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Hinkley Point C Connection

Strategic Optioneering Report

Additional Information June 2010

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1 Introduction

- 1.1 Over the past few months National Grid has been consulting on potential route corridors associated with a proposed electricity transmission line between its existing substations at Bridgwater and Seabank (Avonmouth).
- 1.2 Many statutory consultees, local communities and interest groups have requested additional information that will explain why National Grid has ruled out alternatives to the proposed overhead line, particularly on the use of subsea High Voltage Direct Current (HVDC) cables.
- 1.3 This paper, produced by National Grid Electricity Transmission plc (referred to in this report as "National Grid"), has been prepared to provide additional information to interested parties on:
- National Grid's policy with regard to underground cables;
 - the range of subsea options that National Grid considered during its technical assessment, including a cost breakdown of each option;
 - a discussion of transmission losses associated with HVDC technology, and
 - a discussion of the transmission network's carbon footprint.
- 1.4 National Grid owns the high voltage electricity transmission system in England and Wales and is responsible for operating the transmission system across Great Britain. It has a statutory duty to develop and maintain an efficient, coordinated and economical system of electricity transmission under Section 9 (2) of the Electricity Act 1989. This includes a duty to connect new generating stations to the transmission system. The form which these connections take depends on a number of factors including the location and capacity of the new generating stations.
- 1.5 Although National Grid can discuss with generators potential connection locations and options available, the final location decision is that of the Generator. When a Generator applies to connect at a specific point on the transmission system National Grid is obliged to make a connection offer.
- 1.6 As well as these duties, National Grid is bound by the requirements of a series of technical standards which govern the design and operation of the transmission

system. These standards include the National Electricity Transmission System Security and Quality of Supply Standard (NETS SQSS)¹ and the Grid Code. Connection offers are made in strict compliance with the technical standards.

1.7 It should be noted that the form, content and any modifications to the NETS SQSS must be approved by the energy regulator OFGEM.

1.8 National Grid is required to offer and honour terms for connection of new generation which do not conflict with these obligations². Accordingly such offers are assessed on the basis of:

- the technical viability of the connection;
- the connection not unduly adversely impacting the timing of the connection dates and other commitments made to connectees, and
- the need to be efficient, coordinated and economic.

1.9 The last of these requirements is reflected in National Grid's regulatory obligations. It is designed to protect electricity consumers from the potential for National Grid to over-invest in its system and thus burden the electricity industry and society in general with unnecessary cost.

1.10 To ensure this is the case the energy regulator, OFGEM, at regular intervals scrutinises the investment plans of National Grid. OFGEM employs independent technical consultants to formally review a selection of detailed projects, and the overarching business processes and policies adopted by National Grid. Detailed reports are made to OFGEM and these are publicly available at:

<http://www.ofgem.gov.uk/Networks/Trans/PriceControls/TPCR4/ConsultantsReports/Pages/ConsultantsReports.aspx>

¹ National Electricity Transmission System Security and Quality of Supply Standard Version 2.0 : 24/06/09

² Based upon the Ofgem consultation of 8th May 2009, National Grid may also apply to Ofgem, in restricted circumstances, to be derogated in its connection to new users, provided it can demonstrate a manageable solution not giving rise to excessive operating costs and not compromising other obligations including Nuclear Site Licences. Such “connect and manage” positions will only be deemed acceptable by the regulator if the works ultimately restore compliance with the NETSQSS.

- 1.11 Ofgem uses these assessments as part of the process it employs to set the level of revenue that National Grid is entitled to earn.
- 1.12 Within this regulatory framework, National Grid promotes infrastructure developments which are fit for purpose, provide value for money and continue to deliver the required standards of security and reliability.
- 1.13 The form of transmission investment is therefore a balance between the technical compliance, economic costs, amenity impact and deliverability. In this context National Grid is required to make judgements and assessments between the alternative options.

2 UNDERGROUND CABLES

- 2.1 Underground cables are amongst the suite of technical solutions National Grid can use when seeking to add capacity to the transmission system. However, a number of significant issues with the use of underground cables affect its deployment and therefore there is limited use on the high voltage transmission system (e.g. 675km out of a total transmission network of 7,900km).
- 2.2 These issues include operability issues, such as the management of charging currents, potential cable cooling systems, impact on system voltage and the need for supplementary reactive compensation equipment. As well as these operability issues there are significant construction issues which together account for 400kV underground cables costing significantly more, between 12 and 17 times as much, than the equivalent overhead line.
- 2.3 Given its duties as set out above, to develop the transmission system in an efficient, coordinated and economical manner, National Grid must therefore, in the first instance, consider adding transmission capacity and connecting new generation by overhead line connections, rather than by underground cables. As a result, the use of underground cables as a total connection solution is not considered at the Strategic Optioneering Stage.
- 2.4 However, undergrounding some sections of route may well be considered when detailed route alignments are being developed and following public consultation. These will include of nationally or internationally designated areas of amenity value,

exceptionally constrained estuaries or major river crossings and exceptionally constrained urban areas.

