Atkins. The key aspects of the proposal are the development by Rolls-Royce of new turbines designed specifically to operate in ebb and flood mode with very low heads of water e.g. less deep/smaller tidal range. The development from scratch of an outline design for a new axial flow, contra rotating turbine concept, for use in a barrage type structure, has made good progress in the 6 month programme. Atkins have progressed a barrage caisson design of lighter construction than a conventional barrage, on the Cardiff-Weston alignment. This lighter construction method requires less concrete and therefore may be cheaper than the traditional construction methods proposed for conventional schemes.

Whilst still early in the development cycle the technology shows some potential to be competitive with other Severn schemes. It has the potential for lesser environmental impacts due to the reduced restriction of flows. However, there is still a potentially significant reduction in tidal prism at spring tides.

Installed Capacity (MW)	Annual Output (TWh)	Capital Cost	Energy Cost (£/MWh)	Construction Time	Potential Environmental Impact
5800	16.8*	£16.9bn *[£16.9bn – £23.9bn]***	119* [119-168]**	11 Years	900 ha habitat loss

Table 15: Summary details - Tidal Bar

* Costs include compensatory habitat@ 2:1 and contingency @15%but exclude optimism bias.
**Energy costs have been calculated at a 8% discount rate for the financing period and 3.% thereafter.
***The time to build the energy scheme once the technology is sufficiently developed, does not include time to provide compensatory habitat which may extend the overall project length
^ Indicates proposer figures but excludes any combination from pumping
[x] Indicates independent assessment of SETS proposals

The slow moving contra-rotating turbine has been developed with fish passage in mind, however the effectiveness of this configuration in this respect would need to be substantiated by further study.

Next steps

The SETS programme has been successful in identifying the potential of schemes into the future and specifically the risk areas that need to be addressed (and associated time required to achieve this). Proposers can use the outcome of SETS to promote their schemes in other locations or to support bids for any funding opportunities that they will wish to pursue. Prospects for any further public sector funding for SETs-type technology will depend on the outcome of the Comprehensive Spending Review.

8. Next steps for Severn tidal power

- In the light of the findings of the feasibility study the Government does not see a strategic case to bring forward a Severn tidal power project in the immediate term.
- However it recognises that factors which will determine the feasibility of a project could change over time.
- This chapter sets out the circumstances in which Government may choose to review the case for Severn tidal power, so that it can be considered by the Committee on Climate Change in the work they will be doing on the level of renewables ambition required to meet the UK's 2050 greenhouse gas reduction target.
- A review would consider the case for a power scheme in the context of the UK's climate change and energy goals. It would also take into account any future legislative and technical developments, which could for example bring in a wider range of available technology options.
- It is unlikely that a review would take place before 2015.
- The development of tidal range options outside the Severn is being considered separately by the private sector. The huge scale of a Severn scheme is unique and while we hope the study will be useful to other tidal range feasibility studies its conclusions do not bear on schemes outside the Severn.
- Some examples of further work on environmental impact assessment which might be necessary in any future review are set out at the end of the chapter.

In the immediate term, the Government expects to meet the UK's 2020 renewable energy target without a Severn scheme. DECC's projections for 2050 also indicate that if other low-carbon technologies – renewables, nuclear and CCS – develop as expected Severn tidal power will not be needed. But looking forward to 2050, the possibility remains the UK may need a large scale renewable scheme. Given the contribution a Severn scheme could make we are not ruling out such development in the future.

The Government has asked the Committee on Climate Change (CCC) to assess the scope for renewable energy in meeting carbon budgets and the 2050 emissions target, setting possible pathways through to 2030, The CCC is due to report by the end of March 2011.

In their report of the period beyond 2020 the CCC will :

- consider the economics of renewable technologies – current and future, including scope for cost reduction, and possible changes in costs due to changes in factor prices - and compare these with other low-carbon technologies (e.g. nuclear and CCS power generation);

- consider the extent to which technologies and infrastructure add to system flexibility (e.g. smart grids, interconnection, storage) and provide scope for addressing intermittency of renewable power generation;

- assess the scope for renewable energy uptake, given supply chain and stock turnover constraints;

- develop scenarios, with a range of renewable penetration across all sectors at different points in time (e.g. for 2030 and 2050), highlighting circumstances when higher levels of investment in renewable energy may be appropriate, and key decision points; and

- build on their existing analysis of the path to 2020, drawing out any implications from the longer-term analysis for actions and ambition over the next ten years.

In the light of the feasibility study and the CCC's wider analysis it is not expected that a further review of Severn tidal power will be needed before 2015 at the earliest.

Review points

Possible conditions under which a review could be needed include any of the following:

- if predicted future costs of alternative technologies are expected to become comparable with Severn costs, either due to increasing costs of those technologies or reducing public costs of a Severn scheme;

- if technologies playing a key role in meeting 2050 targets are not expected to be deployed as required e.g. increases in costs, effectiveness in reducing emissions is not as great as anticipated, long lead times into building;

- if the level of unpredictable intermittent renewables required to meet goals cannot be sustained by the grid and more predictable, though still intermittent, energy is needed;

- if a larger and quicker contribution to decarbonising UK electricity supplies is needed than is currently expected;

- if the UK ambition for renewable energy or an indigenous power supply increases.

Building on the work of the feasibility study, the review would be expected firstly to examine the need for a Severn tidal power scheme. If this looks strong, the review would then need to consider the best scheme, any technology developments including the performance of tidal range barrages now under construction in other countries, and the ability to comply with relevant legislation. As the Severn

Embryonic Technologies Scheme has demonstrated, there may be ways of reducing environmental impacts through innovation in the future which should be considered as part of the review.

Any review would also need to consider the implications a potential scheme would have on the public finances, and whether these would be affordable from Government's perspective.

Links with wave and tidal policy

Whilst the Severn represents the UK's foremost and one of world's largest tidal range resources, there are other suitable UK sites and learning from the Severn study and developments elsewhere should help develop tidal range power in the UK.

More widely, the Government is committed to harnessing the benefits which a successful marine renewable sector can bring to the UK and to introducing measures to encourage the development of marine energy[28]. This work will include complementary elements such as grid availability, industrial and supply chain development, synergies with offshore wind, economic regeneration, skills and academic excellence. The Government is will be making detailed proposals for Marine Energy Parks by the end of the year.

Further work

The work of the feasibility study has highlighted some of the key issues that would need to be addressed in the design of a Severn power scheme and identified work areas for the future. The list below presents some examples, depending on the legislative requirements of the day.

Environment results and Environmental Impact Assessment

As part of the Environmental Report, several suggestions have been made on how further certainty on environmental impacts can be gained, increasing confidence on impacts and narrowing the ranges presented. For example:

Quantifying and testing the effects of construction and operation activities on the hydraulic, sediment and morphology regime in the Severn estuary, and how effects on these could be mitigated, would help improve certainty of the results produced so far. The use of 3D flow modelling, rather than 2D, to help modelling of sediment flow could also be considered.

A large amount of the data used to inform the marine ecology study are derived from studies done 20 or 30 years ago, so do not include information on some habitats and species. Updating and expanding this data from a wide range of sites would help gather more comprehensive information. Field research would also be useful to establish a more accurate and certain understanding of some habitats and species,

28 The Coalition: our programme for Government, 2010

as some of the data used, including terrestrial and freshwater ecology information, has only used desk-based research.

In turn, this could help identify the most appropriate mitigation measures and lead to trials studying how successful they will be. In turn this could narrow the amount of compensation required. Likewise, scale studies of habitat creation could help increase certainty on their effectiveness and potentially reduce the need for over-compensation to reflect risk.