- 2.5 National Grid's policy related to the use of underground cables, which reserves consideration of their use to areas of technical constraint and to areas of the highest recognised amenity value, can be found at:

<http://www.nationalgrid.com/uk/LandandDevelopment/SC/Undergrounding/>.

3 Subsea Cables

- 3.1 With regard to the Hinkley C Project and the options considered, National Grid has been requested on a number of occasions to provide further explanation of its decision to rule out the use of subsea cables.

- 3.2 As set out in the Hinkley Point C Strategic Optioneering Report published in December 2009, AC and DC subsea cables were considered (Options H5, 5a, H6, H7, H7a and H20). Intuitively these options look viable as they provide direct undersea routes and avoid the need for new overhead lines in the region. Indeed, that is why they were considered and evaluated by the design team.

- 3.3 Following detailed analysis it became clear that application of such technology in this part of the network could not be credibly promoted by National Grid given its obligations for efficient, coordinated and economical development of the transmission system. In this paper we seek to explain the analysis underpinning that conclusion and why the subsea options were discounted.

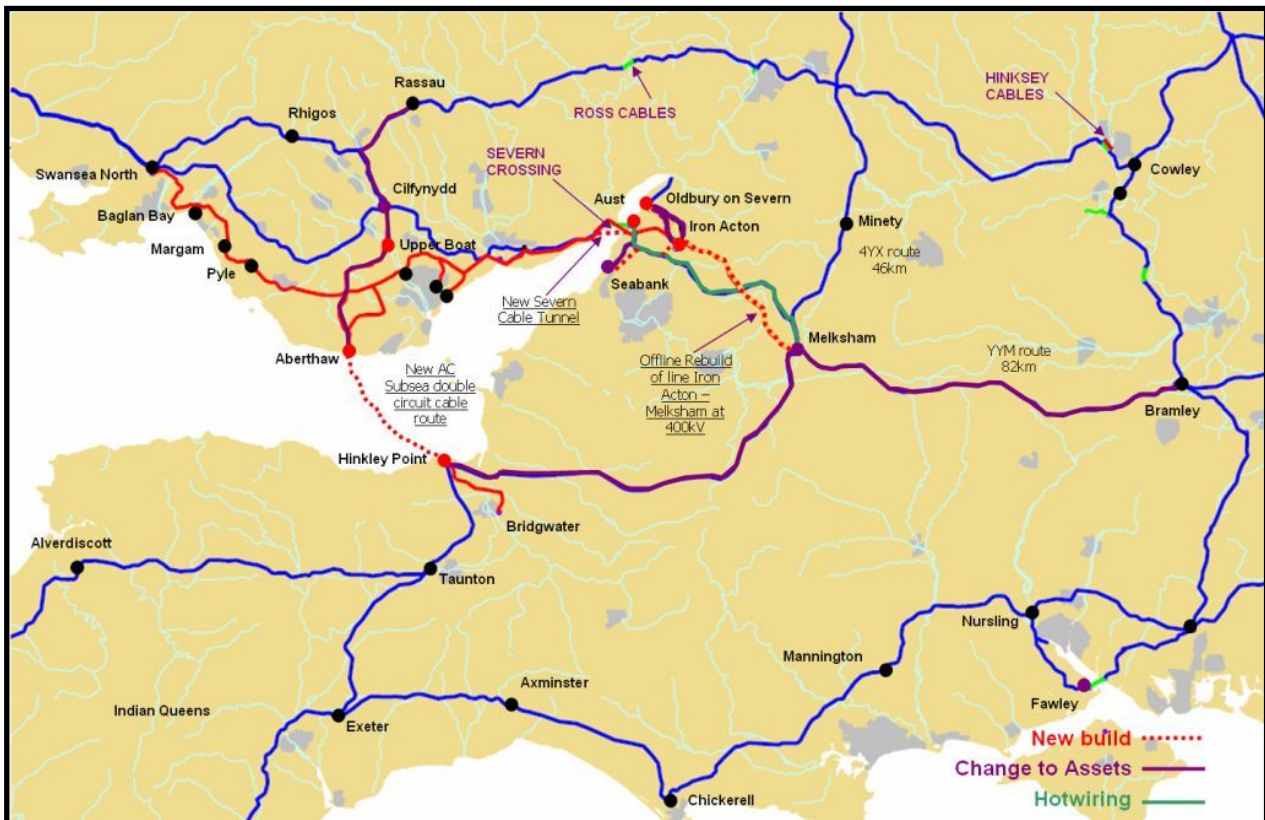
- 3.4 The following sections include cost estimates for each of the options presented. The base unit cost estimates are derived from National Grid's internal asset management system. National Grid's base unit costs are determined by using a number of sources of data and then aggregated dependent on the most recent application. The data sources include:

- Historic actual contracts from the last 5 years
- Recent and live contracts
- Informed estimates and quotations

3.5 As discussed above, the asset management system and individual project proposals are subject to regular scrutiny and review by the energy regulator OFGEM who employs independent technical consultants to robustly and formally review the detailed projects, the overarching business processes and policies adopted by National Grid. Detailed reports are made to OFGEM and these are publicly available at <http://www.ofgem.gov.uk/Networks/Trans/PriceControls/TPCR4/ConsultantsReports/Pages/ConsultantsReports.aspx>

3.6 Subsea Cables between Hinkley – Aberthaw

3.7 Option H5 and H5a were options connecting Hinkley Point with Aberthaw in South



Wales via AC and DC subsea cables, over a distance of 30km.

Figure 1: Option H5 / H5a – Hinkley Point – Aberthaw (AC or DC Subsea cables)

3.8 Option H5 considered the subsea connection via an HVDC link.

- 3.9 National Grid has to design the system so that power continues to flow even if parts of the system break down or are taken out of service for maintenance. We have to make sure power continues to flow safely and reliably, and that no damage is cause to equipment connected to the system.
- 3.10 This is done by conducting a comprehensive suite of power system studies and scenario analysis that ensures the design of the transmission system is technically compliant with engineering standards.
- 3.11 In this case our studies concluded that given the generation background as set out in Section 3 of the Strategic Optioneering Report, the required capacity of the subsea cables needs to be 4000MW in order to resolve both transient instability and circuit overloads. A further explanation of these issues is provided in the short film “Connecting Hinkley Point C – The Technical Challenges”.
- 3.12 This 4000MW of capacity is the minimum required to ensure that the transmission system continues to operate within operational standards following transmission faults in the Oldbury part of the network (Oldbury-Melksham double circuit). In other words, following a fault on transmission circuits in the region, the subsea cables must be capable of carrying up to 4000MW of power, otherwise electricity supplies in the region will not meet reliability or quality standards. In comparison, the overhead line solution (H10/H10a), described later, provides 6000MW of capacity which is 2000MW more.
- 3.13 As well as the HVDC link, substantial works would be required in and around South Wales in order to facilitate the potential power flows. The scope of works is shown in the table below and was estimated to cost in the region of £2.19bn.

Item	Description	Estimated Cost
New Substation Build	Hinkley Point, Oldbury, Aust, Iron Acton, Aberthaw, Upper Boat	£490m
Substation Modifications	Seabank, Fawley, Cilfynydd, Melksham	£100m

New Overhead lines	Seabank – Aust, Connections to Oldbury, Iron Acton – Melksham 400kV	£105m
Modifications to Overhead Lines	Melksham – Bramley, Connections to Oldbury, Hinkley Point – Melksham	£255m
New Cable Cost	New Severn crossing 400kV cable tunnel, Hinskey Cables	£279m
HVDC Converters	8 x 1GW VSC Converters (4 at Hinkley Point and 4 at Aberthaw)	£800m
HVDC Cable Sealing Ends	8 units (4 at Hinkley Point and 4 at Aberthaw)	£1m
HVDC cables	4 x 1GW cables x 30km	£156m
Total Estimated Cost – Option H5		£2.186bn

Table 1: Option H5 - HVDC Cost Breakdown

3.14 Option H5a considered the subsea connection via AC cables. As well as AC cables, substantial works would be required in and around Aberthaw in order to facilitate the potential power flows in the region. The scope of works is shown in the table below and was estimated to cost in the region of £1.8bn.

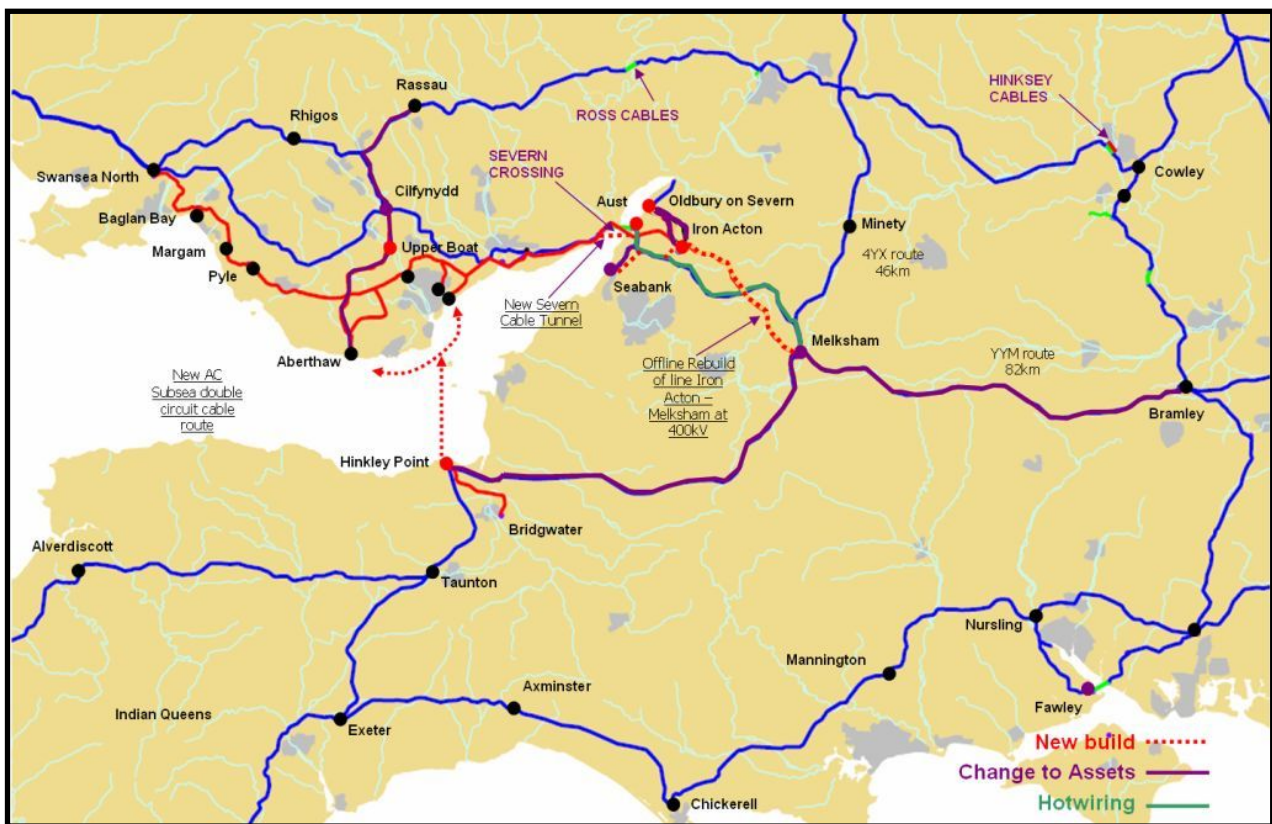
Item	Description	Estimated Cost
New Substation Build	Hinkley Point, Oldbury, Aust, Iron Acton, Aberthaw, Upper Boat	£490m
Substation Modifications	Seabank, Fawley, Cilfynydd, Melksham	£100m
New Overhead lines	Seabank – Aust, Connections to Oldbury, Iron Acton – Melksham	£105m

	400kV	
Modifications to Overhead Lines	Melksham – Bramley, Connections to Oldbury, Hinkley Point – Melksham	£255m
New Cable Cost	Hinkley Point – Aberthaw, New Severn crossing 400kV cable tunnel, Hinkley Cables.	£864m
Total Estimated Cost – Option H5a		£1.814bn

Table 2: Option H5a AC Cables Cost Breakdown

3.15 Subsea Cables from Hinkley Point to elsewhere in South Wales

3.16 Options H7 and H7a considered AC and HVDC subsea cables from Hinkley Point to an



alternative location in South Wales, not Aberthaw.

Figure 2: H7 / 7a – Hinkley Point to South Wales (not Aberthaw)

3.17 Although the connection would be longer than Aberthaw the scope of works required in the wider network to facilitate potential power flows would be very similar to those, but in excess, required for Option 5 and 5a with additional reinforcements required at the connection point in South Wales network. Due to the sizeable power flows any connection on the South Wales side shall require a connection at 400kV and the relevant reinforcements to reach the South Wales 400kV network.

3.18 A cost breakdown for Option H7 is provided in the table below:

Item	Description	Estimated Cost
New Substation Build	Hinkley Point, Oldbury, Aust, Iron Acton, Aberthaw, Upper Boat	£490m
Substation Modifications	Seabank, Fawley, Cilfynydd, Melksham	£100m
New Overhead lines	Seabank – Aust, Connections to Oldbury, Iron Acton – Melksham 400kV	£105m
Modifications to Overhead Lines	Melksham – Bramley, Connections to Oldbury, Hinkley Point – Melksham	£255m
New Cable Cost	New Severn crossing 400kV cable tunnel, Hinskey Cables	£279m
HVDC Converters	8 x 1GW VSC Converters (4 at Hinkley Point and 4 in South Wales)	£800m
HVDC Cable Sealing Ends	8 units (4 at Hinkley Point and 4 in South Wales)	£1m
HVDC cables	4 x 1GW cables x greater than 30km	Over £156m
Total Estimated Cost – Option H7		Over

	£2.186bn
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Table 3: Option H7 HVDC Cables Option H7 Cost Breakdown

3.19 Option H7a considered the subsea connection via AC cables. As well as AC cables, substantial works would be required in and around the region in order to facilitate the potential power flows. The scope of works is shown in the table below and was estimated to cost in the region of £1.8bn.

Item	Description	Estimated Cost
New Substation Build	Hinkley Point, Oldbury, Aust, Iron Acton, Aberthaw, Upper Boat	£490m
Substation Modifications	Seabank, Fawley, Cilfynydd, Melksham	£100m
New Overhead lines	Seabank – Aust, Connections to Oldbury, Iron Acton – Melksham 400kV	£105m
Modifications to Overhead Lines	Melksham – Bramley, Connections to Oldbury, Hinkley Point – Melksham	£255m
New Cable Cost	Hinkley Point – South Wales, New Severn crossing 400kV cable tunnel, Hinskey Cables.	Over £864m
Total Estimated Cost – Option H7a		Over £1.814bn

Table 4: Option H7a AC Cables Cost Breakdown

3.20 Subsea Cables from Hinkley Point to Seabank



3.21 Option H6 and H20 were options connecting Hinkley Point with Aberthaw in South Wales via AC and DC subsea cables, over a distance of approximately 60km.

Figure 3: H6 – Hinkley Point to Seabank HVDC Subsea Link

3.22 Option H6 considered the subsea connection via an HVDC link. National Grid’s analysis, based on the NETSQSS, concluded that given the generation background as set out in Section 3 of the Strategic Optioneering Report, the required capacity of the subsea cables would be 4000MW.

3.23 This 4000MW of capacity is the minimum required to ensure that the transmission system continues to operate within operational standards (thermal & stability) following transmission faults in the Oldbury part of the network (Oldbury-Melksham double circuit). In comparison, the overhead line solution (H10/H10a) described later provides 6000MW of capacity which is 2000MW more.

3.24 As well as the HVDC link, substantial works would be required in and around the region in order to facilitate the potential power flows. The scope of works is shown in the table below and was estimated to cost in the region of £1.6bn.

Item	Description	Cost
New Substation Build	Hinkley Point, Oldbury, Aust	£206m
Substation Modifications	Seabank, Fawley, Melksham	£67m
New Overhead lines	Connections to Oldbury	£6m
Modifications to Overhead Lines	Melksham – Bramley, Connections to Oldbury, Hinkley Point – Melksham, Seabank – Aust	£213m
New Cable Cost	Hinskey Cables	£22m
HVDC Converters	8 x 1GW VSC Converters (4 at Hinkley Point and 4 at Seabank)	£800m
HVDC Cable Sealing Ends	8 units (4 at Hinkley Point and 4 at Seabank)	£1m
HVDC cables	4 x 1GW cables x 63km	£327m
Total Estimated Cost – Option H6		£1.642bn

Table 5: Option H6 HVDC Cables Cost Breakdown

3.25 Option H20 considered the subsea connection via AC cables. As well as AC cables, substantial works would be required in and around the region in order to facilitate the potential power flows. The scope of works is shown in the table below and was estimated to cost in the region of £1.9bn.

Item	Description	Cost
New Substation Build	Hinkley Point, Oldbury, Aust, Including	£304m

	Reactive Compensation requirements	
Substation Modifications	Seabank, Fawley, Melksham, Including Reactive Costs	£153m
New Overhead lines	Connections to Oldbury	£6m
Modifications to Overhead Lines	Melksham – Bramley, Connections to Oldbury, Hinkley Point – Melksham, Seabank – Aust	£213m
New Cable Cost	Hinskey Cables, Hinkley Point – Seabank Cables	£1.25bn
Total		£1.926bn

Table 6: Option H20 AC Cables Cost Breakdown

3.26 The costs of each of the subsea cables options are summarised in the table below:

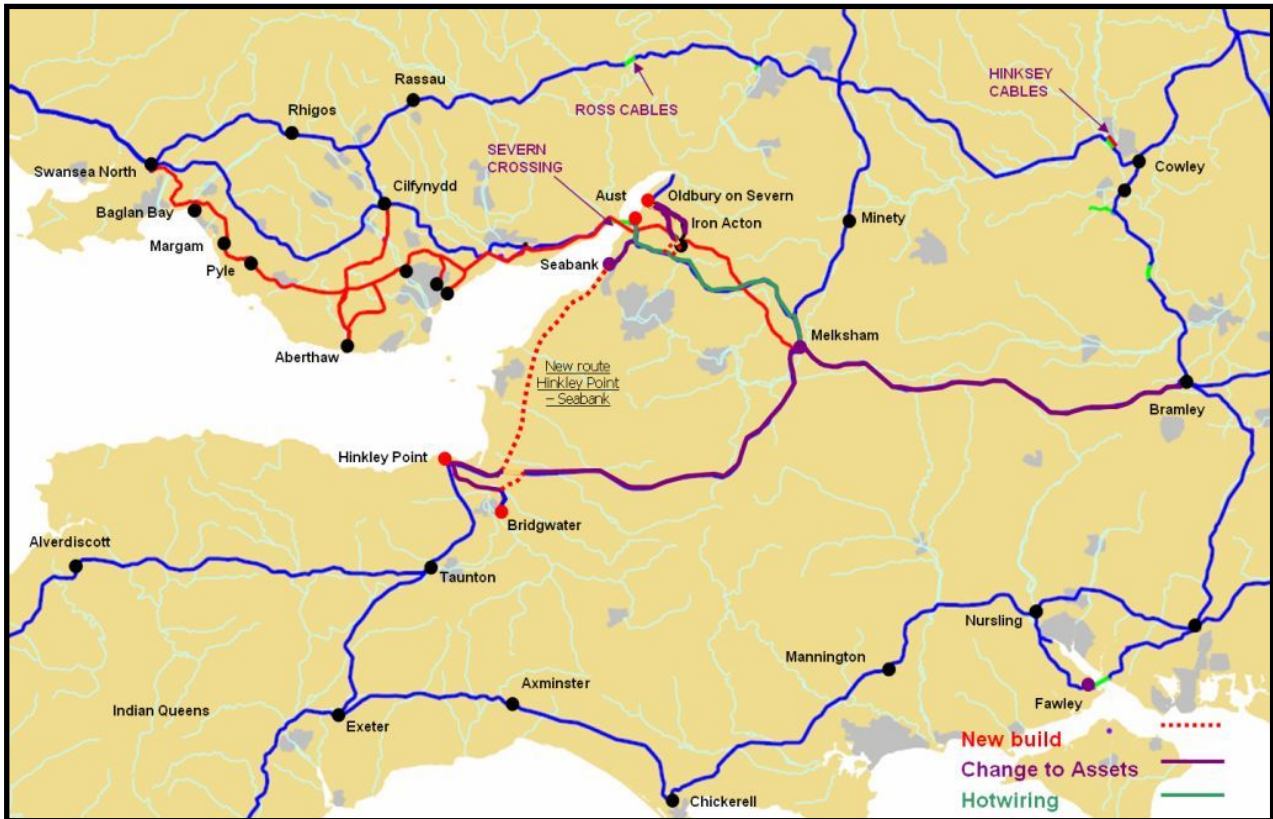
Option	Description	Cost Estimate
H5	HVDC Subsea Cables from Hinkley Point to Aberthaw	£2.186bn
H5a	AC Subsea Cables from Hinkley Point to Aberthaw	£1.814bn
H6	HVDC Subsea Cables from Hinkley Point to Seabank	£1.642bn
H7	HVDC Subsea Cables from Hinkley Point to South Wales	Over £2.186bn
H7a	AC Subsea Cables from Hinkley Point to South Wales	Over £1.814bn
H20	AC Subsea Cables from Hinkley Point to Seabank	£1.926bn

Table 7: Cost Summary of the Subsea Options

3.27 The next section considers the proposed overhead line options.

3.28 New Overhead Line routes between Hinkley Point and Seabank

3.29 Options H10 and H10a propose new overhead line routes between Hinkley Point and Seabank. Option H10 is a proposal for a new route while Option H10a considers taking over the existing overhead line route owned by WPD and operated at 132kV. Option H10a would replace the existing 132kV overhead line with a new 400kV line and also involve the construction of a new substation at Churchill. The overhead line solutions



provide 6000MW of capacity which will potentially facilitate up to a further 2000MW of generation in the region.

Figure 4: Option H10: Hinkley Point to Seabank New Overhead Line

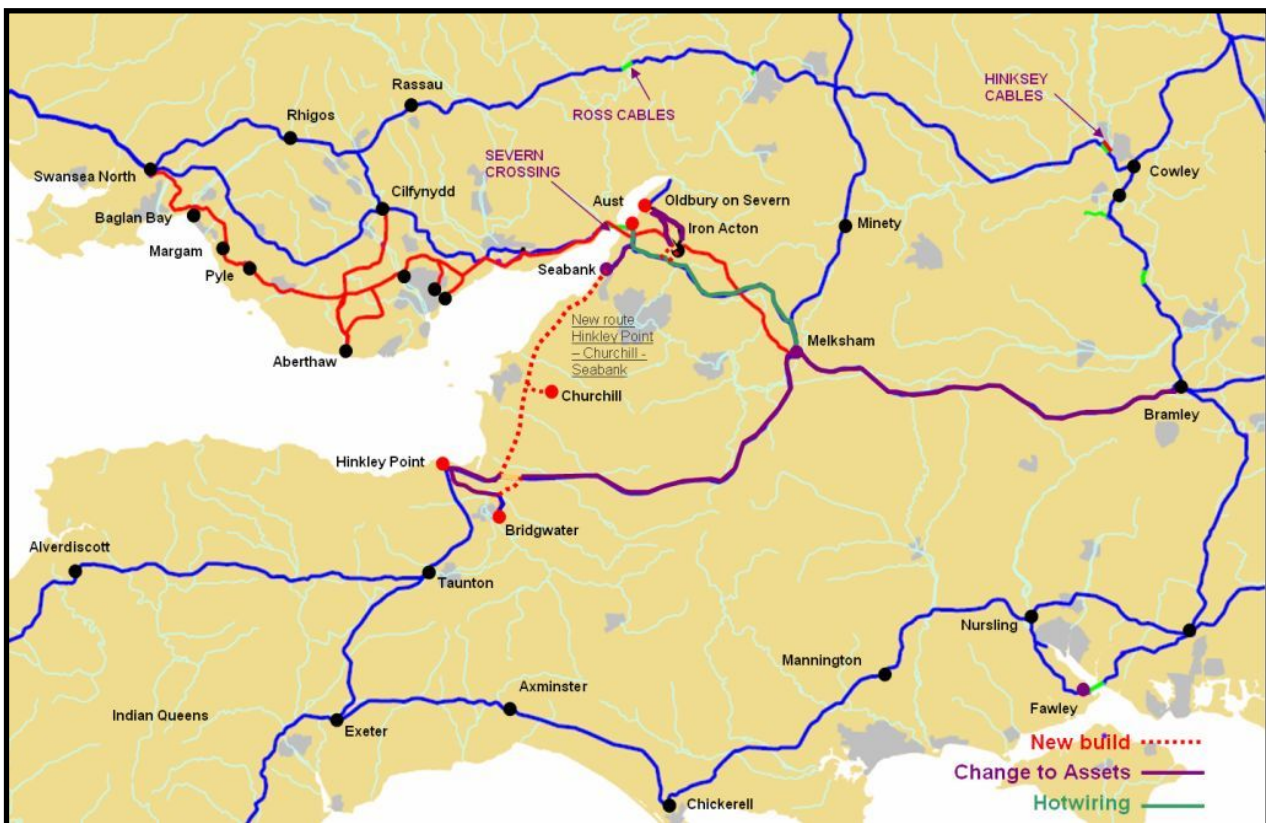
3.30 H10 – Hinkley Point to Seabank New Overhead Line

Item	Description	Cost
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Hinkley Point C Connection – Strategic Optioneering Report - Additional Information

New Substation Build	Hinkley Point, Oldbury, Aust, Bridgwater	£218m
Substation Modifications	Seabank, Fawley, Melksham	£67m
New Overhead lines	Connections to Oldbury, Hinkley Point to Seabank	£135m
Modifications to Overhead Lines	Melksham – Bramley, Connections to Oldbury, Hinkley Point – Melksham, Seabank – Aust	£213m
New Cable Cost	Hinskey Cables	£22m
Total		£655m

Table 8:



Option H10: New Overhead Line Cost Breakdown

3.31 Figure 5: H10a – Hinkley-Seabank OHL utilising existing WPD 132kV overhead line route

Item	Description	Cost
New Substation Build	Hinkley Point, Oldbury, Aust, Bridgwater, Churchill	£251m
Substation Modifications	Seabank, Fawley, Melksham	£67m
New Overhead lines	Connections to Oldbury, Hinkley Point to Seabank	£144m
Modifications to Overhead Lines	Melksham – Bramley, Connections to Oldbury, Hinkley Point – Melksham, Seabank – Aust	£213m
New Cable Cost	Hinskey Cables	£22m
Total		£697m

Table 9: Option H10a New Overhead Line utilising existing WPD route cost breakdown

4 Summary

4.1 The following table summarises the costs of the subsea cables options and the two overhead line options.

Option	Description	Cost Estimate
H5	HVDC Subsea Cables from Hinkley Point to Aberthaw	£2.186bn
H5a	AC Subsea Cables from Hinkley Point to Aberthaw	£1.814bn
H6	HVDC Subsea Cables from Hinkley Point to Seabank	£1.642bn
H7	HVDC Subsea Cables from Hinkley Point to South	Over £2.186bn

	Wales	
H7a	AC Subsea Cables from Hinkley Point to South Wales	Over £1.814bn
H10	Hinkley Point to Seabank Overhead Line	£655m
H10a	Hinkley Point to Seabank Overhead Line utilising the existing WPD 132kV route	£697m
H20	AC Subsea Cables from Hinkley Point to Seabank	£1.926bn

Table 10: Cost Summary

- 4.2 The overhead line options H10 & H10a are substantially lower cost than the subsea options, with the proposed new overhead line element making up less than a ¼ of the of the overall project cost of these options.
- 4.3 All the options highlighted in this document require additional infrastructure to facilitate the generation connections, at Hinkley Point, Oldbury-on-Severn and Seabank. The majority of these works and associated costs are required whichever option is chosen, for new substations (especially at the point where new generators connect) and other overhead line works also required. These additional costs are highlighted in the option cost breakdowns in this document.
- 4.4 As well as these substantial differences in cost, overhead lines also provide up to 6000MW (versus 4000MW) of transmission capacity which means that they will be able to accommodate additional generation, beyond what we know about today, without the need for more development. In contrast an HVDC solution would require further incremental capacity, at extra cost, to facilitate extra generation in the region.
- 4.5 Further, the use of HVDC technology in this part of the transmission system would also be very challenging. HVDC systems are normally set up to behave a bit like “oil tankers”. They are set up for the bulk transfer of power in one direction, normally between two countries. In this case we need the HVDC system to carry 4000MW of power but at the same time be dynamic enough to change direction of the power flow very quickly, in less than 200ms. The fastest response time by an installed VSC HVDC system is currently in the region of 350ms. This would pose a significant technical risk

to design and operational risk to the reliability and quality of power supplies in the region.

- 4.6 National Grid must promote the most economic technically compliant solutions. Hence the route corridor study and consultation have been progressed on the basis of the overhead line routes described in options H10 and H10a.
- 4.7 The capital costs, which are the most significant cost element, associated with both HVDC and AC subsea solutions of this capacity were all in excess of £1.6bn which was over twice the total project cost of the overhead line options H10 and H10a.
- 4.8 National Grid has also been requested to provide information on the cost of transmission losses and the carbon footprint associated with overhead lines and HVDC solutions.

5 Transmission Losses

- 5.1 Transmission losses occur in all electrical equipment and are related to the operation and design of the equipment.
- 5.2 Overhead lines are generally constructed from aluminium conductor bundles. The estimated level of transmission loss is dependent on the load carried by the line. The assumed average load for an overhead line is 50%. Transmission losses typically range from 0.7-1% per 100km per circuit based on the circuit rating.
- 5.3 In the case of the Hinkley Point to Seabank overhead lines, 60km, the average transmission losses are estimated to be 0.5-1.0%³.
- 5.4 Transmission losses in HVDC systems stem from each of the components within the system. Losses from DC cables are much lower than those of an overhead line, however, losses in the converters (of which there are two per 1000MW, one at each end of the link) are significant.
- 5.5 The HVDC technology required in the case of Hinkley Point is the VSC type. The transmission losses in a VSC converter range from 1-2% per converter. Meaning they

³ Note that the Bridgwater to Seabank overhead lines comprise of two circuits.

range from 2-4% per link, taking account there is a converter at each end of the link. These are substantially more than that of an equivalent overhead line.

- 5.6 Transmission loss considerations therefore make the case for HVDC technology less economic.

6 Carbon Footprint

- 6.1 National Grid is committed to managing its emissions of greenhouse gases. As such it is working with other stakeholders to develop industry wide policies and agree the use of suitable tools to capture the costs of carbon within in its asset investment methodologies and processes.
- 6.2 To date, independent studies⁴ have estimated the lifecycle carbon emissions from the transmission network based on current research and available information on raw materials & manufacturing, construction, operation & maintenance and decommissioning & disposal phases.
- 6.3 The carbon footprint of the major elements of the transmission system is dominated by the transmission losses whilst in service. Generic estimates indicate that this could account for >95% of emissions on a life cycle basis. As mentioned above, the HVDC systems have higher losses than the overhead lines and therefore they would not be justified on the basis of carbon assessment alone, regardless of any differences in the carbon footprint associated with the manufacture and construction phases.

7 Conclusion

- 7.1 National Grid has a statutory duty to develop the transmission system in an efficient, coordinated and economical manner. In this paper we have analysed the subsea and overhead line options, and provided a cost breakdown of each option. In addition we have described the technical issues associated with each option.

⁴ Lifecycle Assessment of the Transmission Network in Great Britain, Gareth P.Harrison, Edward (Ned).J.McLean, Serafeim Karamanlis, Luis F. Ochoa.

- 7.2 With regard to HVDC technology we have discussed both transmission losses and carbon emissions.
- 7.3 Given our statutory duties, which in effect seek to ensure that National Grid makes the most economic technically compliant infrastructure investments, the comparison of costs associated with each option led to National Grid's decision to discount these options prior to the consultation on the potential route corridors.

8 ABBREVIATIONS

AC	Alternating current
bn	Billion
DC	Direct Current
DNO	Distribution Network Operator
GW	Gigawatt (1000 million Watts)
HV	High Voltage
Hz	Hertz
km	Kilometre
kV	Kilovolt (1000 Volts)
MW	Megawatt (1 Million Watts)
NETSQSS	National Electricity Transmission System Security and Quality of Supply Standard
Ofgem	Office of the Gas and Electricity Markets
OHL	Overhead line